Oil, natural gas and solar energy – 100,000 women and men

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Total
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In this issue:

4 Editorial and Presidential
5 News
6 Bachelor Thesis
11 Board Highlighted: Warden
12 MSc Thesis
15 Symposium 10th Half Lustrum
17 ISW Aachen-Bochum
18 Study Abroad
22 PhD Article
26 Mining House ‘De Teerput’
27 Photo page
29 Weber Puzzle
31 Graduation Subjects
31 MV Calander

Advertising:

2 Total
28 EBN
32 Shell
Dear Reader,

Approximately one year ago I was asked to be a part of this wonderful committee. Ever since then we produced three Natural Resources and gained a lot of experience, I would like to thank my fellow members for their hard work. 

Summer holidays have started and that means it is time for the fourth and last Natural Resource of this academic year. For this edition we visited a mining house for one last time, the house we visited is called ‘De Teerput’ and it is the house of one of the member’s of this year’s committee. You can read all about the ins and outs of the house in this edition. 

Furthermore, in this Edition you can find an article written by Jacintha Tjia and Coco Antonissen, who talk about their Study Abroad adventures in Indonesia, which is excellent reading material to get in the summer mood! Additionally a PhD article about Value of Information Assessment in Reservoir Management written by a student studying Petroleum Engineering, Eduardo Barros.

The edition also contains a Bachelor thesis about Characterization of Natural Fractures in the Upper Berda Formation of the Alima Anticline in Tunisia by Alisha Pengel.

Because it is our last edition, we really hope to get a good answer to the Weber Puzzle, so take the puzzle with you wherever you are going this summer to make sure it is solved.

On behalf of the whole editorial staff I would like to thank all contributors for their articles and photographs and wish our successors the best of luck! 

Glück Auf, 

Yasna Witteveen
Chief Editor

Dear members and other readers,

The academic year of 2014-2015 is as good as over and unfortunately this is already the last edition of the Natural Resource Magazine that will appear before the next year starts. This indirectly also means that the 123rd board is soon going to make place for the a new board. In case you missed the announcements, the new board will consist of Floor Crispijn, Jasper Snoeren, Julian van Dingen, Coco Antonissen and Max Felius. The official changing of the boards will take place during August but of course we are already quite busy with prepping the young grasshoppers for the great year they are going to experience.

In this last period we had some nice activities and trips. Among which, a visit to the South of France where we visited honorary members of the MV and dropped by the second year students who were busy doing fieldwork in VESC. As always the roads were perfect for cruising around, the weather was good and the wine tasted fine.

Besides our trip to France, the Pieter Steeneken Golf Trophy took place on a golf club in Glimmen.

Every year the Steeneken family and a large group of MV alumni come together to have a golf tournament in remembrance of honorary MV member Pieter Steeneken. It was a nice day but the golfing itself turned out to be quite hard. 

As our committees have been very busy this entire year with organizing activities and helping us as the board to keep the association running on all kinds of levels they deserved a little thank you. We decided to rent a large boat and go on a boat ride with a couple of drinks. We travelled from The Hague to Delft and of course the final destination was “Het Noorden”. Fortunately the sun was shining during this trip which made the whole day very relaxed.

I would like to wish you all a very enjoyable summer break and conclude with a firm and harmonious,

Glück Auf!

Marnix Koops
President der Mijnbouwkundige Vereeniging
$8 trillion alternative energy boom is a win for copper

Here’s a bit of energizing news: In 2014, for the first time in four decades, the global economy grew along with energy demand without an increase in global carbon emissions. That’s according to energy policy group REN21’s just-released Renewables 2015 Global Status Report, which attributes this stabilization to “increased penetration of renewable energy and to improvements in energy efficiency.” What this means is that as the world’s population continues to grow, and as more people in developing and emerging countries gain access to electricity, the role alternative energy sources such as wind, solar and geothermal play should skyrocket. Between now and 2040, a massive $8 trillion will be spent globally on renewables, about two thirds of all energy spending, according to Bloomberg New Energy Finance. Solar power alone is expected to draw $3.7 trillion. This is good news indeed for copper, necessary for the conduction of electricity in all energy technologies, whether they be traditional or alternative. The use of some carbon-emitting fossil fuels—coal, for instance—will likely drop off over the years, but copper will remain an irreplaceable component in our ever-expanding energy needs.

http://www.mining.com/web/8-trillion-alternative-energy-boom-is-a-win-for-copper/

Iron ore prices hit six-day highs, but rally won’t last say experts

The price of iron ore recovered Wednesday for the sixth consecutive day after Brazil’s iron and steel association released figures showing volumes produced by Vale (NYSE:VALE) were flat year-on-year in May 2015. The steelmaking commodity traded at $62.53 a tonne, up $1.19 from Tuesday, and almost 40% higher since early April levels. Both the MIBI-62 and MIBI-58 Premium Index now sit about $3/tonne below the recent highs seen two weeks ago.

The price of Australia’s biggest export earner has been on a roller-coaster ride this year, dropping to a decade-low at the start of April as increased low-cost output from miners including Rio Tinto (LON:RIO) and BHP (ASX:BHP), as well as weaker demand in China caused oversupply. Tumbling stockpiles in the Asian nation, the world’s biggest user, after imports missed expectations, helped to spur gains in April, May and the first two weeks of June. But experts warn the rally won’t last long. Goldman Sachs Group, for instance, is predicting prices to drop again below $50 a tonne as low-cost supplies from Australia and Brazil expand and a slump in steel squeezes mills’ profits, CNBC reported.


EIA: Argentina, China lead shale development outside N. America

Argentina and China have respectively drilled more than 275 and 200 wells targeting shale plays over the past 2 years, providing each country with the potential to significantly increase production of shale gas and tight oil, the US Energy Information Administration highlighted on June 26 in an energy update. In Argentina, YPF SA reported production in April of 22,900 b/d of oil and 67 MMcfd of natural gas from three joint ventures in the Neuquen basin’s Vaca Muerta shale formation in the west-central portion of the country. The JVs are with Chevron Corp. at Loma Campana field, Dow Chemical Co. at El Orejano field, and Malaysia’s state-run Petronas at La Amarga Chica field (OGJ Online, Aug. 28, 2014). China Petroleum & Chemical Corp. (Sinopec) and OAO Gazprom also have recently signed a memorandum of understanding with YPF to jointly develop from Vaca Muerta.

Initial shale exploration and development efforts in China, meanwhile, have focused on the Longmaxi formation in the Sichuan basin in the south-central part of the country. EIA notes that while several international companies are active in China, much of the early effort has been led by China National Petroleum Corp.’s (CNPC) PetroChina Co. Ltd. and Sinopec.

http://www.ogj.com/articles/2015/06/eia-argentina-china-lead-shale-development-outside-n-america.html

Gas faces more competition from coal, renewables, IEA official says

Natural gas faces growing competition from coal and renewable energy sources at a time when its potential demand growth is slowing down, an International Energy Agency official said. “The last large contracts for [LNG] were signed in 2014 just before oil prices collapsed. We believe it is still competitive, but there are risks,” said Laszlo Varro, who heads IEA’s gas, coal and power markets division. “LNG is the only option besides pipelines to transport large amounts of gas from country to country, but it’s very expensive,” Varro said during a June 25 presentation at the Centre for Strategic and International Studies. “The coal industry in the United States is dreaming of the day when gas prices go $5/MMBtu higher, because it costs more than that to transport US LNG to Europe and Asia.” Varro spoke 3 weeks after IEA said in its 2015 Medium-Term Gas Market Report that global demand would rise 2%/year through 2020, down from the 2.3%/year it projected in its year-earlier forecast. It said weaker gas demand in Asia, where persistently high gas prices caused users to switch to other options until very recently, was behind the downward revision.

The characteristics of natural fracture systems is very valuable information when considering exploiting a fractured subsurface oil /gas reservoir. Open fractures are like highways for fluid flow and knowing the orientation, length and intensity of these fractures will greatly improve the accuracy of fluid flow models and ultimately the limit for economic exploitation of the reservoir. But even more interesting than the characteristics is the relation between fracture characteristics and the reservoir geometry. For example if a reservoir contains fractures that terminate at bed boundaries, fluid flow in the vertical direction will be very limited compared to a reservoir with fractures that simply propagate through the bedding (Cooke and Underwood, 2001). It’s also important to be able to predict the occurrence of certain fracture sets throughout the reservoir. For example if a fractures set was formed pre-folding, one could expect this set to be present through the entire reservoir, while fracture sets that formed during folding will only be present in the folded part of the reservoir.

This thesis focused on the study of fracture systems in a an outcrop analogue. An outcrop analogue is a 3D outcrop with similar geology and stress history similar to the reservoir being studied (Pringle et al., 2006). In the past outcrop studies have only provided 2D information (as one cannot see through the outcrop to capture the third dimension) and the data was used mainly to support inter-well reservoir models (Pringle et al., 2006). But in more recent studies, like this project, fractures are being interpreted in 3D reconstructions of the outcrop.

In this research project fracture planes were interpreted in a 3D model of the Upper Berda Formation in the Alima anticline in Tunisia. The aim of this project was to characterize fractures (orientation, height and spacing) and to investigate the relation between these characteristics and the outcrop geometry.

1. General description of the anticline (Riley et al.,2011) and outcrop
The Alima anticline is located in central Tunisia near the border with Algeria. It’s part of the Metlaoui Range, an E-W trending range in the southern Tunisian Atlas Mountains. The Alima anticline has a length and width of respectively ~ 18 km and 8 km and is thought to have formed due to far foreland brittle deformation. The southern flank of the anticline is steep, while the northern flank is gently dipping. The outcrop that was studied is located in the eastern corner of the southern flank of the Alima anticline. It has a length and height of respectively 253 m and 103 m.

The outcrop is an exposure of several layers of the Upper Berda Formation (Late Cretaceous). A small gorge splits the exposed rock body into two parts (Fig. 1).

Two different types of limestone can be distinguished: the lower part of the outcrop consists of somewhat white limestone beds and the upper part of the outcrop consists of somewhat red limestone beds. The upper part of the outcrop surface (orientation 338/77) has a steeper dip angle than the lower part of the outcrop surface (orientation 338/40). The orientation of the beds themselves does not vary greatly throughout the outcrop and is set to be 149/70 .There is a large normal fault going through the entire height of the outcrop.

2. Methodology
The characterization of fractures was done using two programs Open Plot and GOCAD. A 3D model of the Upper Berda outcrop was already created by two students as part of a master thesis in Tunisia. The model was created with 86 photos of the outcrop and PhotoScan (Agisoft) software. The students used GPS coordinates of six locations in the lower part of the outcrop to scale the model.

As a result the lower part of the outcrop model is an accurate representation of the outcrop in space, but the upper part of the outcrop is not. The upper part of the model is also deformed to some extent due to the fact that photos were taken from the base of the outcrop.

Open Plot
First Open Plot was used to represent fractures in the outcrop model as rectangular 2D planes in 3D space. These planes have an orientation and specific dimensions (length and width). Fracture planes were drawn onto the 3D outcrop model (Fig.2) by selecting the begin and end point of the fracture on the topographic surface and a third point on a plane along which the fracture continues into the outcrop. The intersection of a drawn fracture plane with the outcrop model (topographic surface) is defined as the height of the fracture. Thus fracture height and orientation were obtained using Open Plot.

Fig. 1: A picture of the outcrop model facing south. A small gorge splits the outcrop into two parts. The black lines indicate the boundary between the white beds (lower part) and the red beds (upper part). The yellow line indicates the strike of the large normal fault. Notice the offset in the black boundary line.

Fig. 2: Rectangular fracture planes in Open Plot. The length of the rectangle corresponds to the height of the fracture. The short side of the rectangle decides the orientation of the entire plane.
Due to lack of information it was not always possible to know in which direction the plane continues into the outcrop (dip direction). That is why three groups regarding fracture quality were created:

**Good Quality Fractures**

It was clearly visible in the outcrop model along which surface in which direction the fracture continued into the outcrop. This group contains 67 fractures.

**Moderate Quality Fractures**

It was not clearly visible in the outcrop model along which surface in which direction the fracture continued into the outcrop. This group contains 406 fractures.

**Bad Quality Fractures**

It was not at all clear along which surface in which direction the fracture continued into the outcrop. This group contains 371 fractures.

Only the good quality fractures were actually considered when analysing orientation results.

**Correction of fracture height**

The distance between the begin and end points of the fracture plane was interpreted as the fracture height. However the height of the fracture intersections with the outcrop are not necessarily the true height of the fractures.

Fig.3 gives a cross section of the outcrop and portrays why a correction for the fracture height is needed. Assuming that the bed orientation is constant and the fractures are perpendicular to the bedding, the correction factor is equal to sin(x):

\[ x = 180^\circ - (d.a.1 - d.a.2) \]

\[ \text{True height} = \text{apparent height} \times \sin(x) \]

**GOCAD**

The next step was to investigate the relation between fracture height and bed thickness and the relation between fracture spacing and the bedding. Because it’s easy to create curves in GOCAD this program was used to draw the bed boundaries. A “solid version” of the outcrop model (no texture on the outcrop surface) was used to draw the bed boundaries were a series of boundaries was clearly visible (Fig.4). In reality the bed boundaries are planes, but in GOCAD they were simplified and reduced to lines. The bed thickness was obtained by measuring the vertical distance between two successive bed boundaries. The thickness was measured at a place where the two bed boundaries were (about) parallel to each other and the distance measured was perpendicular to both boundaries.

Later the fracture data obtained in Open Plot was loaded in GOCAD and the intersections of the fracture planes with the outcrop were visualized together with the bed boundaries. An extensive procedure (which will not be discussed) was followed to finally obtain several closed polygons, each containing the fracture intersections within either a part of a bed or roughly an entire bed.

**Fracture Spacing**

Fracture spacing is by definition the perpendicular distance between fracture planes (G Bertotti 2014, pers. comm., 12 June). Applying this definition was not feasible because the dip direction of the fracture planes in a bed would have to be known (due to the intermingling of good quality and moderate quality fractures this was not the case) and it is not always obvious what the perpendicular distance is when planes are not parallel. So instead the 2D fracture spacing was calculated as 1 / fracture intensity (see Fig.5.). Fracture intensity depends on the total height of the fractures within an area. Thus fracture intensity does not only take into account the number of fractures, but also the size of the fractures. The bounded regions drawn in GOCAD roughly coincide with beds.

![Fig. 3: Barney facing the outcrop surface.](image)

**Fig. 3:** Barney facing the outcrop surface. [Blue] outcrop surface, [Purple] upper and lower bed boundary, [Green] fracture plane perpendicular to bed (true fracture height), [Red] fracture intersection with outcrop (apparent fracture height as viewed by barney).

\[ d.a.1 = \text{dip angle bed (70°), } d.a.2 = \text{dip angle outcrop surface (40° - 77°).} \]

![Fig. 4: Bed boundaries in GOCAD.](image)
The area of these closed polygons ranges from 4.6 - 155.3 m² with an average value of 58.2 m².

4. Results
Orientation
The majority of the fractures in the outcrop dip roughly NE and NW, but there are also several fractures which dip WSW. These orientations will give rise to intersecting fracture planes and the presence of conjugate fractures was indeed noted while drawing fracture planes in Open Plot (Fig. 7). This leads to several options for a conjugate set: the NE-NW dipping fractures, the WSW/W-NE dipping fractures or the WSW/W-NW dipping fractures could belong to a conjugate set (Fig. 6).

According to (Salvini & Storti, 2004) fractures that trend almost perpendicular to the axial surface (and thus propagate perpendicular to the bedding) are associated with pre- or post folding processes. Structures that trend parallel to the axial surface are commonly associated with folding (Salvini & Storti, 2004). However (Bergbauer & Pollard, 2012) found that pre-folding joints can influence the stress field in such a way that new joints form sub-parallel to existing ones during folding. Results indicate that there are 23 fractures (from all subsets) that are roughly perpendicular to the bedding and thus can be assumed to have been formed pre/post folding. The majority of the 23 fractures dip roughly NE and two fractures dip WSW. The absence of NW dipping fractures within the margins is peculiar. Assuming that these 23 fractures formed before/after folding, while the remaining 44 did not, the possibility that NE-NW dipping fractures are a conjugate set is overruled.

Fracture intensity = P21 = L/A
Fracture spacing = 1/P21

\[ P21 = \text{fracture intensity (m}^{-1}) \]
\[ L = \text{total height of fractures (m)} \]
\[ A = \text{area of bounded region (m}^2) \]

Example calculation (see fig. 5):
\[ P21 = 8/6 \text{ m}^{-1}, \text{Fracture Spacing} = 6/8 \text{ m}. \]

The total length of the fracture intersections (so the sum of fracture heights) within the polygon could be calculated, as well as the total area of the polygon. These two parameters were used to obtain the fracture spacing in a specific bed.

This information suggests that there might be a WSW-NE conjugate set that formed post/pre folding.

The 44 remaining fractures are not perpendicular to the bedding and thus it can be assumed that the NW dipping fractures must have formed during folding. There are also fractures roughly parallel to the NE dipping pre/post folding fractures.

This could be due to the phenomena (Bergbauer & Pollard, 2012) discussed. Another possibility is that the NE-WSW conjugate set formed pre-folding, but fracturing continued on into the early stage of folding. Eventually this lead to subparallel fractures.

Fracture Height
Fractures start as small flaws or weak points in a fabric (rock). Naturally smaller fractures are more abundant than larger ones: fracture height distributions are often power law distributions (Odling et al., 1999).

\[ \text{Fracture Height} = P_{21} = L/A \]
\[ \text{Fracture spacing} = 1/P_{21} \]

\[ P_{21} = \text{fracture intensity (m}^{-1}) \]
\[ L = \text{total height of fractures (m)} \]
\[ A = \text{area of bounded region (m}^2) \]

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This could be due to the phenomena (Bergbauer & Pollard, 2012) discussed. Another possibility is that the NE-WSW conjugate set formed pre-folding, but fracturing continued on into the early stage of folding. Eventually this lead to subparallel fractures.
Starting at a fracture height of 1 meter and onwards, the shape of this fracture distribution is indeed similar to that of a power law distribution (Fig. 8). Fracture heights smaller than 1 m appear to be less abundant in the histogram. The fact that smaller fractures are less abundant in the results is caused by resolution issues. Fractures smaller than 1 m were more difficult to distinguish leading to a drop in frequency.

The fracture height is purely my interpretation, which means it does not necessarily agree with reality. The interpretation of fracture height depends on resolution and point of view. Looking back at outcrop photos in a later stage of the project brought doubt regarding the interpretation of fractures. In the outcrop model it may not have been clear, but by zooming in on photos, fractures appeared to be longer than first thought (fracture height was underestimated). A rough estimation for the uncertainty in fracture height was obtained by comparing the fracture height of 10 drawn planes (5 in the white limestone and 5 in the red limestone) with the later interpreted fracture height. Fracture height was underestimated by 4 meters.

Thus in figure 8 it seems that fractures are most abundant between 0 m and 4.9 m. However one must keep in mind that the fracture height was underestimated by roughly 4 meters.

As mentioned earlier the fracture height measured in Open Plot is the apparent fracture height and needs to be corrected to obtain the true height (Table 1). For the lower part of the outcrop, the correction factor is close to 1, meaning apparent fracture height is about equal to the true height. A correction is not necessary for this part of the outcrop. For the upper part of the outcrop the apparent fracture height is about 2 times larger than the true height. This can lead to a significant difference when fractures are long and must be corrected for. This correction however, could not be applied in this project as a consequence of the used fracture sampling method. Fractures were divided into groups based on quality, but not based on lithology (white and red limestone beds). In short when analyzing data it’s not obvious which fractures belong to which part of the outcrop. Based on a rough estimation 281 fractures would need a height correction (1/3 of the total amount of 844).

Bed Thickness
Based on table 2 the white limestone beds are generally thinner than the red limestone beds. Because only a relatively small fraction of the entire outcrop was sampled this distribution is probably incomplete, but based on a visual comparison of red limestone beds that weren’t measured with white limestone beds, it is likely that this result will come up again even if more beds are measured.

Comparing figure 8 with Table 2 suggest that fracture height is limited by the bed thickness. The “fracture height limit” at 4.9 m (beyond a fracture height of 4.9 m there is a clear drop in frequency) is close to the maximum bed thickness of 4.5 m. But when taking into account the estimate that the fracture height is actually 4 m more, this relation between fracture height and bed thickness no longer applies. Fracture height then exceeds the maximum bed thickness, which is in agreement with observations in Open Plot: fractures propagate through bed boundaries (Fig. 9).

<table>
<thead>
<tr>
<th>Dip Angle Bed</th>
<th>Dip Angle Outcrop</th>
<th>x</th>
<th>Correction Factor</th>
</tr>
</thead>
<tbody>
<tr>
<td>70°</td>
<td>77°</td>
<td>33°</td>
<td>0.54</td>
</tr>
<tr>
<td>70°</td>
<td>48°</td>
<td>70°</td>
<td>0.94</td>
</tr>
</tbody>
</table>

Table 2: The minimum, maximum and average values of the bed thickness. A total of 19 beds were measured: 12 in the lower part and 7 in the upper part of the outcrop.

<table>
<thead>
<tr>
<th>Bed Thickness lower part (m)</th>
<th>Minimum</th>
<th>Maximum</th>
<th>Average</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0.5</td>
<td>3.3</td>
<td>1.8</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Bed Thickness upper part (m)</th>
<th>Minimum</th>
<th>Maximum</th>
<th>Average</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1.5</td>
<td>4.5</td>
<td>3.1</td>
</tr>
</tbody>
</table>

Fracture Spacing
According to Table 3 the fractures in the lower part of the outcrop have a larger spacing than those in the upper part of the outcrop. However there is very little data on the spacing in the upper part, so this distribution cannot be used to make any statements. Figure 10 shows the presence of outliers in beds 4, 6 and 9 (white limestone beds) and an increase in spacing in beds 14, 15 (white limestone) and 16 (red limestone). Beds 14 and 15 lie in a very weathered zone, thus it is expected that spacing should increase, due to the absence of drawn fractures. The plot shows that there are variations in fracture spacing of roughly 2 m in the white limestone beds. Figure 10 however, does not illustrate a clear difference in fracture spacing in the red and white limestone, suggesting that the mechanical properties of the lithologies are similar.

<table>
<thead>
<tr>
<th>Fracture Spacing lower part (m)</th>
<th>Minimum</th>
<th>Maximum</th>
<th>Average</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0.6</td>
<td>36.3</td>
<td>6.6</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Fracture Spacing upper part (m)</th>
<th>Minimum</th>
<th>Maximum</th>
<th>Average</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0.5</td>
<td>6.2</td>
<td>2.3</td>
</tr>
</tbody>
</table>
Conclusions
Linking fracture characteristics to the geometry of an outcrop analogue can greatly improve the modelling of the mechanical stratigraphy. It is valuable to know the characteristics (height, orientation and spacing) of fractures and even more valuable to know if these characteristics are homogenously spread over the entire outcrop or if the outcrop can be divided into zones with different characteristics. This can greatly improve the understanding of the structure of a subsurface reservoir, which can improve the approach for exploitation.

The results of this research project are far from the complete picture of the mechanical stratigraphy of this outcrop, but the following conclusions are a start:

- Current data suggests that the outcrop contains a pre folding NE-WSW conjugate set that continued on in the early stages of folding which eventually lead to sub parallel NE dipping fractures. During folding NW dipping fractures were formed.
- Fracture height is not limited by bed thickness.
- Current data suggests that white limestone beds are thinner than the red limestone beds.
- Current data suggests that the mechanical properties of the white and red limestone are similar.

References


Fig. 10: Fracture spacing versus bed position (bed number). This plot corresponds with Figure 4. The first bed lies in the bottom right section of the outcrop. Bed numbering continues upward until the highest bed in the upper left section of the outcrop. The red line indicates that beds 1-15 are in the white limestone (lower part) and beds 16-19 are in the red limestone (upper part).


By By

In the beginning of this year your hair was cut off until you were bald. It took a lot of time before your hair grew back. At any point were you concerned that your hair was not going to grow back?

No, when I had hair I already saw that the first coves were forming. When I was bald I looked like a grumpy warden, but everyone knew I was the cutest warden in a long time. I had only got concerns about my hair when the barber had cut a lot off last February. Now I decided to let my dreadlocks grow until they reach my kneecaps.

What are your plans for next year?

My plan is to study good and to work on my bachelor. It is a pity that I can't be a lot in "Het Noorden" next year. I'm also planning to be myself next year.

Finally, what are you going to miss most about last year?

The fact that I can't say as a warden that I have my own pub anymore. I also miss the drunkenness that came along with my position and that it was generally accepted that I was drunk. What I will miss the most are the hangover looks my fellow board members had on a Thursday morning. I also will miss the Rabobank.

What was the most memorable Noordenevening of this year?

(The memory of the warden is not very good, so it took him some time before he answered).

"The last long Noordenevening of this year" The evening the warden and the president had swum together in the Canal. The evening Johannes had spent the night sleeping in the basement of 'Het Noorden'. The evening where Frans saw nothing. The evening that had put the pedel of PS in his place and on this evening the whole board of PS went home with their tail between their legs.

What do you prefer? French fries or Flemish fries

French fries are small, thin, less and pointy. In contrast to Flemish fries which are big, fat, blunt and delicious. Just like miners.

If you compared your fellow board members to Disney/Fairy tale characters. Which would they be?

I compare Marnix with Cinderella. When Marnix lost his own pungel, he felt like Cinderella when she lost her shoe, because without his own pungel, Marnix isn't the princess he always secretly wants to be. I compare Frans with Goofy, just lazy and blunt and he lives his life like a dog: He only eats and sleeps. A trustworthy Husky in the 123 herd. I compare Johannes with Robin Hood. The man who steals from the rich and gives to the poor. The man who thinks fairness is one of the most important things. As treasurer he has the most ideal position to transport the money from the rich to the poor. Talitha, for all the people who knew the story about the holy Barbara. She is just like Rapunzel. Barbara is the holy protector of all miners, and just like Rapunzel she escaped from a big tower.

Name: Dirk Korte
Age: 20
Year: 3rd year AES student
Board function: Warden

How do you think the past year went with board 123 in charge?

(Drinks his beer and laughs) "Just Good". There were a lot of people at the MV-activities. We made sure that there was a good atmosphere. I am very proud of the Honorary Member installation. This was an activity where I spent a lot of time on. I was very excited that the evening went well and that the guests enjoyed it.

What was your favourite 'Noordenhappen'? "The kipkorn". It was the last long Noordenevening of this year and I bought a lot of Kipkorns and ‘van Dobben’ croquettes to satisfy my members. I took the most skillful sjaarsch (freshman) to the kitchen (it’s still a sjaarch) and the next 30 minutes I stuck all my love and compassion in the kipkorns and croquettes. Later on when I started my round in ‘Het Noorden’, Mr. Calis decided to hurl the whole plate with a backwards salto on the ground. So far my best Noordenhap ever.

Secondly, I choose onion, mayonnaise, a burger bun and meat. While this meal was made, I stood in the kitchen commanding the three sjaarsch like Gordon Ramsey. One sjaarsch prepared the bread, the other one was deep frying the meat and the last one added the sauce to the burger. I was in charge of the onions. The result was a handful of onions dripping in mayonnaise on a bun with a tiny piece of meat. A successful Noordenhap I suppose. (again drinks his beer and laughs)

In the beginning of this year your hair was cut off until you were bald. It took a lot of time before your hair grewed back. At any point were you concerned that your hair was not going to grow back?

No, when I had hair I already saw that the first coves were forming. When I was bald I looked like a grumpy warden, but everyone knew I was the cutest warden in a long time. I had only got concerns about my hair when the barber had cut a lot off last February. Now I decided to let my dreadlocks grow until they reach my kneecaps.

What are your plans for next year?

My plan is to study good and to work on my bachelor. It is a pity that I can't be a lot in "Het Noorden" next year. I’m also planning to be myself next year.

Finally, what are you going to miss most about last year?

The fact that I can't say as a warden that I have my own pub anymore. I also miss the drunkenness that came along with my position and that it was generally accepted that I was drunk. What I will miss the most are the hangover looks my fellow board members had on a Thursday morning. I also will miss the Rabobank.
Introduction

Dispersion of tracer particles in a reservoir occurs due to two different mechanisms. On the macro-scale, pressure gradients cause particles to flow from high-pressure to low-pressure areas (convection), while on the micro-scale particles mix due to in-situ concentration gradients (diffusion). The equation describing convective and diffusive processes in two dimensions is defined as (Lake, 1986).

\[
\frac{\partial C}{\partial t} + v_x \frac{\partial C}{\partial x} + v_y \frac{\partial C}{\partial y} - \left[ D_L \frac{\partial^2 C}{\partial x^2} + D_T \frac{\partial^2 C}{\partial y^2} \right] = 0
\]  

where \( C \) is the concentration, \( t \) is time, \( v \) is the superficial velocity, \( x \) and \( y \) are the coordinates, \( D_L \) is a diffusion coefficient in the longitudinal direction (flow direction) and \( D_T \) is a transverse diffusion coefficient (perpendicular to the flow direction). Taylor (1953) described how the effect of transverse diffusion affects the distribution of particles far more than longitudinal diffusion for flow in a tube where the process is mostly convection driven. This result is because transverse diffusion causes particles to dispersion in the direction perpendicular to the flow direction which changes the velocity of a particle. Longitudinal diffusion only causes particles to travel up- or downstream but leave the velocity of the particle unaffected. For very large times, the transverse diffusion coefficient will cause particles to change position in the transverse direction such that particles sample all different streamlines; for large times all particles will travel downstream with the average flow velocity. Taylor concluded that in this limit, the Taylor limit, longitudinal diffusion is negligible.

The dimensions of the diffusion coefficients shown in equation (1) are \([\text{m}^2/\text{s}]\). Therefore, by increasing the value of the diffusion coefficient the Taylor limit will be reached at earlier times (see Figure 1). This effect is remarkable. Although diffusion is a mechanism that causes particles to disperse, the net effect is that it counteracts spreading of particles; all particles will flow downstream with the average velocity rather than different velocities.

Besides spreading of particles due to the convection-diffusion equation (1), there is a third mechanism that causes particles to spread which we call numerical dispersion. Numerical dispersion is not a physical mechanism but is caused by simulation errors inherent in most simulators. The cause is discretization of equation (1). Without going into details, the idea is as follows: every grid cell of a domain can only store a single concentration value for every time step. Therefore, as particles enter a grid cell, the concentration value of the entire grid cell changes. In other words, mixing within a grid cell is instantaneous. A portion of these particles will then immediately start spilling to the next grid cell. Obviously, as this spreading of particles is caused by numerical errors, this is an unwanted effect as it distorts results. An example is shown for a convective scenario \((D_T = D_L = 0)\) in Figure 2. The example shows a pulse with unit concentration which flows from left to right with a velocity of half a grid cell per time step. After only five time-steps, the pulse is smeared over several grid blocks while the injected pulse should flow downstream with unit concentration and a width equal to \(\Delta x\).
where the transverse diffusion coefficient is scaled using the stored information on streamtubes. In fact, all parameters needed to simulate flow are scaled with the predetermined streamtube geometries. On this new domain, convection is described in one-dimension only (longitudinal direction) and numerical dispersion occurring as a result of modeling convection, is only in one dimension too. This would not be the case for a conventional simulator when the flow direction is, for example, diagonal to the grid direction. The importance of this fact will be shown later.

## Methodology

We have developed a model based on streamlines using an explicit upwind scheme for modeling convection (first order accurate) and a central difference scheme to model diffusion (second order accurate). Most of the numerical dispersion is then a result of the scheme used to model convection, which is least accurate.

We use streamlines to align the grid with the local flow directions, such that numerical dispersion due to modeling convection occurs along the streamline only. Streamlines are traced through the domain based on local velocities using the algorithm developed by Pollock (1988). The algorithm assumes velocities are defined at cell boundaries and change linearly within a grid cell. Based on this assumption tracing streamlines does not introduce any extra numerical errors.

Streamlines, which are simply one-dimensional flow paths, are then used to construct streamtubes which have volumes. The model assumes every streamline is the boundary between two neighboring streamtubes and the area between neighboring streamlines defines the geometry of a streamtube. The geometric data on all streamtubes is stored to be used for flow calculations.

By the definition of streamlines, all streamtubes are aligned with the local velocity field. Therefore, numerical dispersion due to modeling convection, only occurs in the streamline direction. Another way of describing this: we can transform the domain from \((x,y)\) to \((x,\psi)\), where \(\psi\) represents the streamfunction, such that all streamlines are aligned and flow occurs in the \(x\)-direction only (see Figure 3). This simplifies equation (1) to

\[
\frac{\partial C}{\partial t} + \nu \frac{\partial C}{\partial x} - D_l \frac{\partial^2 C}{\partial x^2} - D_t \frac{\partial^2 C}{\partial \psi^2} = 0
\]  

(2)
Results

As discussed in the introduction, Taylor (1953) has shown that the effect of diffusion in the longitudinal direction is negligible after a certain amount of time. If we think of numerical dispersion along a streamline in the same fashion as longitudinal diffusion, then this effect too should be negligible at the Taylor limit; the model should be approximately free of numerical dispersion in the flow direction.

There is a valid reason to think of numerical dispersion due to convection in the same way as longitudinal diffusion. By applying Taylor expansion to the explicit upwind scheme, we are able to quantify numerical dispersion by writing the equation in second order accurate differentials. Without going into details, the derivation yields

\[
\frac{\partial C}{\partial t} + v_x \frac{\partial C}{\partial x} - D_{L} \left( \frac{v_x \Delta x - v^2 \Delta t}{2} \right) \frac{\partial^2 C}{\partial x^2} - D_{T} \frac{\partial^2 C}{\partial \Psi^2} = O(\Delta t^2, \Delta x^2, \Delta \Psi^2)
\]

In equation (3) it is the additional term compared to equation (1), \((v_x \Delta x - v^2 \Delta t)/2\), that causes the large numerical dispersion. This term is a second order differential in the flow direction and grouped with the longitudinal diffusion term. The units are also the same as the units of longitudinal dispersion, verifying that numerical dispersion can indeed be thought of in the same way longitudinal diffusion causes smearing of particles. By inserting the parameters used in our model, the effect of numerical dispersion can be quantified to be at least fifty times larger than the value for the longitudinal diffusion coefficient. The question remains if the effect of numerical dispersion in the longitudinal direction is indeed negligible at the Taylor limit, just like longitudinal diffusion, as predicted by Taylor (1953). To answer this question we compare a concentration profile taken from a cross section at the center of the tube from our model with the result of a second order accurate model as shown in Figure 4.

The comparison between the two models as shown in Figure 4 shows a very close match near the Taylor limit. We therefore conclude that, even though for this scenario the term describing numerical dispersion as shown in equation (3) is fifty times larger than the diffusion coefficient, the effect of numerical dispersion is indeed negligible at the Taylor limit.

Next, we will demonstrate the advantage of using streamlines to align the grid to reduce numerical dispersion. To show the potential of streamlines we have applied our model to a more realistic scenario than flow in a tube, described by Overbeek et al. (2004). The results are shown in Figure 5 excluding diffusion \((D_{L} = 0)\). The boundary condition is set such that we have continuous injection over the left boundary of the domain, with unit concentration. Without mixing, the concentration should only be equal to unit concentration (red) or zero (blue). Any other concentration shown in the result is due to numerical dispersion.

\[\text{Permeability}\]

\[\text{Conventional}\]

\[\text{Our model}\]

\[\text{Figure 5 Comparison between a conventional model (mid) and our streamline-based model (bottom) based on the permeability field shown on top. No mixing is involved.}\]
It is difficult to quantify the accuracy of the result, but as the result of our model shown in Figure 5 shows fewer concentrations between zero and unity, we can conclude the results are more accurate. This example shows the potential of using streamlines as a basis for a simulator.

**Conclusions**

We have developed a first-order accurate streamline-based model to simulate in-situ mixing and dispersion. We first used the model to simulate Taylor dispersion in a tube and have shown, by comparing results from our model with those of a more accurate simulator, that the numerical dispersion becomes negligible near the Taylor limit. We then applied the model to a more realistic scenario to show the potential of a streamline simulator compared to a conventional simulator and have shown that using streamlines, numerical dispersion occurs in the longitudinal direction only. The results were compared with a conventional simulator and we conclude numerical dispersion is indeed reduced by aligning the grid with local flow directions. Further research has to be done into extending this model to three dimensions. Determining streamline geometries is potentially very hard for geologically complex scenarios.

**References**


The Petroleum Session

The Petroleum Session was opened and hosted by chairman and, since the preceding Saturday, Honorary Member, Jan Dirk Jansen. Han Tiebout from GustoMSC had an interesting talk about innovations concerning arctic drilling. As member of technical committees of the Offshore Technology Conference and the Arctic Technology Conference, he gave an expert overview of the challenges that are posed by arctic offshore drilling. The second speaker in this session was Martin van Staveren, founder of VSRM consultancy and lecturer at the University of Twente, and he carried the crowd away with his talk on risk management: ‘Ground, Risk, Innovation & Bounded Rationality’. Most of the crowd were not familiar with the bounded rationality concept beforehand, but Mr. Van Staveren managed to teach and inspire them simultaneously. The Morning Petroleum session was concluded, and the attendees, still very much inspired, took to the sandwiches with much gusto.

The Afternoon Petroleum Session started with a presentation by Theo Klimp, Fleet Director of Royal Wagenborg. The typical offshore commute by helicopter is not a very safe travel method, and leads to multiple casualties per year. Royal Wagenborg, in cooperation with shipbuilder Niestern Sander and Royal Dutch Shell, recently completed a project called the “Walk2Work Vessel”, a ship containing several ground-breaking technological components, such as motion compensated gangplanks and cranes, as well as a dynamic positioning system. This innovative designed ship is specifically built transport manpower and supplies to offshore drilling and production rigs in the safest manner possible. Following this, even more insight into the world of offshore services was given by Joop Roodenburg, CEO of Huisman, manufacturer of offshore heavy construction equipment. He explained how his company strives for a “Safer, Faster, Greener” way to do business. His colourful storytelling skills will make sure that no student, or indeed any attendee, will soon forget how and why we deal with safety issues.

The Mining Session

The Morning Mining Session was kicked off by Christopher Robben, from Tomra Sorting Solutions. When Mr. Robben was first told about the theme for the Symposium, he immediately mentioned that instead of minimizing risk, most people consider sensor based sorting technology to increase risk, and therefore, the title of his very well received presentation became “Intentionally Introducing Risk”. The practice of sensor based sorting is commonplace in recycling, but the applicability to mining operations is still very much in development, especially in complex ore mining, operations that can probably be said to profit most from pre-sorting. The following speaker in the morning mining session was Henk van Muijzen, the managing director of IHC Mining, who discussed developments in dredge, off-shore and deep sea mining, another forefront of the mining engine’s working area. Innovative dredge mining systems captured the whole room’s attention to such an extent that after the Q&A, the hungry mining session attendees discovered that the lunch break had already commenced 15 minutes earlier. Luckily, there were more than enough interesting and tasty sandwiches to go around.

In the afternoon, we were treated to a very exceptional sight. Frederik Ekenstedt Manager for Mine Automation for Boliden Minerals AB, had arranged a live feed from the Kristineberg Mine in north Sweden, where all automated processes, as well as truck movements, ventilation data and much more was all relayed directly from the mine by WLAN straight from the production face to the Mine offices, the Boliden Technology Department, and for a short while, to a group of awe-struck engineers in that theatre in Delft. The following speaker, Koen Meijer, Project Manager Hsarna at Tata Steel Research, did not have a live feed, but did present a comprehensive update of the Hsarna project progress, which showed not only that the Hsarna smelting furnace is an ideal way to reduce the carbon footprint of steelmaking, but also that the furnace has other beneficial effects and might become a serious full-scale candidate to compete with conventional blast furnaces.

After Mr. Peters had finished, the symposium was concluded with some words of thanks, which we would like to summarize and reiterate here. We are very grateful to our Committee of Recommendation for all their advice and for bringing us into contact with some of our speakers. We are of course very thankful to all our speakers, some of whom have travelled significant distances to speak at the Symposium, and all of whom have invested a considerable amount of time in preparing interesting and unique presentation to share with us. The Session Chairman, who have moderately moderated the sessions, some despite a total lack of preparation due to their last minute stepping-in, have our gratitude for all their efforts. And a special word of thanks goes to Piet Hein van der Kleijn, who assisted us with advice, interesting proposals, and valuable contacts. Last but certainly not least a we would like to thank the HalfluCo for their commitment and hard work during the entire Halflustrum, to Shelley van der Graaf, who skillfully directed the flow of the day and the Q&A sessions. The speakers and subjects presented a wide range of mining and mineral processing, and we sincerely hope that the attendees agree with us that it was a very interesting and at times spectacular session.

After the Parallel Sessions had ended, the Mining and Petroleum tracks came together again for the wind-up of the day. This was done by Nina Liem from Royal Dutch Shell, who spoke to us about floating LNG, large ships that act as production platform and liquefying plant, and by René Peters from TNO who told us some interesting things about maximizing the gas exploitation in the Netherlands, which offers some more perspectives for the self-sufficiency of our country in the light of recent geopolitical developments.
My first International Student Week (ISW) in Aachen-Bochum was a beautiful experience. The stories I heard about such a week are definitely true, during an ISW you will meet a lot of mining engineers from different countries in Europe and it is hard to find some sleep due the awesome activities. Besides that, you will be able to show them how we Delft miners rule with our comfortable clogs and our singing skills. This ISW we stayed in two different places, Aachen and Bochum, this gave us the opportunity to visit more mining related facilities.

The first meeting point was on Saturday the 9th of May at Bochum Central station, where we(Talitha Groenewold and I) were picked up by two of the organizers. Luckily Bochum is near the Dutch border, so the biggest part of our journey we were able to travel through the Netherlands. When we arrived at the Student accommodation, the first thing we did was getting a beer and enjoy the singing from one of the Spanish guys, who was already drunk. With some delay (7:00 is too early in my opinion) we started the first day with a city tour in Bochum, the tour guide told us that most of the building were destroyed in the war and that the current buildings are made in one style. After some jokes about art in the city, we went to the ‘Deutsches Bergbau Museum’. The museum exhibits includes a wide range of unique object from the history of mining, this makes it one of the most important mining museum in the world. We finished the first day in Bochum with a well-deserved BBQ in front of the museum.

The next day we visited a mine called Graf Wittekind. This mine was not as we expected, but even better. It was one of the oldest coal mines in the region and for me the most impressive excursion of the week. We entered the mine in two different groups, my group went first and some of us were surprised about the narrow (±120 centimeter) entrance. It was even becoming narrower (±40 centimeter) during the two hour tour, but after some crawling and sweating we reached the entrance black and satisfied.

On Tuesday the ThyssenKrupp AG Steel Factory was scheduled, with a huge hangover we entered the bus for a tour along all the parts of the factory. After this exhausting but impressive tour, we went to the Fiege Brewery in Bochum. While waiting for the right man, the first Fiege beer was already tasted and during the tour we had the chance to taste different types of beer and gain insights to the art of Fiege brewing. Anyway we ended the tour with unlimited beer, a currywurst and a powerful Glück Auf at the top of the brewery, so a perfect start of the last evening in Bochum. The rest of the evening we went to a party called the Zwei Stunden party, the bar is open from 22:00 till 24:00 and in these two hours it escalated really quickly. The rule ensures that people can drink a couple of beers and will still be able to study or work the next morning. But this was not our case, so when we got our entrance card and entered the club it seemed like we did not learn from the hangover this morning.

Even though the party stopped at 24:00, we had problems with catching the bus at 8:00 for visiting Komatsu Mining. Here a guide showed us the impressive machines they are making for mines all over the world and he lead us step by step through the process of making these expensive things. We were lucky that one of the largest excavators was in the last phase of production, so that we had the possibility to see how immense these things can be. In the afternoon the Aachen board joined and they went with us to the Open Pit Mine of RWE in Hambach. Though it was one of the mines we already visited in our first year, the scale of the mine and a bucket wheel excavator stays impressive.

After a good night of sleep we started the first day in Aachen with a welcome döner, a city tour and in the afternoon the memorable Beerathlon was scheduled. The start was at the drielandenpunt and the finish was a really nice BBQ place in the forest. The next day we had two company visits, Rheinkalk Lhoist Group, a global leader in lime, dolime and minerals, and a modern Lead Smelter(BERZELIUS Stolberg GmbH). It is hard to imagine that workers of the Lead Smelter are not allowed to drink while they are working in extremely hot places.

On the last evening the thanksgiving was held and as a tradition all the people of the ISW thank the organizing board and give them a present brought from their country. They already knew what they would get from us, our delicious sweaty clogs with jenever inside. Although we were the last to thank them(they saved the best), I am pretty sure our present was really appreciated and that we made some really good friends these days!

Glück Auf!
Almost one and a half year ago we both, Coco Antonissen and Jacintha Tjia, decided we wanted to go on exchange. Not just to some ordinary place, but to somewhere adventurous, to Indonesia. And an adventure it was for sure.

After all the paperwork was done, which was more complicated than we thought it would be, we could finally start arranging things. We found out a few other students from TU Delft were also going to Institut Teknologi Bandung for a semester and we got to know each other during a few drinks in the city of Delft. One thing was clear; nobody knew where we could get information, how to find accommodation or even when the semester started. But we combined all our knowledge and it turned out that together we knew more than we thought.

Jacintha heard from another girl who was going to Bandung it was possible to arrange accommodation before hand. After some e-mail contact the room was settled. Everything seemed okay and the room had very good facilities. Coco on the other hand, wanted to check out rooms when she arrived in Bandung, so she didn’t arrange anything. But before we arrived in Bandung, we both decided to go on a holiday in Indonesia. Not together, but we still met up a couple of times.

One thing that was arranged very well is that we both got a ‘mentor’ assigned. This was just a regular student from the faculty we wanted to follow courses at. Coco’s mentor was very enthusiastic, she invited Coco to stay at her family’s house in Jakarta for a week. This was also Coco’s first week in Indonesia, and the timing couldn’t be any better. As Indonesia is the biggest Muslim country in the world, Coco arrived in the middle of one of the biggest events: the Ramadan. Her mentor was of course also fasting, like most of the people in Indonesia. She didn’t expect Coco to follow the same diet as her and her family, but Coco still tried. This was more difficult than she thought it would be, since it meant no eating or drinking from sunrise till sunset. While Coco was suffering in the heat without water, Jacintha was chilling at the beach and visiting nice temples. Jacintha also visited some relatives in Jakarta, where she is originally from. After a nice week in Jakarta, Coco also decided it was time to relax in the sun so we both met up in Bali. We partied in Kuta and headed to the Gili Islands to do some diving. We were both planning on doing a ‘Scientific diving’ course at ITB and a diving license was a pre. Jacintha already had hers and Coco followed the 3-day course in Gili Trawangan. A few days were left before introduction days started so Jacintha decided to spend the last few days with her boyfriend on Lombok, and Coco spend these days between the monkeys in Ubud.

When we finally arrived in Bandung we spent the first few days in a hostel, together with another student from the TU Delft. He already arranged a room through a contact from ITB and this sounded very nice. The room that Jacintha arranged on the other hand, turned out to be unavailable. Eventually the three of us could live in the same complex, which turned out to be an amazing place. This complex had a beautiful rooftop view over the city and the friendliest lady ever who did our washings and was always ready to help us with all our problems. Although she didn’t speak English we always felt very comfortable with her.
The following days more and more exchange students arrived in Bandung, of whom many also decided to live in the same complex as us. During the introduction days we met even more students from all around the world for instance; Germany, France, Vietnam, Japan, Cambodia and many from the far far city of Groningen. Everyone was very enthusiastic about the exchange and many activities were planned. Everyone wanted to discover Indonesië and Bandung itself.

After using the public transportation for a week we realized a scooter is essential in a chaotic city like Bandung. At first we were a bit hesitant, but eventually driving in this crazy traffic turned out to be less scary as we thought it would be. Jacintha’s first trip was a bit more stressful, as she immediately lost the others and ended up on the highway. But everyone is so friendly in Bandung, they all helped her to find her way back home. So after Coco and the others were worrying about her for an hour back home, she arrived safe and sound. Luckily the other rides went better and even the local police guys became our best friends. They even know Jacintha’s whole life story after she forget her wallet and drivers license and had to wait with the policemen for an hour before a friend got her license back at home.

After two weeks of exploring Bandung and a mini surftrip to the beach the semester finally started. Completely in line with all the preparations this turned out to be very chaotic as well. Our classes were supposed to be in English but instead they were given in Bahasa Indonesia. In consultation with our supervisors we changed most of our courses. Still some of them were given in Bahasa Indonesia but we figured we could handle it with the help of our super friendly classmates and Google translate. Also a big difference with Delft is that the first lecture of the day already starts at 7 am. Because of the morning prayer at 4 am, everyone wakes up early anyway. Except for us, so 7 am was a hard task.

Most of the courses we followed together and the coolest of them definitely was the Scientific Diving course. For this course we had to be at the campus at 6.30 am on a Saturday morning to prepare everything for the diving practice in the university’s swimming pool. Surprisingly it was freezing cold every time so at the end of the dive nobody felt their toes anymore. After mastering all the required diving skills we went on a field trip to a small island in the Bay of Jakarta, pulau Pramuka. This excursion was not like the ones we were used to from Delft. The conditions were somewhat primitive, we had to share 4 matrasses on the floor with about 25 other girls. And it got even worse. After a night with not a lot of sleep, about 23 alarms went off at 4 am. Time for morning prayer in the room...

Nevertheless this trip was unforgettable. We did two dives in a beautiful surrounding and even had time for an afternoon of snorkling, although Jacintha had to fill this afternoon with counting marine animals on the beach for her other course. Coco called it the ‘fish-course’, since Jacintha can name all the marine animals in the ocean now. So after a long exhausting but also amazing weekend it was time to go back to Bandung and evaluate the obtained data.

Bandung is a very big city with approximately 2.4 million inhabitants. There are many activities you can do during free time. For instance we went to the movies quite often, almost every week. The cinemas were surprisingly fancy and incredibly cheap. One of the things we did that we never did before was going to karaoke.

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hours were kind of stressful for Coco since she had to be in class on time. In the end she had to go straight from the bus after a 27 hours journey to make it in time. Nevertheless it was totally worth it!

The week before Christmas we had our final exams. This went quite different than we were used to in Delft. One week before nobody even knew what the schedule would be and what the teachers did expect from us. We were told that our exams would be in English. Surprisingly, one of the teachers gave us an exam in Bahasa Indonesia. We weren’t even that surprised that it happened, but of course we couldn’t answer questions we didn’t understand. After we explained that we didn’t understand it he was kind enough to translate them for us, so eventually it wasn’t a problem. Since the exam week was also our last week in Bandung we had to say goodbye to everyone as well.

Jacintha’s mentor and one of our best friends in Bandung organized a goodbye party for us at her parents’ home. Since a party in Indonesia means that there is a lot of food we also made our Dutch contribution: bitterballen and appelflappen. First everyone was worried we didn’t add enough sugar to the appelflappen, Indonesians love sugar, but they liked it a lot. About half of the Indonesian unmarried girls wear a Hijab (headscarf), so this means many of our classmates wear them as well.

When we finished our busy weeks at the university we went outside of the city every now and then. One of our favorite trips was to Karimunjawa, a very beautiful and undiscovered tropical island in the North of Java. Since not a lot of people go there, getting there took us a while. Together with two other Dutch girls we booked a night bus that drove us in about 18 hours to the harbor. Jacintha was so stressed and tired that she slept the whole journey. Unfortunately the bus was delayed so we missed our boat that only went 5 times a week. Luckily we only had to stay at the harbor for one night. We made some friends on the bus and eventually they showed us a place to stay once we arrived at Karimunjawa. There weren’t a lot of options but this homestay seemed very nice. On the island we did a lot of snorkeling trips since that is the thing the island is famous for. The snorkeling was even better than expected, for both of us it was the most beautiful place for snorkeling where we have ever been. There were fish everywhere and the corals were in very good condition.

Also the food on the island was incredibly delicious. On the night market you could choose your own fish or squid that was caught on the same day. For only a euro we had the best fish ever, fresh from the BBQ. Unfortunately we had to head back to Bandung after 3 great days. Our bus was, of course, delayed again. Therefore the last few hours were kind of stressful for Coco since she had to be in class on time. In the end she had to go straight from the bus after a 27 hours journey to make it in time. Nevertheless it was totally worth it!

The week before Christmas we had our final exams. This went quite different than we were used to in Delft. One week before nobody even knew what the schedule would be and what the teachers did expect from us. We were told that our exams would be in English. Surprisingly, one of the teachers gave us an exam in Bahasa Indonesia. We weren’t even that surprised that it happened, but of course we couldn’t answer questions we didn’t understand. After we explained that we didn’t understand it he was kind enough to translate them for us, so eventually it wasn’t a problem. Since the exam week was also our last week in Bandung we had to say goodbye to everyone as well.

Jacintha’s mentor and one of our best friends in Bandung organized a goodbye party for us at her parents’ home. Since a party in Indonesia means that there is a lot of food we also made our Dutch contribution: bitterballen and appelflappen. First everyone was worried we didn’t add enough sugar to the appelflappen, Indonesians love sugar, but they liked it a lot. About half of the Indonesian unmarried girls wear a Hijab (headscarf), so this means many of our classmates wear them as well.
well. We were both wondering what it would look like on us but in the shops we never dared to try them. When we confessed this to our classmates they directly got a few out of the closet so we could finally try them on. The girls were very enthusiastic and taught us the different styles of wearing a Hijab for each occasion. The guys thought it looked good on us as well but still we felt a bit awkward. The party was a great success and we were very sad to say goodbye to everyone. Luckily many of our Indonesian friends are planning on studying in the Netherlands or somewhere else in Europe in the next few years.

Also with our exchange student friends and housemates we had a goodbye party. This one was slightly different from the one with our classmates since they do like to go out and have a few drinks in contrary to our classmates who are generally more conservative. Both goodbye parties were great although of course we didn’t want to leave yet at all. But we had one great prospect: at New Year’s Eve we would all meet at Gili Trawangan, the island where we also did some dives in the summer before we went to Bandung. Most exchange students and even two Indonesian friends were there. Together we did a few more dives and partied for some more nights. But then, after postponing the moment for as long as possible, we really had to say goodbye to everyone.

Coco travelled for another week with her parents before going back to the cold Netherlands after six months while Jacintha still had another adventure to start. She decided to take a study break and travelled for 4 more months together with her boyfriend all the way through Asia. She come back to the Netherlands one week late for the final semester in Delft, but she had an amazing time in South-East Asia.

While writing this story all the great memories came back and we realize even more how special and unforgettable our exchange period in Indonesia has been. We made some friends for life and although it sounds like a cliché it feels like an enrichment to our lives. Bandung now feels like a second home and we will never forget how lucky we were to get this opportunity. Indonesia is a great country and we will definitely visit it again, hopefully soon!
Think of making a difficult decision: you want to achieve something, you have many options to move towards your goal, and you try to choose the best alternative to get there. Things may get more complicated if your problem involves uncertainty: you need to consider scenarios of what can happen in reality, even though there is only one reality, only one true scenario. Now you try to find a solution that is the best, in average, over all the possible scenarios, which is not necessarily the best one for the true scenario. It looks like the uncertainty is stopping you from choosing the best solution for your problem, so you would like to reduce it or, ideally, to get rid of it. Additional information can help you with that, by revealing you a little bit more of what reality looks like, which allows you to re-think the scenarios you need to consider for your decision. But information does not come for free. If you are going to pay for it, you’d better find a way of quantifying how much it is worth it first. You need to assess the value of the additional information by measuring how much it helps improving your decision making process.

My PhD research work is about investigating ways of assessing the value of information in the context of reservoir management. In the next pages, you will find an extract from our first paper describing how we propose to approach this problem. The original paper is entitled “Value of information in closed-loop reservoir management” and authored by E.G.D. Barros (me) and my supervisors Prof. J.D. Jansen (TU Delft) and Prof. P.M.J. Van den Hof (TU Eindhoven). (and it is listed in the references section)

**Introduction**

Over the past decades, numerical techniques for reservoir model-based optimization and history matching have developed rapidly, while it has also become possible to obtain increasingly detailed reservoir information by deploying different types of well-based sensors and field-wide sensing methods. Many of these technologies come at significant costs, and an assessment of the associated value of information (VOI) becomes therefore increasingly important. In particular assessing the value of future measurements during the field development planning (FDP) phase of an oil field requires techniques to quantify the VOI under geological uncertainty. An additional complexity arises when it is attempted to quantify the VOI for closed-loop reservoir management (CLRM), i.e., under the assumption that frequent life-cycle optimization will be performed using frequently updated reservoir models. This paper describes a methodology to assess the VOI in such a CLRM context.

**Background**

CLRM is a combination of frequent life-cycle production optimization and data assimilation (also known as computer-assisted history matching); see Fig. 1. Life-cycle optimization aims at maximizing a financial measure, typically net present value (NPV), over the producing life of the reservoir by optimizing the production strategy. This may involve well location optimization, or, in a more restricted setting, optimization of well rates and pressures for a given configuration of wells, on the basis of one or more numerical reservoir models. Data assimilation involves modifying the parameters of one or more reservoir models, or the underlying geological models, with the aim to improve their predictive capacity, using measured data from a potentially wide variety of sources such as production data or time-lapse seismic. For further information on CLRM see, e.g., Jansen et al. (2005, 2008, 2009), Naevdal et al. (2006), Sarma et al. (2008); Chen et al. (2009) and Wang et al. (2009).

![Fig. 1: Closed-loop reservoir management as a combination of life-cycle optimization and data assimilation.](image)

An efficient model-based optimization algorithm is one of the required elements for CLRM. Because of the inherent uncertainty in the geological characterization of the subsurface, a non-deterministic approach is necessary. Robust life-cycle optimization uses one or more ensembles of geological realizations (reservoir models) to account for uncertainties and to determine the production strategy that maximizes a given objective function over the ensemble; see, e.g., Yeten et al. (2003) or Van Essen et al (2009). The objective function $J_{NPV}$ is defined as

$$J_{NPV} = \frac{1}{N} \sum_{i=1}^{N} J_i$$

(1)

where $\mu_{NPV}$ is the ensemble mean (expected value) of the objective function values $J$ of the individual ensemble members. The objective function $J$ for a single realization is defined as

$$J = \int_{t=0}^{T} \left( q_o(t, \mathbf{m}) r_o - q_{wp}(t, \mathbf{m}) r_{wp} - q_{wi}(t, \mathbf{m}) r_{wi} \right) \left(1 + b \right) \ dt$$

(2)

where $t$ is time, $T$ is the producing life of the reservoir, $q_o$ is the oil production rate, $q_{wp}$ is the water production rate, $q_{wi}$ is the cost of water produced, $r_o$ is the price of oil produced, $r_{wp}$ is the cost of water produced, $r_{wi}$ is the cost of water injected, $b$ is the discount factor expressed as a fraction per year, $r$ is the reference time for discounting (typically one year), and $\mathbf{m}$ is a realization of the vector of uncertain model parameters (e.g., grid block permeabilities or fault multipliers) – the $m$ member of the ensemble $(\mathbf{m}_1, \mathbf{m}_2, \ldots, \mathbf{m}_M)$ of $M$ realizations. The outcome
of the optimization procedure is a vector \( u \) containing the settings of the control variables over the producing life of the reservoir. Note that, although the optimization is based on \( N \) models, only a single strategy \( u \) is obtained. Typical elements of \( u \) are monthly or quarterly settings of well head pressures, water injection rates, valve openings etc.

Efficient data assimilation algorithms are also an essential element of CLRM. Many methods for reservoir-focused data assimilation have been developed over the past years, and we refer to Oliver et al. (2008), Evensen (2009), Aanonsen et al. (2009) and Oliver and Chen (2011) for overviews. An essential component of data assimilation is accounting for uncertainties, and it is generally accepted that this is best done in a Bayesian framework:

\[
p(m|d) = \frac{p(d|m)p(m)}{p(d)} \tag{3}
\]

where \( p \) indicates the probability density, and \( d \) is a vector of measured data (e.g. oil and water flow rates or saturation estimates from time-lapse seismic). In equation (3) the terms \( p(m|d) \) and \( p(m) \) represent the prior and posterior probabilities of the model parameters \( m \), which are, in our setting, represented by prior and posterior ensembles respectively. The underlying assumption in data assimilation is that a reduced uncertainty in the model parameters leads to improved predictive capacity of the models, which, in turn, leads to improved decisions.

**Methodology**

We propose to use the CLRM framework to simulate how information comes into play when operating the field, in order to assess its value. In our setting, we intend to not only quantify how information changes knowledge (through data assimilation), but also how it influences the results of decision making (through optimization). We express the optimized production strategy in the form of a control vector \( u \) which typically has tens to hundreds of elements (e.g. bottom hole pressure, injection rates or valve settings at different moments in time) and which needs to be updated when new information becomes available. The procedure consists of a sort of twin experiment on a large scale, because the analysis is performed in the design phase — when no real data are yet available. Note that classical CLRM is performed during the operation of the field whereas we are considering here an a-priori evaluation of the value of CLRM (i.e. in the design phase). The workflow starts with an initial ensemble of \( N \) realizations which characterizes the uncertainty associated with the model parameters. From this ensemble, one realization is selected to be the synthetic truth in the reservoir. The results of decision making (through optimization) imply the availability of completely informative data without observation errors, and the expected VOI therefore forms a theoretical upper bound (i.e. a "technical limit") to the expected VOI.

We note that this repetition is similar to the use of multiple plausible truth cases in Le and Reynolds (2014a, 2014b). The flowchart in Fig. 2 shows the complete procedure. The workflow can be adapted to compute the expected value of clairvoyance (VOC), which simply means that at some time in the reservoir life we suddenly know the truth so we can perform life-cycle production optimization on the true reservoir model. Such a clairvoyance implies the availability of completely informative data without observation errors, and the expected VOC therefore forms a theoretical upper bound (i.e. a "technical limit") to the expected VOI.

\[
VOI = \bar{J}_{\text{NPV}} = \frac{1}{N} \sum_{i=1}^{N} \left( J_{\text{NPV,post}} - J_{\text{NPV,prior}} \right) \tag{4}
\]

![Fig. 2: Complete workflow to compute the expected VOI.](image-url)
**Example**

We applied the proposed VOI workflow to a simple reservoir simulation model representing a two-dimensional (2D) inverted five-spot water flooding configuration; see Fig. 3. In a 21x21 grid (700x700 m), with heterogeneous permeability and porosity fields, the model simulates the displacement of oil to the producers in the corners by the water injected in the center. We used multiple ensembles of $N = 50$ realizations of the porosity and permeability fields, conditioned to hard data in the wells, to model the geological uncertainties. For a complete list of the reservoir model descriptive parameters and economic parameters considered in this example, please refer to the full version of our paper (Barros et al., 2014). The simulations were used to determine the set of well controls (bottom hole pressures) that maximizes the NPV. The optimization was run for a 1,500-day time horizon with well controls updated every 150 days, i.e. $M = 10$, and, with five wells, $u$ has 50 elements. We applied bound constraints to the optimization variables ($200 \text{ bar} \leq p_{\text{prod}} \leq 300 \text{ bar}$ and $300 \text{ bar} \leq p_{\text{inj}} \leq 500 \text{ bar}$). The initial control values were chosen as mid in-between the upper and lower bounds. The whole exercise was performed in the open-source reservoir simulator MRST (Lie et al., 2012), by modifying the adjoint-based optimization module to allow for robust optimization and combining it with the EnKF module to create a CLRM environment for VOI analysis. The average NPV for the initial ensemble is $\$53.5 \text{ million}$ when using base line control (fixed mid in-between-bounds bottom hole pressures: 400 bar in the injector and 250 bar in the producers) and $\$55.7 \text{ million}$ when using robust optimization over the prior (i.e. without additional information). The workflow was repeated for different observation times, $t_{\text{data}} = \{150, 300, \ldots, 1350\}$ days. For this 2D model we assessed the VOI of the production data (total flow rates and water-cuts) with absolute measurement errors ($e_{\text{f_u}} = 5 \text{ m}^3/\text{day}$ and $e_{\text{wct}} = 0.1$). The VOI and the VOC were computed for each of the nine observation times.

![Fig. 3: 2D five-spot model (left); 15 randomly chosen realizations of the uncertain permeability field (right).](image)

Fig. 4 depicts the results of the analysis for production data. Dashed lines correspond to expected values and solid lines to percentiles quantifying the uncertainty of the information measures. Here, $P_x$ is defined as the probability that $x\%$ of the outcomes exceeds this value. The markers correspond to the observation times at which the analysis was carried out. In Fig. 4 we note that, like for the toy model example, clairvoyance loses value with observation time, following the previously described stepwise behavior. In addition, by observing the percentiles, we realize that, in this case, the VOC has a non-symmetric probability distribution. The high values of $P_{10}$ indicate that, for some realizations of the truth, knowing the truth can be considerably more valuable than indicated by the expected VOC; however, the $P_{50}$ values, which are always below those of the expected VOC, indicate what is more likely to occur. The same holds for the VOI, as can be observed in Fig. 4 (right). The observation that provides the best VOI is the one at $t_{\text{data}} = 150$ days. Note that in our example the earliest observation seems to be the most valuable one, but that this may be case-specific. Fig. 5 (left) depicts the expected values of VOI (blue dots) and VOC (black line). The plot confirms that clairvoyance can be considered the technical limit for any information gathering strategy and that the expected VOC forms an upper-bound to the expected VOI. We also note that the expected VOI comes closer to the expected VOC with time. Indeed, as water breakthrough is observed in more producers, the production data of this five-spot pattern become more effective in revealing the main features of the true permeability and porosity fields. Fig. 5 (right) illustrates this in a different way by displaying the chance of knowing (COK), defined as the ratio VOI/VOC (Bhattacharjya et al., 2010). Although the VOI clearly approaches the VOC, their ratio does not change substantially with time.

This example shows how the proposed workflow can be used for VOI assessment. For this case, where we are considering the possibility of observing production at a single time, we recommend the production data to be collected at $t_{\text{data}} = 150$ days and we estimate this additional information to be worth $\$2.8 \text{ million}$. 

![Fig. 4: Results for the VOI analysis of production data in the 2D model: VOC (left); VOI (right).](image)
Conclusion
We proposed a new workflow for VOI assessment in CLRM. The method uses elements available in the CLRM framework, such as history matching and robust optimization. First, we identified the opportunity to combine these elements with concepts of information value theory to create a VOI analysis instrument. We then designed a generic procedure that can, in theory, be simply implemented in a variety of applications, including our optimal reservoir management problem. Next, the workflow was illustrated with an example and the results were analyzed. Because we take into account that the production strategy is updated periodically after new information has been assimilated in the models, we believe that our proposed method is more complete than previous work to estimate the VOI in a reservoir engineering context.

The main drawback of our proposed VOI workflow is its computational costs; it involves the repeated application of robust optimization and data assimilation, which requires a very large number of reservoir simulations. Depending on the types of optimization and assimilation methods used (e.g., adjoint-based, ensemble-based, or gradient-free) there may be large differences in the computational requirements, but even in case of using the most efficient (i.e., adjoint-based) algorithms, the computational load of the workflow will be huge. Hence, if the method is to be applied to real-field cases, some serious improvements regarding the number of simulations required are necessary. Despite its computational cost, we conclude that our approach constitutes a rigorous VOI assessment for CLRM. For this reason, we recommend that it be used as the reference for the development of more practical and less computationally demanding tools to be applied in real-field cases.

Acknowledgements
This research was carried out within the context of the ISAPP Knowledge Centre. ISAPP (Integrated Systems Approach to Petroleum Production) is a joint project of TNO, Delft University of Technology, ENI, Statoil and Petrobras. The EnKF module for MRST was developed by Olwijn Leeuwenburgh (TNO) and can be obtained from http://www.isapp2.com/data-sharepoint/enkf-module-for-mrst.

References

Fig. 5: Results for the 2D model: the expected VOI is upper-bounded by expected VOC (left); the COK (right).
Once we arrived at ‘De Teerput’ it became clear that the house was informed about our visit on that same day. Also, our beloved member Wesley was not able to attend. To be able to enter the house we had to climb up a narrow staircase with a lot of mining equipment hanging on the wall. In the kitchen we were welcomed by the youngest member of the house named Lars, who was cooking for hours to prep a delicious meal for the evening. After we were handed a welcome beer, they gave us an exclusive tour around the house and showed us the hybrid room of Wesley which is the living and his own sleeping room combined. Many mining equipment which was spread out around the house, turned out to be originated from an old illustrious mining house named ‘Het Zwarte Gat’. After this informing tour, dinner was ready. The meal was excellent. The menu consisted of tagliatelle with bacon and vegetables with on the side a cordon bleu. As a desert we had flan and the aperitif was a ‘Springbokje’. This was the drink of the house, consisting of crème de menthe and amarula liquor.

During the dinner we were entertained by Randy and his vivid never ending stories. An interesting story came by about Wesley and his lost door. This made it unnecessary for us to ask questions from our question list. When we asked if the cooking skills were always that good, it became clear that not everybody in the house knows his way in the kitchen.

One time a house member tried to make gravy from a breaded chicken schnitzel by adding hot water to it. This resulted in drowned chicken schnitzels. All of this was served with partly shelled beans and badly cooked potatoes.

During the after dinner dip, we watched the champions league game Atletico Madrid versus Real Madrid and we were introduced to the soccer drinking game. Each person choses a player and when the player is involved in an event that person has to drink. After a cozy evening and lots of fun we ended the evening. We hope that this mining house lasts longer than the previous mining houses we visited this year.
Werken in het hart van de Nederlandse E&P industrie
Puzzle 'The mixed Double Puzzle'
This puzzle concerns the aftermath of a fight to the death between a fourteen meter long Tyrannosaurus-Rex and an eight meter long Triceratops. The T-Rex severed the spine of the Triceratops but was skewered on the horns of this sturdy creature. Their bones ended up piled together and were further mixed up and mutilated by scavengers. In the picture you see a series of collected bones of both species. Ignoring the ribs and vertebra, can you identify which bones belong to which dino?
Solution Puzzle “Riddles in the Sand”.

Using the alphabetical list of hieroglyph signs, available in many books, the cryptic message can be deciphered to read: “At distance 217 m west of location B-X there is a magnetic anomaly over 20 m possibly stone at 4 m depth ending in large structure perhaps a funeral chamber.” Obviously the engineer killed by the landmine had intended to come back later for some illegal grave digging. Recently magnetic surveys have been used extensively by the Egyptologist Joseph Wegner and his team in an area 100 km north of Luxor. Under the desert sand they detected no less than 6 tunnels and grave chambers of pharaoh’s of the little known Abydos dynasty, unfortunately all plundered. These date from the time that the Hyksos invaders ruled in the north (1680–1527 BC). It is quite possible that some of their rulers were entombed in the Western Desert area. Since they had adopted Egyptian practices their tombs should also be similar. Below you see a rather simple picture of the hieroglyph alphabetic signs of which there are several versions. The sign for e and i is the same and to prevent confusion our man has hatched sign for i.
**MV Calendar / Graduation Subjects**

<table>
<thead>
<tr>
<th>Date</th>
<th>Event</th>
</tr>
</thead>
<tbody>
<tr>
<td>Friday 14 August t/m Sunday 16 August</td>
<td>Nuldejaarsexcursie</td>
</tr>
<tr>
<td>Saturday 15 August</td>
<td>Mijndoop</td>
</tr>
<tr>
<td>Sunday 16 August t/m Friday 21 August</td>
<td>OWEE</td>
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<td>Wednesday 25 August</td>
<td>ALV</td>
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<td>Bestuurswissel</td>
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<td>Friday 4 September</td>
<td>Barbaraborrel</td>
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<td>Thursday 10 t/m Sunday 13 September</td>
<td>Bergbau Seen Cup</td>
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<tr>
<td>Wednesday 30 September</td>
<td>Inauguratie</td>
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<tr>
<td>Friday 2 October</td>
<td>Barbaraborrel</td>
</tr>
<tr>
<td>Friday 6 November</td>
<td></td>
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</table>

<table>
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<tr>
<th>Name</th>
<th>Date</th>
<th>Subject</th>
</tr>
</thead>
<tbody>
<tr>
<td>Jiani Zhou</td>
<td>28 April 2015</td>
<td>Modeling MIC and Metal Precipitation with a 1D Reactive Transport Model (GE)</td>
</tr>
<tr>
<td>Machiel van der Linde</td>
<td>22 May 2015</td>
<td>Characterization of alteration and mineralization in Chimu Fm quartzite with near-infr red spectroscopy (RE)</td>
</tr>
<tr>
<td>Sidney van den Berg</td>
<td>5 June 2015</td>
<td>NMR Applications in Petrophysical Characterisation of Shale Gas Formations (RG)</td>
</tr>
<tr>
<td>Alex van El</td>
<td>22 June 2015</td>
<td>Modeling Dispersion and Mixing in EOR Processes (PE)</td>
</tr>
<tr>
<td>Muhammad Hassam Wajahat</td>
<td>25 June 2015</td>
<td>Numerical Modelling of Salt Precipitation During Gas Production (RG)</td>
</tr>
<tr>
<td>Tom Leeftink</td>
<td>26 June 2015</td>
<td>Comparative Analysis of Shale Permeability Measurements (RG)</td>
</tr>
<tr>
<td>Xiaofei Gan</td>
<td>2 July 2015</td>
<td>Twin-Horizontal Downhole Water Loop Production System (PE)</td>
</tr>
<tr>
<td>Tom van den Ende</td>
<td>3 July 2015</td>
<td>Extension viscosity aspects of HPAM in porous flow. An experimental and numerical study (PE)</td>
</tr>
</tbody>
</table>

Petroleum Engineering (PE), Geo-Engineering (GE), Reservoir Geology (RG), Resource Engineering (RE), Delft Aardwarmte Project (DAP)

**Colophon**

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Photo taken by: Alan MacKenzie
Location: Seven Sister Cliffs, Sussex, England
IN SEARCH OF EXPLORERS

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