Natural Resource

Officieel Orgaan van de Mijnbouwkundige Vereeniging

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Natural Resource

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Editorial

Dear reader,

With the summer holidays closing in, I'm sure everyone is busy packing his suitcase to head for warmer places. Don't forget to bring this edition to the nice places you're going to visit!

This edition contains a great variety of articles from both professors and students. Once again, we thank everyone contributing to this edition. The amount of input this edition was humongous, the received articles almost didn't fit the pages anymore.

For the first time this year we received a correct answer to the Weber Puzzle, sent by Richard Hontelez! We hope next year more correct responses will follow. Remember, you might win a case of beer!

This is already the fourth and thus last edition of the year. I hope you enjoyed reading this year's Natural Resource as much as we did making it. It has been fun being this year's Natural Resource Committee. We all did our best to pull off an amazing series of Natural Resource. I almost couldn't image a better team! We would like to thank all the contributors of this year's editions.
But yet the time has come to pass on the magazine to a fresh group of students, full of new inspirations. I am convinced our successors will provide us with four more beautiful editions.

I hope everyone passes their exams and enjoys their well-deserved vacation! For the last time this year, I'd like to conclude with a massive, ■

Glück Auf!

Shelley van der Graaf
Chief Editor

Presidential

Dear members, extraordinary members and other interested,

I'm writing this presidential after we've just came back from the first cultural excursion in four years. On Friday the 30th of June at 7:30 we left the faculty and it can't have been more than 5 minutes later that the first cans of golden goodness were opened and the excursion promised to be a good one. With two freshmen, called 'Glück' and 'Auf' bringing around our refreshments, we started our excursion. The excursion combined two things that miners love, being mines and drinking. One of our stops, a wine tasting in an a hand mined copper mine, combined this perfectly. Giving one of our honorary members, Duco Drenth, the opportunity to buy a bottle of wine for everyone he had convinced to become a member of KIVI. The trip included many more serious stops though such as the 'Saarländisches Bergbau Museum Bexbach', a very intriguing mining museum and the 'Völklinger Hütte', a melting furnace declared by Unesco as a World Heritage site.

Obviously there were much more activities during this last quarter of reign of our board. We organised the 4th of May Commemoration Day on the second of May, with a lecture about the coalmines and miners of Limburg during the second world war in the old faculty. After which we moved to the commemoration window where Prof. Weber told an intriguing story about the names on the window. Then we sang the ' Glück Auf' in commemoration of the fallen Miners. Afterwards we joined the general commemoration ceremony of all student associations.

We had the last few company presentation of our sponsors. Twenty-five miners ran in the Batavieren race to end in the 122nd place. The 75th yearbook committee had their yearbook presentation where they gave me the opportunity to show my (lack of) mining skills. Thereafter we had the annual dinner with Karl-Heinz Wolf as a mystery guest. As we are looking forward to the last few activities such as a LaTeX workshop, visiting one of our honorary members and the second year students in Vesc and another trip to one of our other honorary members the week thereafter, we are slowly coming to the end of our year being the Board of the MV.

As we are slowly coming to the end of the year I'd like to, on behalf of my Board, thank all who made this year possible, including all sponsors, honorary members, extraordinary members, student members, the staff of the faculty and all others who supported us throughout the year. Personally I'd like to thank my Board for all their effort for the board and the association as a whole. Lastly I'd like to thank the Natural Resource Committee for publishing four beautiful, informative and entertaining editions of the Natural Resource. Having said that I'd like to conclude with a firm and harmonious, ■

Glück Auf!

Luuk Mulder
President der Mijnbouwkundige Vereeniging

News

10 April 2014: Earth vibrated for half an hour billions of years ago

A billion years ago the earth was hit by an earthquake with a magnitude of more than 10.8 on the Richter scale. The entire planet was shaking for half an our and rocks were pulverized. The atmosphere was very hot and the sea probably began to boil, according to a study by American scientists published in the science journal Geochemistry, Geophysics Geosystems. They have calculated what happened when an asteroid struck the Earth. 3.26 billion years ago. The planet was still very young. " We knew it was big, but we did not know how big," says researcher Donald Lowe Thursday. The space rock was between 37 and 58 kilometers wide. It hit into the earth with a speed of about 20 kilometers per second. The impact released one billion times more energy than the atomic bombs on Hiroshima and Nagasaki in 1945.
Source: www.nu.nl

10 April 2014: Sound of undersea earthquake captured

For the first time, sound has been measured above the sea surface created by an undersea earthquake. Dr. Läslo Evers recently published in in Geophysical Research letters. Who works for the Royal Netherlands Meteorological Institute KNMI and TU Delft (CEG faculty).
Evers and his colleagues found out that infrasound (sound with very low frequency) which was measured with land based microbarometers on Tasmania had to originate from this earthquake. This is surprising because sound created on the oceans floor can normally not be heard above the sea surface. The water-air interface functions as a kind of mirror, reflecting all sound. "But there is an exception", says Evers. "If the wavelength of the sound is longer than the water column, then it can pass this interface."
"We thus found out that besides the hydro acoustic stations we can also use ground stations to measure what's going on in the oceans", says Evers. He expects that all sorts of under water sound sources, ranging from earthquakes and volcano eruptions, to under water nuclear tests, floating ice bergs and chanting whales, can be better localized in the near future thanks to this finding.
Source: www.delta.tudelft.nl

28 April 2014: New purple-pink mineral, 'Putnisite', discovered in Australia

Now called putnisite, the mineral was discovered in a surface outcrop of Polar Bear Peninsula. While workers with a mining company were prospecting for nickel and gold, one of them noticed the bright pink grains and sent the mineral to the Commenwealth Scientific and Industrial Research Organization. Putnisite, a strontium calcium chromium sulfate carbonate, has both a unique chemical composition and a unique crystal structure.
Source: www.huffingtonpost.com

13 May 2014: 301 miners killed in Turkish mine disaster

An explosion in an underground coal mine killed 301 miners in the Turkish city of Soma. The explosion occurred during the shift change and at that time 787 workers were underground. A fire caused by the explosion burned for two more days making rescue work nearly impossible and only after four days all the deaths were recovered. Turkey is well known for its terrible working conditioned underground. It tops the list of 'deaths per million tons of mined coal' with 7.22 deaths, more than 5 times the amount of China (1.27 deaths per 1 million tons)! Turkey itself has no specific health and safety guidelines for the mining industry and uses a 20 page document published in 1992 by the EU on underground mineral extraction as its main guideline. Typical mine-inspections are often described as 'office-based' and are announced weeks in advanced so the mines can prepare itself. Inspectors that do go underground are shown the best working parts of the mine and aren't allowed to walk around freely. The Soma mine was inspected only weeks before the accident and everything was found to be okay.
Source: www.cnn.com

3 June 2014: Explosion at Shell Moerdijk

A large explosion and a resulting fire took place at a Shell chemical plant in Moerdijk. During maintenance of an MSPO-plant (Moerdijk Styrene PropeneOxide) one of the two reactor vessels collapsed and exploded. As a result of the explosion 50 000 liters of ethylbenzene caught fire. Two people got hurt and suffered mild burns, but left the hospital a day later. The plant in Moerdijk produces around 2.5 million tons of styrene per year, around 10% of the world production, which is mainly used for the production of polystyrene plastics.
Source: www.nrc.nl

10 June 2014: NAM places earthquake sensors in Groningen.

The Nederlandse Aardolie Maatschappij (NAM) is going to place earthquake sensors in over two hundreds households in Groningen this summer. This enables them to measure above the ground how severe the earthquakes are and the damage they cause.
"Above ground record is new," said a spokesman for the NAM. "Now we can measure the strength of the earthquake at the surface. So far, there is little knowledge in this." The results are combined by TNO with measurements underground.
Source: www.nu.nl

16 June 2014: 'Oil price at its most stable since 1970s '

According to BP, the price of oil is at its most stable since 1970. The huge increases in US oil production offsets disruption to supply from places such as Libya.
Since the beginning of the unrest in the Middle East in 2011, the world production has a disruption of 3 million barrels per day. But this was offset by a similar increase in production in North America by the rise of the extraction of oil form shale gas.
Source: www.ft.com

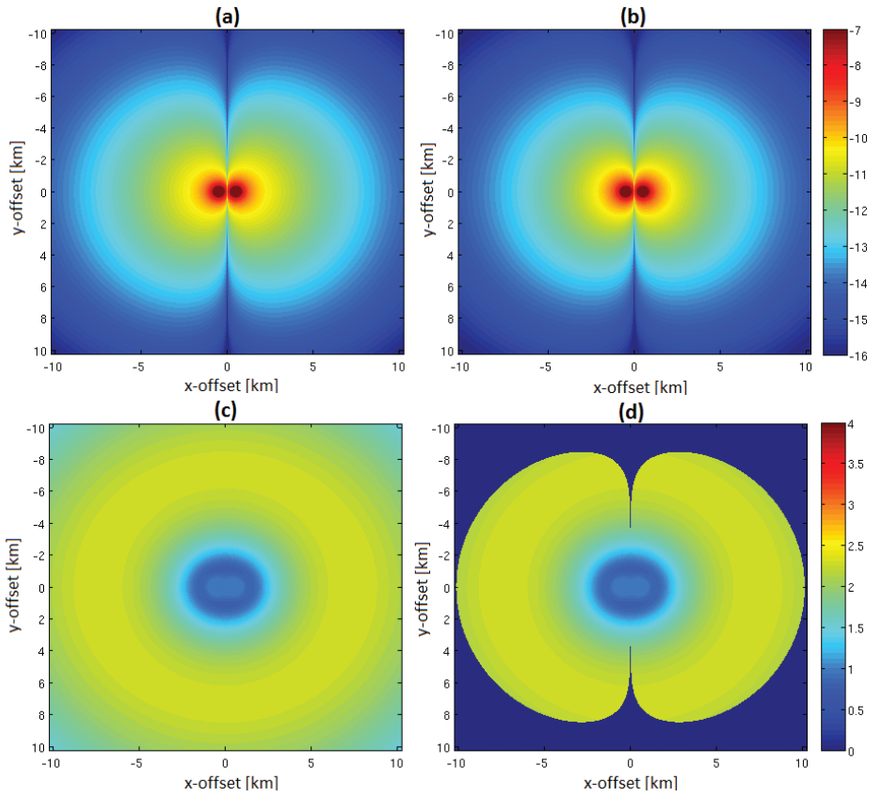
Bachelor Thesis

By Joeri Brackenhoff

For the past decades a wide range of methods have been used in the field of geophysics. The main goal of these methods is to obtain information of the subsurface. For this goal drilling cores can also be used. Drilling cores give an exact representation of the subsurface however this is very expensive and the core only represents a few meters laterally in the subsurface. The advantage of geophysical methods is that a large portion of the subsurface can be explored with a single method.

The most commonly used methods are Seismic, Self-Potential or SP, Gravity, Magneto telluric or MT, Nuclear Magnetic Resonance or NMR, Ground Penetrating Radar or GPR and Electromagnetism or EM. The seismic method is based on the reflection and refraction of acoustic waves in the subsurface. It gives a very good lateral definition of structures in the subsurface and therefore the presence of a reservoir. On the other hand it has a very low sensitivity to fluid contents and other parameters of the subsurface. SP is based on the electric potential naturally occurring in the subsurface. It is very cheap and easy to employ due to the fact that no source has to be utilized but it is not very accurate and does not always occur. Gravity is based on the weight and density of materials in the earth and can therefore be used for the exploration of heavy minerals and ores. MT is based on the presence of a naturally occurring EM field and therefore is not unlike the EM and GPR method with the main difference being the fact that for the last two a source is used and therefore the primary field is artificial. The MT method like the SP method is relatively cheap and not hard to utilize but again it is very dependent on the presence of the EM field occurring naturally. The NMR method is mainly used to look for groundwater. By sending out a magnetic pulse at a certain frequency the groundwater starts to resonate and the response can be used to measure the volume of groundwater. The EM and GPR method are very much alike. In both cases a source is used to induce a primary EM field which then creates secondary EM fields based on the parameters of the subsurface. EM, MT, GPR and NMR are therefore very sensitive to the parameters of the subsurface and can react very differently to a reservoir depending if it is filled with oil or water. The difference between the EM and GPR method is in the frequency and therefore the exploration depth. The GPR method uses very high frequencies which mean that the EM field behaves as a wave and because of this the field penetrates only very shallow depths. The EM method on the other hand uses very low frequencies which mean that the field has a diffusion behavior and therefore penetrates very deep into the subsurface. As mentioned before the EM method is very sensitive to parameters of the subsurface however its lateral resolution is very bad. The main advantage of the EM method over the GPR method is that it can be used to study reservoirs which are located far deeper than the GPR method can reach.

In recent years the method that has been used mostly on land and in marine environments is the seismic method because of its good resolution. When looking for hydrocarbons, it has the limitation that the contents of the reservoir cannot be easily derived from this method. In marine environments the EM method has been used in combination with the seismic method in order to not only find the reservoir but also discover its contents (Andreís and MacGregor, 2007) by combining the good lateral resolution of the seismic method and the sensitivity to the contents of the reservoir. The reason why EM was combined with seismic is because both methods can penetrate very deep into the subsurface and the presence of an active source means that the response is more constant and reliable. However the EM method has only very sparsely been used on land (Constable et al, 2010). This is mostly due to the ►



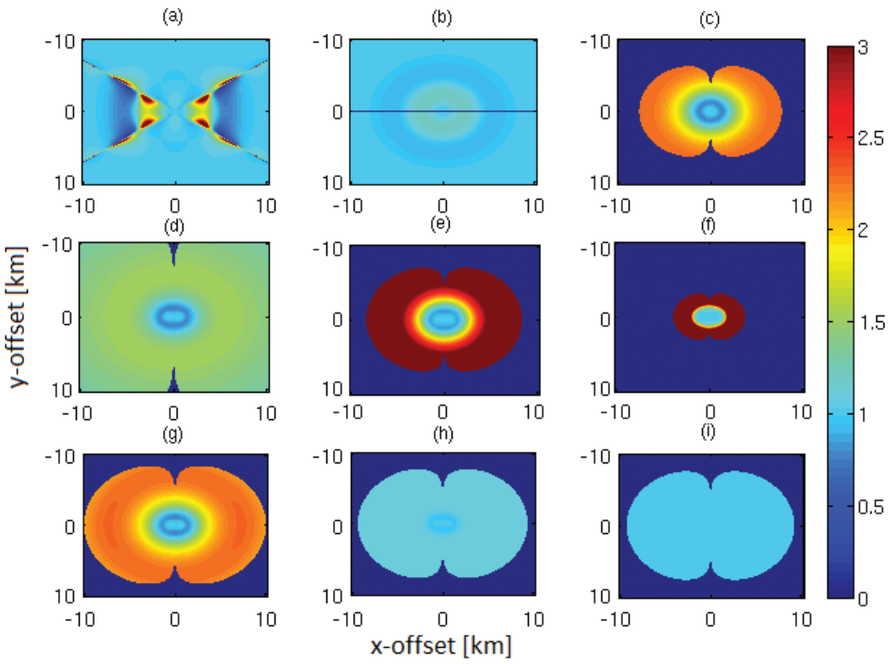
▲ *Figure 1: Electric field strength in V/m for component a horizontal source and vertical receiver at depth of 100 m at 0.5 Hz frequency (a) with reservoir (b) without reservoir. (c) Ratio between (a) and (b). (d) Ratio between (a) and (b) with electric field strength below noise level removed. The area of the figures is 10 by 10 km. (from Brackenhoff, 2014).*

presence of noise. Noise are EM fields that have not been created by the primary source but rather by other sources such as railways, factories houses and other things that are very present on land. Due to the high strength of these fields a lot of the response from the subsurface is dominated by these fields that do not contain any information about the subsurface. Recent studies have shown however that the EM method could be used more effectively by using vertical receivers instead of horizontal ones (Streich et al. 2010). This is because most of the electromagnetic field on land which could be perceived as noise is horizontal and thus has no strength in the vertical field (Hunziker et al, 2011). Also the EM field is very sensitive to changes perpendicular to its own orientation. Because the subsurface changes with depth the vertical EM field is perpendicular to this change and therefore should contain more information about the subsurface.
In order to see if this met
hod indeed holds any promise a survey was planned in Schoonebeek, the Netherlands close to the border with Germany. In Schoonebeek a lot of oil is recovered from reservoirs several hundreds of meters deep in the subsurface. Before the survey was done, modeling was used in order to check if the survey was plausible and what kind of setup should be utilized.

Modeling

The modeling was done by using a code named EMmod created by Dr. Jürg Hunziker from TU Delft. If one is interested in the workings of this code they should consult Hunziker et al. (2014). The way the modeling was done is illustrated in figure 1.

In figure 1 the electric field strength is modeled at a depth of 100 m where the vertical receivers can be placed. The source is horizontal and assumed to be a line source. The advantage of a line source is that the electric field strength is higher than with a point source. The source is located in the middle of the figures ranging from (-500,0,0) m to (500,0,0) m. The model is based on the subsurface of Schoonebeek with one difference between fig 1a and fig 1b. The first does have the model included and the second one does not. The reason for this is that the electric field strength is different depending if there is oil in the reservoir which has a much lower electric conductivity than subsurface layers or groundwater. In fig 1c the ratio between these fields is shown. The higher this ratio the more a reservoir influences the field strength. Thus if this ratio is very high it should be much easier to monitor with an EM survey. As mentioned earlier on land there is a lot of noise present in the form of EM fields from factories, farms, pipelines and the likes. The strength of these fields can be estimated and every part of the field that is below this noise level can be considered to be dampened by the noise. Therefore in fig 1d this part of the field is cut out.



▲ *Figure 2: Ratio for a frequency of 0.5 Hz horizontal source and (a) a parallel horizontal receiver, (b) a perpendicular horizontal receiver and (c) a vertical receiver. Ratio for a horizontal source and vertical receiver at a frequency of (d) of 0.1 Hz, (e) 1.0 Hz and (f) 10 Hz. Ratio for a horizontal source and vertical receiver at a frequency of 0.5 Hz with an electric conductivity of the reservoir of (g) 0.005 S/m, (h) 0.05 S/m and (i) 0.5 S/m. The area of the figures is 10 by 10 km. (from Brackenhoff, 2014).*

In order to see how the field reacts to differences in certain parameters the model with the reservoir is altered and ran through the code several times. By checking how the ratio and the area that is above the noise level changes an ideal combination of parameters can be achieved. An example of three parameters is given in figure 2. All the subfigures are presented in the style of figure 1d. Figure 2 represents the change in three parameters. Figures 2a to 2c shows a different setup of the source and receiver, figures 2d to 2f shows the different frequencies at which the source transmits the primary EM field and figures 2g to 2i shows the electric conductivity of the reservoir. The purpose of figures 2a to 2c is to show that the electric field strength is higher when both the source and receiver are horizontal but the ratio between having a reservoir and no reservoir is much lower. This result supports the claim that a vertical receiver is more sensitive to the reservoir than a horizontal receiver. From figures 2d to 2f the conclusion can be drawn that for lower frequencies the area of the field that is above the noise level is larger but the ratio decreases slightly. For a large area with a strong ratio the frequency should not exceed 1.0 Hz but also not be lower than 0.1 Hz. Finally in figures 2g to 2i the conductivity of the reservoir is considered. From well logs a conductivity of 0.005 S/m was derived ►

for the Schoonebeek oil reservoir. However in Schoonebeek an Enhanced Oil Recovery or EOR method is used using steam to improve recovery rates. The effects of this steam could cause a decrease in electric conductivity. The figures 2g to 2i show that if this were to occur, the effect on the ratio of the field is very drastic. Therefore the change caused by the steam injection should be kept into consideration when the survey is conducted.

Using the results of this modeling it can be determined that low frequencies should be used with a vertical receiver and a horizontal source. The receivers should be located a few kilometers away from the source because the ratio near the source is very low. These conclusions have been derived in greater detail by considering more parameters in Brackenhoff (2014). The results in that report have been used as a basis for the survey in Schoonebeek.

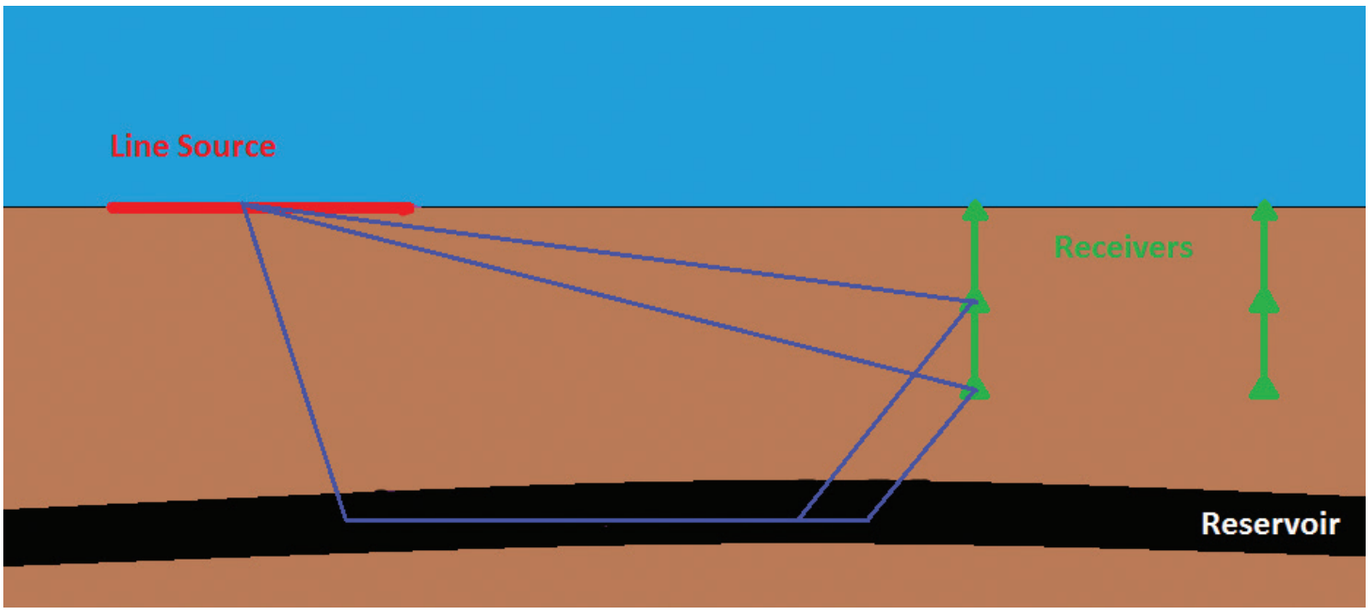
Survey

The survey in Schoonebeek was the main goal of the modeling and the other studies done in the feasibility of using a vertical receiver. The way the survey is set up is schematically represented in figure 3.

In figure 3 the subsurface contains a reservoir with an electric conductivity which is much lower than the rest of the reservoir. The primary EM field is created at the line source. As mentioned before a line source is used because it increases the field strength and therefore a larger part of the EM field measured at the receiver will be above the noise level. As can be seen from the figure a large part of the EM field travels through the subsurface. This is accumulation of the energy of the field due to the low electric conductivity. Also a part of the electric field strength does not travel through the reservoir but only through the subsurface above it. This happens with a larger part of the field if the frequency is higher. This part of the EM field does not contain any information about the reservoir and therefore is of no interest. Also in the figure the placement of the receivers can be seen. This is the most important part of the entire survey. As can be seen the receiver are actually buried at several different depths. By combining the measurements at several depths a dipole can be constructed to measure the electric field strength. Here also lies one of the greatest problems with a survey using vertical receivers. Horizontal receivers can be buried just beneath the surface but when placing vertical receivers a dipole of considerable length needs to be achieved. In order to make these boreholes, it needs to be drilled with special equipment which takes a lot more time and money. Also in order to correctly measure the vertical EM field, the dipole itself needs to be perfectly vertical which is almost impossible to achieve. Therefore the vertical dipole will also contain a part of the horizontal field. This part needs to be as small as possible and therefore the borehole cannot deviate too much.

After the receivers were placed they were given time to settle in the subsurface. During this time the noise level at these receivers was also measured in order to see which part of the received signal would need to be filtered out during the survey. The survey not only used vertical receivers but also horizontal receivers. This was done to check if the results using a vertical receiver were indeed better than at a horizontal receiver. The horizontal receivers that were used can also be employed for MT surveys and can therefore not only measure the electric field but also the magnetic field.

The survey took place over the course of a few days. The horizontal receivers were placed at the start of the survey and removed at the end of the survey. After the receivers were placed the source was ►



▲ *Figure 3: Schematic representation of CSEM-line source method on land. The lower conductivity of the reservoir causes the energy of the field to accumulate in its medium. (from Brackenhoff, 2014).*

▲ *Figure 4: Drilling equipment used to place the vertical receivers.*

used to transmit a primary EM field. The several different receivers logged the entire day until the logging data was recovered at the end of the day. After the survey the data that was recorded will be processed and conclusions will be drawn from this.

Summary

To summarize, the goal of the work done by the author was to discover if there was any feasibility to using the vertical receiver for the EM method instead of horizontal ones. The modeling shows that there is indeed cause to believe this. The results of the modeling were used during the survey in Schoonebeek. The results of this survey are currently being processed to see if the method indeed holds the promise from the modeling. ■

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De Limburgse mijnen en mijnwerkers tijdens de bezetting

Door Serge Langeweg

De volle productiecapaciteit van de twaalf Nederlandse kolenmijnen was tijdens de bezetting in Duitse handen. Voor de mijndirecties en de mijnwerkers betekende dat een dilemma. Voor de Nederlandse economie en samenleving was het van belang dat de eigen kolenproductie ongestoord doorging. De import van buitenlandse steenkool en van olie viel weg en dus was Nederland voor wat betreft de energievoorziening op zichzelf aangewezen. De vraag waarop de mijndirecties en de mijnwerkers tijdens de bezetting een antwoord moesten zien te vinden was echter waar de grens lag tussen die Nederlandse belangen en de belangen van de Duitse oorlogseconomie, waarvoor de Limburgse kolen ook werden gebruikt.

In dit artikel wordt aandacht besteed aan de wijze waarop de mijndirecties en de mijnwerkers omgingen met ruim vier jaar van steenkolenwinning onder Duitse druk. Hoe reageerden ze op Duitse maatregelen om de kolenproductie te controleren en in hoeverre was er speelruimte om de Duitse wensen en bevelen te omzeilen.

Onder beheer

De Limburgse mijnen hadden tijdens de bezetting te maken met een Duitse beheerder of *Verwalter.* Gedurende het grootste deel van de bezetting werd die functie uitgeoefend door Hermann Bruch, een geschoold mijnbouwkundige. De *Verwalter* was bevoegd voor alle handelingen die de bedrijfsvoering met zich mee bracht. De bevoegdheden van de mijndirecties en de Raden van Commissarissen van de mijnbedrijven werden opgeheven. Maar de *Verwalter* delegeerde die bevoegdheden weer aan de zittende directies, zodat zij de leiding over de mijnen 'normaal' konden voortzetten. Het zal echter duidelijk zijn dat de *Verwalter* altijd over hun schouders meekeek, en dat hij op zijn beurt verantwoording moest afleggen aan zijn superieuren binnen het Duitse apparaat. De mijndirecties troffen het in zekere zin met Bruch, omdat de *Verwalter* niet bekend stond als een scherpslijper.

Kolenproductie

Aan de vooravond van de Tweede Wereldoorlog bedroeg de kolenproductie van de gezamenlijke Limburgse mijnen 12 à 13 miljoen ton per jaar. Dat was te weinig naar de zin van de Duitse bezetter: de productie moest omhoog naar minstens 15 miljoen ton. Via een reeks van maatregelen zetten de Duitsers de mijndirecties en de mijnwerkers onder druk om dat doel te bereiken.

In een aantal stappen werd de arbeidstijd van de mijnwerkers verlengd. Voor bovengronders werd de 54-urige werkweek ingevoerd. De dagelijkse werktijd voor de ondergronders werd van acht uur gebracht op acht uur en 45 minuten. Ook voerden de Duitsers werkzondagen in. Eerst één zondag per maand en op vrijwillige basis. In de loop van 1942 werden dat twee verplicht werkzondagen per maand. Wie niet kwam opdagen liep kans in Duitsland te worden tewerkgesteld.

Daarnaast probeerden de Duitsers via het beloningssysteem de individuele prestaties van de mijnwerkers te verhogen en mochten mijnwerkers sinds 1941 na hun pensioengerechtigde leeftijd blijven doorwerken. Het aannemen van extra personeel paste ook in het streven om de productie te verhogen. Veel mannen meldden zich vrijwillig bij de mijnen aan. Omdat die spontane aanmeldingen onvoldoende nieuwe arbeidskrachten opleverden, voerden de mijndirecties daarnaast een actief wervingsbeleid in Limburg, maar ook in de rest van Nederland.

De mijndirecties waren kieskeurig bij de selectie van nieuwkomers. Veel sollicitanten werden afgekeurd om medische redenen of omdat ze anderszins niet geschikt werden bevonden voor het werk ondergronds. Uit latere verklaringen van mijndirecteuren bleek dat de mijnen wel genegen waren zoveel mogelijk arbeidskrachten op te nemen. Maar uit overwegingen van veiligheid bij het werk ondergronds moesten de mijndirecties eisen stellen aan de fysieke capaciteiten van degenen die zich voor mijnarbeid aanboden. Zo wezen ze het dwingende voorstel van Verwalter Bruch af om ruim 2.000 Nederlanders die in de mijnen bij Aken werkten, over te nemen. Volgens de mijndirecties waren dat uitsluitend werkkrachten die ze eerder hadden afgestoten, omdat ze om verschillende redenen niet voldeden.

De Nederlandse mijnen verzetten zich eveneens met succes tegen het plan van Bruch om vrouwen en invaliden in het bovengrondse bedrijf van de mijnen te plaatsen. Daardoor zouden arbeidskrachten vrij komen voor het werk ondergronds. Het ging niet door, omdat de mijndirecties aanvoerden dat bovengronds vooral ouderen werkten, en jongeren die nog in opleiding waren. Beide groepen waren niet inzetbaar in het ondergrondse bedrijf.

In januari 1944 stelde Bruch zelfs voor om onderduikers in dienst te nemen, met de belofte dat ze niet gestraft zouden worden. De mijndirecties wimpelden het voorstel als onuitvoerbaar af. Het zou onmogelijk zijn de onderduikers te bereiken en welke onderduiker zou zo goedgelovig zijn om zich op basis van een simpele toezegging aan te melden? Het illustreert dat de mijndirecties wat speelruimte hadden om een eigen beleid uit te voeren.

Die ruimte bleek ook bij de tegenwerpingen van de mijndirecties tegen het voornemen van de Verwalter om Russische krijgsgevangenen in te zetten, zoals in de kolenbekkens van de Kempen, Luik en Aken op grote schaal gebeurde. Met allerlei argumenten slaagden de mijndirecties erin het plan net lang genoeg tegen te houden. De bevrijding voorkwam dat het plan daadwerkelijk werd uitgevoerd.

Arbeitseinsatz

Al snel na de Duitse inval werd duidelijk dat werk in de mijnen een zekere mate van bescherming bood tegen Duitse maatregelen. Werklozen die verplichte tewerkstelling in Duitsland (*Arbeitseinsatz*) wilden ontlopen, vonden bij fysieke geschiktheid een toevluchtsoord in de mijnen. De mijn als veilige haven voor hen die verplichte arbeid in Duitsland wilden ontlopen, kreeg een nieuwe dimensie toen de Duitsers in de loop van 1942 de *Arbeitseinsatz* uitbreidden tot Nederlandse arbeiders die niet werkloos waren. Overal in het land werden bedrijven die in de ogen van de Duitsers van geen belang voor de oorlogsindustrie waren, gesloten. Andere werden gedwongen het personeelsbestand in te krimpen. In 1943 moesten voormalige militairen terug in krijgsgevangenschap en werden in de zogenaamde jaargangenactie mensen geboren tussen 1920 en 1924 opgeroepen zich bij de arbeidsbureaus te melden. Die verplichting gold ook voor ▶

een groep studenten. De op deze wijze vrijgekomen arbeidskrachten werden vervolgens verplicht in Duitsland tewerkgesteld. Mijnwerkers moesten zich ook melden, maar als zij ondergronds werkten, ontvingen ze doorgaans een stempel op hun distributiekaart en een vrijstellingsbewijs. Bovengronders liepen een groter risico, zeker wanneer zij ongeschoold waren. Zij kregen in lang niet alle gevallen vrijstelling. Zo vertrokken in 1943 minstens vijfhonderd jonge bovengrondse Nederlandse mijnwerkers verplicht naar Duitsland.
In de praktijk betekende werk als ondergronder een redelijke zekerheid niet naar Duitsland te worden gedeporteerd.

Verzuim en verzet

De mijnen moesten de toename van het personeelsbestand kunnen rechtvaardigen met stijging van de productie. Dat lukte niet. Tot en met 1943 bleef de productie stabiel op een niveau van 12 à 13 miljoen ton per jaar. Bovendien daalde de arbeidsproductiviteit voortdurend. Oorzaken van de stagnerende productie en de afnemende arbeidsproductiviteit waren, naast het structurele tekort aan geschoolde mijnwerkers, het sterk toegenomen verzuim en verzet- en sabotageacties.
In Duitse ogen werd het verzuim voor een deel veroorzaakt door ongeoorloofd wegblijven. In de loop van de bezetting nam dat zogenaamde willekeurig verzuim fors toe. Toch was het willekeurig verzuim marginaal vergeleken met het verzuim wegens ziekte. Naast een toename van ziektegevallen door het steeds kariger voorzieningenniveau in de loop van de oorlog, ging in het ziekteverzuim waarschijnlijk veel willekeurig verzuim schuil. Zeker nadat de Duitsers in 1942 onder dreiging met strafvervolging de verplichte zondagdiensten hadden ingevoerd, nam op doordeweekse dagen het aantal ziekmeldingen sterk toe. Veel mijnwerkers kwamen op zondag werken, streken het dubbele loon en wat extraatjes op en meldden zich vervolgens door de week een paar dagen ziek. Het verzuim moet ongetwijfeld worden gezien als een uiting van onvrede onder de mijnwerkers. De toenemende schaarste aan van alles en nog wat speelde mee, evenals de steeds hardere manier waarop de Duitse autoriteiten in het dagelijks leven ingrepen. Maar vooral bleek eruit dat veel mijnwerkers uitgeput raakten van het harde werk en de lange arbeidsuren.
Ook sabotageacties speelden een rol bij het achterblijven van de productie bij de Duitse wensen. Voor de mijnwerkers zelf hadden sabotageacties grenzen. Sabotage van grotere omvang bracht onaanvaardbare risico's met zich mee en dat was niet verenigbaar met het principe van wederzijdse, gezamenlijke verantwoordelijkheid voor de veiligheid ondergronds. Saboteren op kleine schaal gebeurde wel geregeld. Transportbanden werden beschadigd en wissels onklaar gemaakt, zodat het kolentransport stokte. In motoren werd zand gestrooid en er werden zoveel mogelijk stenen tussen de kolen geladen. Daarnaast uitte zich de onvrede door het kalken van allerlei anti-Duitse leuzen op muren en mijnwagens. Het waren allemaal kleine dingen, maar ongetwijfeld gaven ze de mijnwerkers wel het gevoel dat ze íets deden om de Duitse belangen te dwarsbomen.
Veel riskanter was het doorspelen van springstoffen uit de mijn naar verzetsgroepen, of het drukken en verspreiden van illegale blaadjes, waarbij mijnwerkers waren betrokken. Met name op Staatsmijn Maurits was een groep mijnwerkers bij deze laatste vorm van verzet betrokken. In de herfst van 1941 werd een aantal van hen gearresteerd en naar Duitsland gedeporteerd.

Staken

De meest dramatische vorm van verzet vond plaats eind april en begin mei 1943. De Duitse generaal Christiansen riep op 29 april 1943 voormalige Nederlandse militairen op zich te melden voor krijgsgevangenschap en gedwongen arbeid in Duitsland. Spontaan braken op veel plaatsen in het land protststakingen uit. Dezelfde dag nog gingen ook de Limburgse mijnwerkers in staking. Aan het eind van de middag legde als eerste het kantoorpersoneel van de Oranje-Nassau Mijn I in Heerlen het werk neer. Dat voorbeeld werd 's avonds door ondergrondse mijnwerkers van verschillende mijnen nagevolgd. De eerste arrestaties door de *Sicherheitspolizei* volgden diezelfde nacht. Desondanks breidde de staking zich de volgende dag uit. Van de ochtendploegen bleef ongeveer de helft weg, de middagdienst staakte vrijwel ►

▲ *Figuur 1: Vernielingen op het kantoor van de mijn Oranje-Nassau IV in Heerlerheide door zich terugtrekkende SS-troepen op 18 september 1944 (Collectie Continium Kerkrade).*

▲ *Figuur 2: Bronzen herdenkingsplaquette Staatsmijn Hendrik in Brunssum (Collectie Continium Kerkrade).*

volledig. Die 30e april kondigde de bezetter het politiestandrecht af. Dat betekende dat verdachten meteen, zonder vorm van proces, konden worden doodgeschoten. Dat overkwam op 2 mei zeven deelnemers aan de stakingen, waaronder de mijnwerkers Reinier Savelsberg, Meindert Tempelaars en Servaas Toussaint. Ze werden gefusilleerd in het bosgebied De Hamert bij Arcen in Noord-Limburg. Een dag later werd een vierde staker, Hein Horstman, na zijn arrestatie bij een vluchtpoging in Maastricht doodgeschoten.
Door deze represailles verliep de staking daarna snel. Op dinsdag 4 mei was de situatie weer min of meer normaal. Wel bleef een aantal opgepakte hoge mijnbeambten nog een paar maanden in Sint Michielsgestel in hechtenis. Tien doodvonnissen tegen stakers werden omgezet in 15 jaar tuchthuisstraf. Via het kamp Vught werden de veroordeelden overgebracht naar Dachau. Daar overleed een van de stakers, Wim Schepers. De overige overleefden het kamp en keerden na de bevrijding naar huis terug.

Bevrijding

Na de april-mei staking volgde nog een moeilijk anderhalf jaar van bezetting. De mijnstreek werd in september en oktober 1944 bevrijd. Bij hun terugtocht vernielden Duitse troepen bedrijfsinstallaties van de mijnen en sleepten ze van alles en nog wat mee naar Duitsland. Vooral bij de Oranje-Nassau Mijnen was de situatie ernstig. De Duitsers bliezen een deel van de elektrische centrale op. Met man en macht kon net op tijd worden voorkomen dat de pompen uitvielen en de mijn onder water liep.
Overigens waren de problemen van de mijnen niet verdwenen met de aftocht van de Duitse bezetters. Ook de tijd onmiddellijk na de bevrijding was moeilijk. Schaarste van materialen, onbruikbare transportwegen, personele problemen, sociale onrust in de bedrijven. En zeker ook de kwestie van het onderzoek naar bedrijfsgenoten die 'fout' waren geweest. In dat kader waren er zuiveringscommissies die het doen en laten van zowel kaderleden als gewone mijnwerkers tijdens de bezetting onderzochten.

Balans

De mijndirecties hadden een zekere speelruimte en ze namen die. Dat was ook een belangrijke overweging geweest om tijdens de bezetting op hun post te blijven. Het was hun overtuiging dat ze de belangen van het land, het personeel en de ondernemingen het best konden dienen door aan te blijven en hun functies te blijven vervullen. Die opstelling was conform de richtlijnen die de Nederlandse gezagsdragers hadden uitgevaardigd. Dat beleid was erop gericht te voorkomen dat de economie instortte, er massale werkloosheid ontstond en de bevolking werd getroffen door een tekort aan noodzakelijke levensbehoeften, zoals steenkool. Mede om die reden achtte de na de oorlog ingestelde Zuiveringsraad het beleid van de Nederlandse mijndirecties acceptabel. Door op hun posten te blijven hoopten de mijndirecties Duitse maatregelen te kunnen verhinderen of ophouden. Dat lukte bijvoorbeeld in het geval van de Duitse plannen om Russische krijgsgevangenen naar de mijnen te halen. Dat lukte niet bij de Duitse eis in mei 1943 om lijsten met stakers te leveren. Toen het naar de zin van de Duitsers te lang duurde, werden leden van de mijndirecties en het hogere kader opgepakt en ontslagen.
Ook de houding van de mijnwerkers week in het algemeen niet af van wat bij de Nederlandse bevolking gebruikelijk was. Men maakte er in de gegeven omstandigheden het beste van. Het feit dat mijnwerkers de kolenproductie op peil hielden, was voor het bezette Nederland van groot belang. Tijdens de oorlogsjaren bleef 90-95 procent van de Limburgse kolen in Nederland, al hadden de meeste mijnwerkers daarvan een ander beeld. Acties van verzet onder de mijnwerkers kwamen voor en een aantal van hen betaalden daarvoor een hoge prijs. De staking van april-mei 1943 is daarvan de meest in het oog springende uiting. In het dagelijkse leven ondergronds was de speelruimte voor verzet of sabotage beperkt. Mijnarbeid is gevaarlijk en riskant, zelfs zonder het saboteren van werkzaamheden. Men moest daar dus erg voorzichtig mee zijn. Bovendien lag ook het risico van verraad, door Duitsgezinde collega's en opzichters voortdurend op de loer. ■

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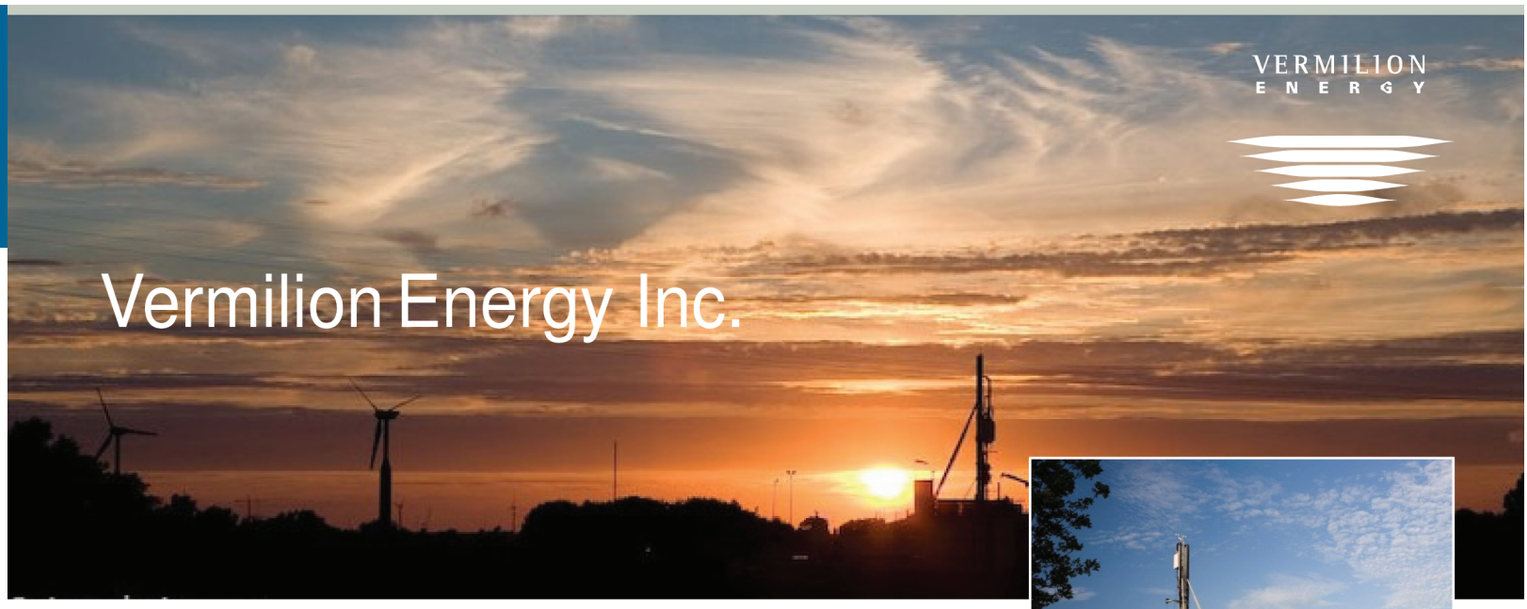

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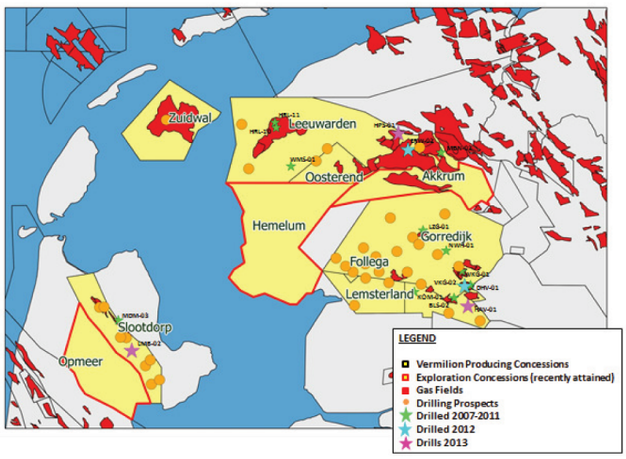


Doorstart van het Mineralogisch Geologisch Museum

Door Duco Drenth

Geachte (ex-)volger van het vak 'Mineralen en Gesteenten', de doorstart voor het Mineralogisch Geologisch Museum gaat door! U kunt uw kennis op het gebied van 'steentjes' vanaf 2015 weer naar believen ophalen, zónder tentamenangst.

In de editie van de Natural Resource van november 2013 stond een oproep voor ideeën. Om zo een doorstart van het met opheffing bedreigde Mineralogisch Geologisch Museum (MGM) te kunnen realiseren. Zoals in het stuk werd aangegeven was de TU Delft namelijk begonnen met de voorbereidingen voor verhuizing van de bijzondere collectie mineralen en gesteenten naar biodiversiteitscentrum 'Naturalis' in Leiden. De mineralen werden verplaatst zodat de ruimte een bijeenkomstruimte kon worden.

Het doel van de oproep in de NR was om de TU een alternatief plan aan te bieden waarbij het culturele erfgoed van het MGM voor een belangrijk deel behouden zou worden op de plaats waar het thuishoort: in het pand aan de Mijnbouwstraat 120. Dit artikel zal u vertellen hoe de ontwikkelingen rondom het mineralogisch museum zijn gegaan.

De ontruiming van het MGM: een gevaarlijke expeditie

Het is niet eenvoudig gebleken om überhaupt de waardevolle mineralen collectie 'te ontmantelen' - zoals de officiële aanduiding heet - ondanks de goede voorbereidingen en de duizenden lege kartonnen dozen die waren verzameld. Mijngeest Caspar heeft namelijk flink 'roet' in het vitrinekasten weten te gooien. Ten eerste de radioactieve mineralen die her-en-der werden aangetroffen.

De radioactieve mineralen veroorzaakte een vertraging van zo'n 3 maanden. Dit omdat die paar glimmende en gammastralende handstukken door mannen in witte pakken in stevige stalen vaatjes moesten worden ingepakt. Deze vaatjes zullen de komende 100 jaar bij de COVRA in Vlissingen worden bewaard, waarna de vaten in de ondergrond geplaatst zullen worden.

Toen men daarna weer de verhuisdozen (en handschoenen) wilde oppakken bleek dat er asbesthoudende mineralen in het museum te liggen. Dit veroorzaakte nog groter alarm dan bij de radioactieve mineralen ('Asbest!'). Het gevolg was weer een vertraging van zo'n 3 maanden en weer een horde aan mannen in witte pakken.

▲ *Figuur 1 & 2: Inpakken van 140.000 stukken gebeurt met de hand, iedere steen (met bakje) gaat zorgvuldig in een plastic zakje.*

▲ *Figuur 3: 5 stalen 'COVRA'-vaatjes met de radioactieve mineralen.*

▲ *Figuur 4: Screenshots van een aantal ingescande mineralen als 'app' (zie ook: http://brightstonesapp.com).*

Inmiddels (status: begin mei 2014): het inpakken van de resterende 100.000 stenen is weer aangevangen onder strenge begeleiding van stralingsinspecteurs en overige experts. Nu hoopt men zonder verder onderbreking - Caspar Volente! - voor de zomervakantie de gehele zaal op de eerste verdieping 'leeg' te hebben. Het schijnt echter dat er ook bijzondere exemplaren van kwik-, lood-, bismut- en arseen (arsenicum)-mineralen in het museum aanwezig zijn.

Het alternatief: een sponsorplan en geld voor een doorstart

In de tijd dat het ontruimen stil lag werd er hard gewekt aan het uitwerken van een realistisch sponsorplan. Het doel daarvan was om middels externe werving voldoende geld bijeen te halen om het MGM voor een periode van ten minste 10 jaar 'rust' te geven. En vooral om aan te tonen dat het MGM moet blijven bestaan.

Dus is het plan gesmeed om (een deel van) de collectie inderdaad onder te brengen bij Naturalis, als professionele beheer instelling, maar dat de TU Delft het recht behoudt om te allen tijde uit die collectie te putten voor hun eigen tentoonstelling in Delft. De doorstart van het MGM wordt dan - na een grondige verbouwing - gehuisvest op de tweede verdieping van het huidige onderkomen (de oude 'AIO'-zolder). Het plan is dat het museum zal worden geïntegreerd met activiteiten van het succesvolle 'Science Centre'. Zie ook de ontwerptekeningen hieronder hoe het één en ander er uit zal komen te zien.

Het Science Centre, pas een kleine 4 jaar geleden geopend in de rechter vleugel van de Mijnbouwstraat 120, ontvangt zo'n 50- tot 60.000 bezoekers op jaarbasis, waaronder ook veel scholieren in de categorie 10-18 jaar. Het Science Centre laat bezoekers op een spelende, prikkelende wijs kennis maken met technische onderwerpen. De insteek is dat het MGM hier prima bij op aansluit.

Contacten met het College van Bestuur en de afdeling Marketing en Communicatie hebben er dan ook toe geleid dat de TUD de mogelijkheid biedt om zo'n doorstart van het MGM mogelijk te maken wanneer dat op een andere manier, met andere partijen, financieel en organisatorisch haalbaar zou zijn. ►

▲ *Figuur 5: Aanzichten van het 'nieuwe' MGM gesitueerd op de tweede verdieping (de oude 'AIO'-zolder) en tot medio de zestiger jaren ook (al) onderdeel van het MGM.*

In de maanden november 2013 tot maart 2014 is derhalve intensief gelobbyd om bij bedrijven interesse te kweken voor een bijdrage voor deze bijzondere doorstartmogelijkheid. Op 4 december, de dag van de Heilige Barbara, is hiertoe ook een speciale stichting opgericht ter begeleiding: de Stichting MGM.

Het werkbudget dat voor de doorstart werd gezocht, bedroeg 1,5 miljoen euro. Dit is voldoende om het museum voor de genoemde 10 jaar in een stevig jasje te hijsen, inclusief een aantal nieuwe snufjes zoals: een virtueel museum op internet en ook als telefoon app, met de mooiste 2.000 mineralen gescand in high-definition, workshops op het gebied van geologie, mineralogie en de delfstofwinning (inclusief ertswinning en olie- en gasproductie), rondleidingen en verhuurmogelijkheden (borrels, diners, etcetera).

Hoofddoel van de vernieuwende opzet is educatief van aard: er is - over het algemeen gesproken - maar zeer beperkte kennis over wat er zich zoal onder onze voeten bevindt. Een doorstart van het MGM als hierboven geschetst kan bij uitstek helpen om het begrip over de diepere ondergrond te verbreden en verbeteren. Recente discussies over onder andere CO2-opslag, gasopslag, aardbevingen, schaliegas, bodemdaling, aardbevingen, het 'opraken' van zeldzame aardmetalen, geven aan dat een aanzienlijke kennislacune bestaat over de wetenschap der geologie en mineralogie. Een bijzonder ingericht, sfeervol, museum kan daarnaast het enthousiasme voor technische en aardwetenschappelijke studies verder stimuleren.

Oproep

Denk mee over hoe het MGM verder gesteund kan worden,
we zoeken nog extra sponsoren!

Opties:

Wilt uw bedrijf of organisatie misschien ook meedoen, in ruil voor interessante sponsor-exposure?
Wilt u misschien zelf zo'n oude vitrinekast adopteren, als 'legacy'?
Wilt u rondleidingen geven?
Wilt u Koempel van het MGM worden?

Draagt allen een steentje bij.

Glück Auf !

Op basis van het opgestelde sponsorplan heeft een aantal bedrijven inmiddels aangegeven deze doorstart mede te willen ondersteunen. Dat heeft er toe geleid dat op 4 april een cheque aan de TU kon worden overhandigd met de eerste 1 miljoen euro, dankzij een gul gift van hoofdsponsor Dietsmann.

Als reactie hierop heeft de TU aangegeven dat de doorstart van het MGM er zeker gaat komen, ook al wordt er nog gezocht naar het ontbrekende half miljoen. Er wordt verwacht dat met extra inspanningen dat geld in de komende maanden gevonden zal gaan worden. De beoogde opening van het MGM staat inmiddels gepland voor het eerste kwartaal van 2015. Uiteraard zult u tegen die tijd nader op de hoogte worden gesteld! Zoals vermeld is er nog financiële bijdrage nodig. Daarom ik wil eindigen met een oproep aan iedereen die in zijn of haar studie genoten heeft van het vak 'mineralen en gesteenten' om het MGM financieel te steunen. Stuur uw reactie naar duco.drenth@planet.nl of secretaris-mv@tudelft.nl. ■

▲ *Figuur 6: v.l.n.r.: Duco Drenth, voorzitter Stichting Mineralogisch Geologisch Museum; Peter Kütemann, CEO Dietsmann; Mark Lammerts, hoofd Marketing & Communicatie TU Delft en voorzitter Stichting Prometheus TU Delft; Luuk Mulder, President Mijnbouwkundige Vereeniging.*

Geological Excursion Morocco

AAPG Student Chapter Delft

By Suzanne Boekhout, Nick Ligtenbarg and Cees Willems

On the morning of Saturday 7 March 2014 fifteen students gathered at the Delft train station to embark on a 7-day geological excursion to Morocco. The group consisted of both Petroleum Engineering and Geology students, first and second year MSc, as well as PhD students. The many different nationalities, including Dutch, German, French, Italian, Indian and Indonesian, and the different backgrounds made it a very varied and interesting group.

Since the foundation of the AAPG Delft Student Chapter in 2005, this was to be the most ambitious field trip to be undertaken until now. In previous years field trips were made to locations within the Netherlands, and in 2013 to Italy. These were not lead by TU Delft staff. The 2013-2014 board decided it was time to make the next step. They cooperated with Professor Giovanni Bertotti from the TU Delft to organize this excursion. The first time would be a trial and if it were a success, the trip would be organized for multiple years.

Departure from the Rotterdam Airport was smooth and around 5PM in the afternoon we arrived in the warm and sunny Marrakech. After picking up the rental cars we headed towards to the Medina (walled city) of Marrakech. After a 4h flight and a long wait at the airport we were in for a little shock as the Medina was completely crawling with people, scooters and vendors. Between all of that we had to drive to our hotel, with parking conveniently handled by some locals on an open square, who, breaking all possible physical laws, managed to park our four American sized cars in a space that would have hosted 1 vehicle in the Netherlands! Afterwards we had our first encounter with the delicious Moroccan cuisine.

On Sunday the first excursion day was planned. After an hour's drive through the Moroccan countryside we arrived at the first outcrop on the edge of a small town east of Marrakech. Some of the group saw their first outcrop ever, an angular unconformity, of which we explored the structure and the rocks in the structure. Giovanni Bertotti gave us short overview on the geological history of Morocco from the Paleozoic to the Tertiary and explained that we would walk through time the coming days, seeing rocks and structural features from this whole period. Afterwards we headed towards the beautiful High Atlas Mountains. After driving south and up through beautiful valleys, we stopped at an outcrop which was both sedimentary and structurally interesting. We investigated very deformed Carboniferous turbidite rocks with Bouma Sequences and many folds and faults, such as a drag fold. Afterwards we drove higher up to an outcrop the principle of conjugate faults to obtain a stress orientation. One of the main subjects during this day was the balance between accommodation space and sediment supply and the type of sedimentary sequences that follow from shifting the balance.

▲ *Figure 2: Beautiful Essaouira.*

▲ *Figure 1: Group photo on the second day.*

The third day started with a geological feedback session on the previous day. This was held in the sun with an ocean view, the advantage of doing fieldwork in Morocco! After discussing various aspects of the previous day we set out for Essaouira, about 150km north of Agadir. We took the touristic route and would be driving through some beautiful valleys with many outcrops. After driving for about an hour we forcefully had to stop due to problems with the braking disc in one of the cars. Driving on sand roads for ►

▲ *Figure 3: Studying carbonate formations.*

the past couple of days had taken its toll on the car. After realising the problem could not be fixed ourselves, several people set out to get a mechanic from the nearest town with help from some locals. Luckily the mechanic was able to fix the problem in less than an hour. We could drive on towards Essaouira through a very thick package of shallow water carbonates deposited during the Cretaceous in a post-rift system. During a long stop we looked into more detail into the carbonates, classified them and investigated the structural features in the outcrop, which were many faults and joints. The group discussed the presence of conjugate (extensional) faults in a large fold structure. The last stop was along a river bed close to the Atlantic Ocean, where in between the carbonate structure suddenly a conglomerate layer with basement rock grains was found. The group discussed several possible explanations for this and found a possible source area where the conglomerate could have come from.
That night we stayed in the Medina of Essaouira, a beautiful city along the Atlantic coast.

On the fourth day the group looked into more detail in the large fold structure that we had already found evidence of during the last day. On the first stop of the day we discussed two possible causes of the enormous fold structure. The fold could be caused by tectonics of by salt diapirism, which is very common in that area. The group did measurements in the field to find evidence for one of the explanations. The observations were inconclusive, so we moved on to the next stop where we had an amazing overview over one flank of the fold. By looking at the structure from a far we found indications of compressional features close to the fold, which indicated that the fold was caused by tectonics and not by salt diapirism. At the end of the day a stop was made to a Moroccan salt mine. Especially the engineers amongst us were very excited to see an actual subsurface operation after so many static rocks. The mine was based on injecting water in the subsurface, dissolving the salt and pumping this to the surface. The water was then evaporated to extract the salt. Compared to a modern German mine it was a little primitive, with some serious HSE issues around their wellhead, which was basically a big hole in the ground.

The final geological day was spent with a morning session going over all the geological aspects we had seen in the last days and discussing the features we had seen, combining them into one big story about the geological history of Morocco. Furthermore Giovanni explained us about the significance of the things we had seen for hydrocarbon reservoirs in other parts of the world.

After the formal geology programme had ended, we went out to explore Essaouira. The final two nights were planned to be spent back in Marrakech. After the drive back to Marrakech, we arrived in our final hotel in Marrakech, where nightlife had to be explored that night. A nice rooftop bar was found where the week was discussed under the enjoyment of some drinks! The last day was spent sightseeing in the beautiful city of Marrakech, buying souvenirs and exploring the tiny streets, big square and mosque and some beautiful palaces in the Medina.

Overall the excursion was a great success. We not only saw and learned about some amazing geological features and structures and gained practical experience in the field, we also fully experienced the Moroccan culture as were driving along routes that a tourist would never take. Morocco proved to be an amazing and very hospitable country with a great culture and cuisine! We are certain that this excursion will be organized for many more years.
Special thanks go out to Prof. Giovanni Bertotti, for being an excellent guide for the entire excursion. Without his extensive knowledge of the Moroccan geology this excursion would not have been possible!
We would also like to thank the companies and organisations that sponsored the AAPG student chapter and the excursion; Total E&P Netherlands, Vermillion Energy, SGS Horizon, Schlumberger, the Petroleum Geologische Kring, KIVI Engineering Society, Delft University of Technology University Fund and of course the American Association of Petroleum geologists. Without their generous sponsorship this excursion would not have been possible! ■

▲ *Figure 4: Beautiful Essaouira.*

X-Ray Micro-tomography helps archeologists to write the biography of ancient ornaments

By Dominique Ngan-Tillard, Wim Verwaal, Ellen Meijvogel, Hans Huisman and Annelou van Gijn

X-ray Computed tomography was originally developed for use in healthcare. It has been applied for many years in a wide range of research domains. X-ray micro-CT tomography (X-ray micro-CT) differs from conventional medical CT scanning in its ability to resolve details as small as few microns in size. It is, up to a certain extent, non-destructive and can be used to study the inner structure of all sorts of materials (geo-materials, woods, metals, ceramics, bones, and soft tissues), including archaeological materials.

In this paper, first, examples of X-ray micro-CT studies carried out by the first author in the field of soil and rock mechanics are referred to. Second, successful applications of TU Delft expertise in X-ray micro-CT to Dutch archaeological soil investigations are presented. Then, focus is put on writing the biography of ancient ornaments with the help of X-ray micro-CT scans realized at TU Delft.

The use of X-Ray (micro-) CT in geo-engineering applications at TU Delft

Ngan-Tillard with her former and current co-researchers used micro-CT in numerous geo-engineering investigations. With the help of micro-CT, they

i) analysed the formation of compaction shear bands in a marl (Raynaud et al., 2008),

ii) revealed micro-structural factors that are responsible for the high friction angle of (Dutch) organic clays (Cheng & Ngan-Tillard, 2006 and Cheng et al., 2007),

iii) quantified deformation patterns caused by cone and needle penetration in sand (Ngan-Tillard et al. 2005a) and weak rocks (Ngan-Tillard et al., 2012) for a better interpretation of test results (Ngan-Tillard et al. 2005b and Ulusay et al., 2014),

iv) use the shape of each grain to measure local rotation and displacement during shearing experiments (Smit, 2009),

v) assessed the quality of bio-grouting in ground improvement experiments (van Paassen et al., 2008 and 2009),

vi) illustrated the role of fines in the mechanical behaviour of mixed sand (Karreman et al., under preparation),

vii) demonstrated the possibility of generating gas by exsolution in peat samples to be sheared for evaluating the impact of gas on the strength of peat, and highlighted the ambiguity of water retention test results obtained with local tensiometers for fibrous peat prone to heterogeneous shrinkage (van der Putte et al., under preparation).

Introduction of X-Ray micro-CT to the Dutch archaeological community

In 2011, Ngan-Tillard and Verwaal introduced the Dutch archaeological community to micro-CT tomography. They scanned archaeological soils to characterize, in a 3-D context, the archeological remains that the soils contain.

The added value of Ngan and Verwaal's micro-CT investigation to traditional sieving and micromorphology analysis is demonstrated (Huisman et al., 2014) for Middle Neolithic midden deposits recovered in Swifterbant, the Netherlands. The scans offered an unparalleled 3-D view on micro-stratigraphy and taphonomy of the archaeological site. They also allowed identifying species level articulated bones or bone fragments that would become separated and unidentifiable during sieving. Phytoliths of silicified plant tissues could be discerned but not identified at the species level, except on the scans of one millimeter wide samples recorded at the micrometer resolution.

In the framework of the PRORAIL project on the in situ preservation of archaeological sites in Flevoland, Ngan-Tillard et al (2014a and 2014b, submitted) used X-ray micro-CT to quantify the resistance of vulnerable archaeological remains (charred and non charred organic remains) packed in pure assemblies or embedded in soils to one dimensional mechanical loading.

On one hand, organic remains are often investigated in archaeological prospection works to assess the degree of conservation of the site. Their study by archeobotanists provides a wealth of information on food, food economy, ecology and landscape management in the past. On the other hand, one dimensional loading simulates ground conditions under the central part of embankments that are built on soft soils for the construction of infrastructure. The experimental work showed that loose assemblies of friable charred eco-facts are likely to be damaged by the construction of medium height embankments (three to five metres). However, such assemblies are unlikely to be found at an archaeological site. In most cases, eco-facts are embedded in a soil matrix and the matrix has a beneficial effect on the preservation of the eco-facts. The eco-facts tested so far will probably not get crushed when included in an archaeological soil above which a ten metre high embankment is constructed. They might however be deformed, flattened and re-aligned. Their resistance to higher compressive loads and more destructive shear stresses, generated, for example, underneath the tip of foundation piles or at the toe of embankment has not yet been examined.

Huisman and Ngan-Tillard (2015, submitted) also applied X-ray micro-CT to archaeological construction materials. They analysed the suitability of modern turfs for making replicas of ancient farms in the framework of Daniel Postman's research at Groningen University. They also modelled decay patterns such as bioturbation in turf wall materials recovered from the archaeological excavation of Frisian elevated mounds directed by Johan Nicolay (Groningen University).

X-Ray (micro-) CT applied to ancient ornaments

In parallel to the study of archaeological soil samples (and their replicas), the authors studied small delicate ornaments that were found at various archeological excavations in the Netherlands.

Specific precautions have to be taken when scanning vulnerable archaeological ornaments. Some of them are mentioned below. Then, the value of X-ray micro-CT scanning is illustrated for three collections of ornaments, i.e., the Zutphen Early Iron Age frothy glass beads, the Borgharen medieval glass beads and the Dutch Neolithic amber beads and buttons.

Tuning X-ray micro-CT data acquisition and processing to the study of ornaments

In the micro-CT scanner installed at TU Delft department of Geoscience and ►

Engineering, a Phoenix Nanotom S manufactured by GE Sensing and Inspection Technologies (Zacher et al., 2010), a source of polychromatic X-ray illuminates the object and a planar X-ray detector records the X-ray transmitted by the object. The object is rotated over 360o step by step and at each step, a radiograph is recorded. The radiographs are then combined to re-construct the object in a series of 2-D slices forming a 3-D data set. The grey value of a voxel, the elementary volume of the reconstructed object, is a measure of the linear attenuation coefficient of the materials present in that voxel. The linear attenuation coefficient is the product of the local density and the local mass attenuation coefficient, the latter being function of both the chemical element(s) present and the incident photon energy.

Bright images with a high density contrast are obtained by tuning the energy of the X-ray beam. On one hand, a high energy beam was necessary to penetrate the highly attenuating lead-glass forming the bulk of the medieval beads. Care was taken not to over-expose the panel detector. On the other hand, a low energy was necessary for scanning the amber artefacts. Amber is a fossil resin produced by trees, it attenuates X-rays weakly.

X-ray micro-CT is often qualified as a non-destructive technique. Nevertheless, cases of glass discoloration caused by a very long exposure to X-ray photon radiation have been reported in (Bertini et al., 2014). Luckily no sign of degradation related to scanning have been observed at the naked eye in the ornaments scanned at TUDelft. And fortunately, (some) damage can be remediated by short exposure to a minimum temperature of 600ºC and UV lights for coloured Manganase glasses that are supposed to be transparent and for blackened yellow lead glasses (Bertini et al., 2014).

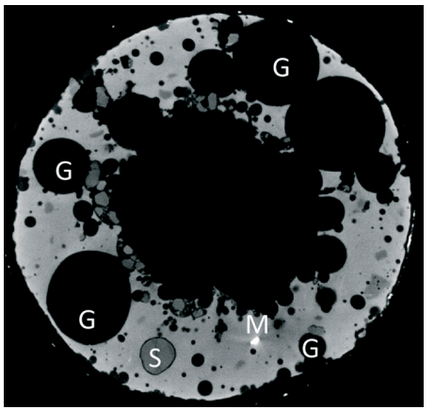
The immobility of the object during scanning is a condition synequanone to a good quality scan. Supporting the artefact by inserting a rod through its perforation is not an option as this might damage the worn surface of the perforation and destroy clues for elucidating the manufacturing or usage of the ornament. Spherical beads had to be fixed with a light tape on a foam support. Others have used bee wax to stabilize the ornaments without damaging them (Bertini et al., 2014).

The geometry of the shaft entries gives hints about bead re-shaping. Most beads were scanned in a tilted position to avoid contact with support and phantom artefact, and therefore disturbance at the bottom and respectively top shaft entries.

After reconstruction, the spatial resolution of micro-CT scans is about one thousandth of the sample width, except for extreme sample magnification when it is governed by the size of the beam spot, 0.9 micrometres for the Nanotom. The spatial resolution varies between 5 and 15 micrometres for the images presented here. Some artifacts such as beam hardening, partial volume, metal, conical beam, (Tarplee, 2011) and phase shift artefacts are inherent to X-ray micro-CT. These artefacts have been detected on the scans of the beads to avoid misinterpretation. All images have been denoised by applying a smoothening 3-D median filter. The different components of the beads have been highlighted using the intuitive volume rendering technique (AVIZO 8.1, 2013). Volume rendering allows to view in real time, from any position, the interior of a 3-D data set by defining the light emission and absorption of each voxel. The light transmission is simulated through the object and displayed using an interactive color map editor. Prior segmentation of the object is not required. Special features can be underlined by clipping the rendered volume with multiple planes. After the exploration of the object by volume rendering, the images can be segmented into the diverse components of the object to allow a quantitative analysis of each component. Ancient glass is not as pure as modern glass. For example, it contains bubbles. Bubbles were introduced during the manufacturing process. They can be identified, separated, measured and counted before being subjected to digital size, shape, and orientation analysis. The orientation of non spherical bubbles gives clues about the direction the molten glass was worked. The results of the bubble analysis can be exploited to characterize the quality of the workmanship and relate the bead quality to a given production centre once many beads from various sites have been scanned.

The strange case of sixty frothy beads: puzzling Early Iron Age glass beads from the Netherlands

About sixty simple small blue-green glass beads were recovered from the excavation of an Early Iron Age urn-field near Zutphen (NL). The simple glass beads have a semi-opaque, almost frothy appearance with many glass bubbles. Such glass is rare in this period in the Netherlands and has been thoroughly investigated (Huisman et al., 2012) with two goals: first, to determine from what primary glass production centre this glass originated, and by what route it could have reached the Netherlands, and second, to determine the nature and origin of the frothy structure of the beads. Micro-CT scans helped to reach both goals. Combined with SEM and microscopy, micro-CT scans showed that the glass itself contains many mineral inclusions and several small copper inclusions dispersed in the glass -and causing star artefacts on the scans- as well as some other heterogeneities (figure 1-2). The copper inclusions were probably added during re-melting to homogenize the colour of the glass. Why the mineral inclusions were incorporated has not yet been clarified. It could be by accident, to serve as filler or in an attempt to give a faience-like look to the beads. The micro-CT scans also showed that the frothy nature of the glass is caused by the presence of a large number of gas bubbles of various sizes ►



▲ *Figure 1: Micro-CT slice of one of the large Zutphen beads. Gas bubbles of various sizes (G), mineral inclusions (S), metal inclusion (M) and heterogeneities in the glass (i) are indicated. From (Huisman et al., 2012).*

occupying up to half of the total volume of the beads! The glass bubbles are both at the surface of the beads and inside the beads. They do not result from a dissolution or corrosion process, as first thought based on macroscopic observations at low magnification, but probably from the inexpert re-melting of the glass fragments or objects. With its many glass bubbles, copper fillings and mineral inclusions, the glass of the Zutphen beads does not resemble glass from Mediterranean production sites.

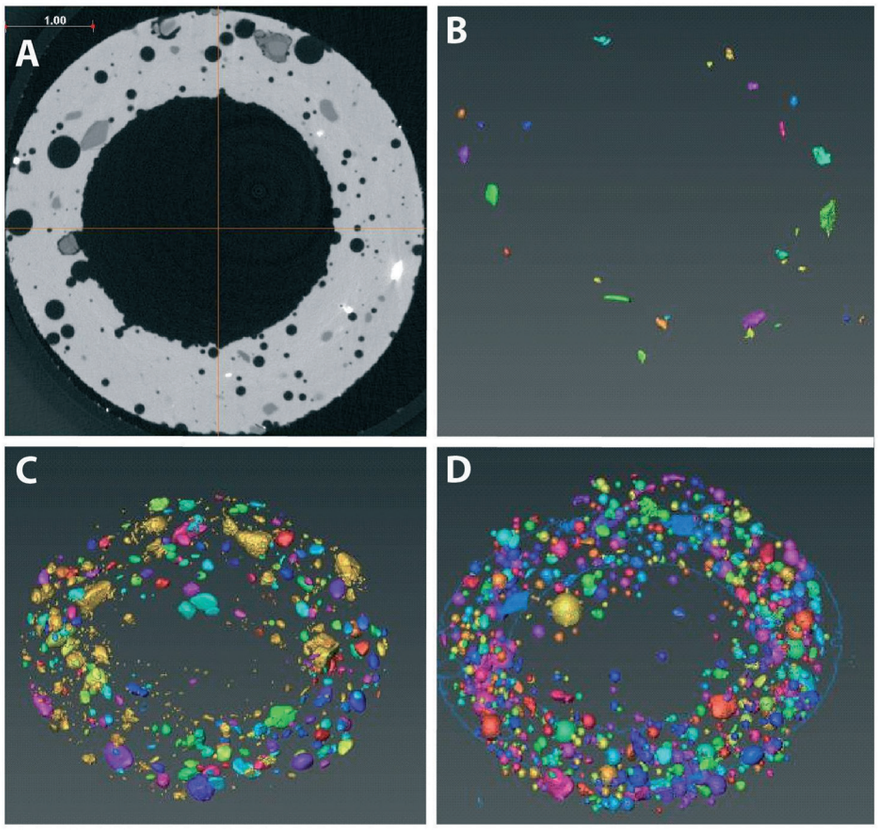
Lights on the Borgharen glass beads collection of the Dark Ages

Four of the numerous glass beads recovered from Merovingian graves in Borgharen, the Netherlands (Lauwerier et al., 2011 and Lauwerier et al., 2014, under preparation) have been selected for scanning based on their typical shape, colour, and decoration patterns.

The micro-CT scans of the four medieval beads provided valuable information about the 3-D inner geometry of the beads and the spatial arrangement of their components. Differences in X-ray attenuation properties as well as in number of bubbles, content in opaque fragments, possibly metals used as opacifier and/or colorant, allowed to distinguish the glass forming the bulk of the beads from the glass (or the paint) used for decoration. The micro-CT scans demonstrate quite clearly how the beads were made even if some of the features highlighted by the scans still have to be elucidated. Details are given in the extended caption of figure 3 for one bead, bead 1058.

A biographical study of Middle and Late Neolithic amber ornaments: contributions from the micro-CT scans

Van Gijn et al. (2013) investigated, with the help of microscopy and scans made in at TU Delft, the role of amber beads in the materiality of burial practices in three different periods of the Dutch Neolithic. The micro-CT scans proved to be very valuable for evaluating the quality of manufacture and repair of the beads and detecting signs of wear, re-shaping and post burial degradation. Van Gijn could conclude that burial practices changed throughout the Neolithic, from burial with personal ornaments given in the state in which they were at the time of the death of their owner in the earliest, Middle Neolithic Hazendonk period, to burial with beads transformed from personal items to collective ones, by regrounding and hence depersonalizing them at the Funnelbeaker time when collective identity was a central concern, and to burial in the following Beaker period with beads displaying different extents of wear as beads were probably refurbished during the life of their owner or offered by different mourners to honour the dead.



▲ *Figure 2: Micro CT-scans of one of the smaller beads from Zutphen. Colours in B,C,D are assigned randomly to individual spatial objects to better distinguish them from each other. A: Slice with small empty bubbles (black), mineral inclusions (darker grey) and metal fragments (white) embedded in glass (lighter grey). B. 3-D rendering of the metal fragment; C: 3-D rendering of the mineral inclusions. D: 3-D rendering of the mineral inclusions and bubbles. From (Huisman et al., 2012).*

Micro-CT scanning is also an effective technique to analyse ancient drilling technologies by interpreting tool marks on the walls of narrow and elongated bead shafts. Replicas of the Neolithic amber beads have been perforated with various pointed tools (chert and antler drills and a heated copper thread) by van Gijn and her colleagues and scanned. Preliminary scan results indicate that drilling in the Neolithic was in some cases followed by partial abrasion of the small scale roughness of grooves formed by the drilling tools (van Gijn and Ngan-Tillard, under preparation). Using the same approach, ancient beads can be authentified (Yang et al., 2011).

Conclusions

In the last 25 years, the tremendous development of X-ray microtomography has allowed an enormous progress in the understanding of soil and rock behaviour at the grain level. Studying with the help of a micro-CT scanner the microstructural response of geomaterials to environmental changes, whether they are of mechanical, hydro-thermical or biological origin(s) is exciting, and even more exciting when the materials contain archaeological remains. ►

X-ray Micro-Computed Tomography (X-ray micro-CT) is also an excellent technique to measure and inspect small delicate ornaments of the past. It reveals their composition and inner structure without damaging them. In particular the geometry of narrow bead shafts becomes clear on micro-CT scans. From the scans, archeologists can draw conclusions about the way the beads were made, worn and at some occasions, reworked before being deposition. The origin of the materials selected to make the beads, their production centre and trading routes can even be traced by combining micro-CT scans to other information, such as results of XRF or SEM and EDEX analyses. Signs of post-burial deterioration become obvious on the micro-CT scans. Forgery is easily detected.

Further developments

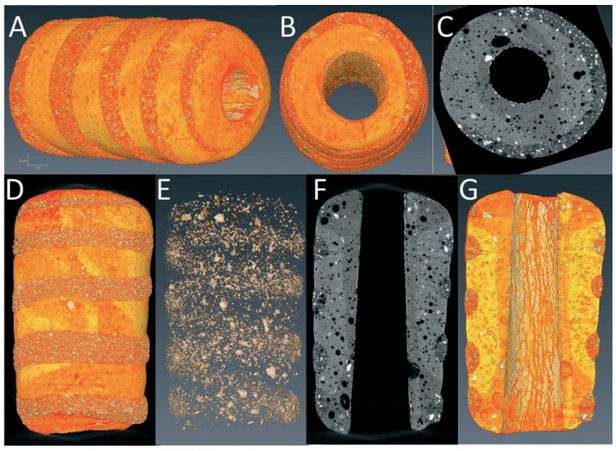
By combining X-ray tomography to 3-D XRF mapping of the beads, it will be possible to compare the chemical elements of their various components and progress in the identification of the bead production centre and trade routes. This hybrid technique is no longer restricted to synchrotron radiation facilities. It has already been implemented in some laboratory equipment.

The micro-CT scans constitute a form of virtual preservation of the ornaments. They will be stored in open access mode at the 3TU datacentrum (http://datacentrum.3tu.nl/en/home/) with their meta-data together with 3-D visualisation and processing tools. Meta-data will cover scan, reconstitution and post-reconstitution parameters. They will include documentation of the context in which the ornaments have been recovered with scans of man-made drawings of the rescue excavations and 3-D digital reconstitutions of the burial environment made from these scans. The meta-data will be associated to open source publications explaining the state-of-the art interpretation of the data. The 3-D visualisation and processing tools will be open source and linked with open source interfaces (Zhang et al., 2012). The whole data set and related information will be managed in a sustainable way for a long term accessibility.

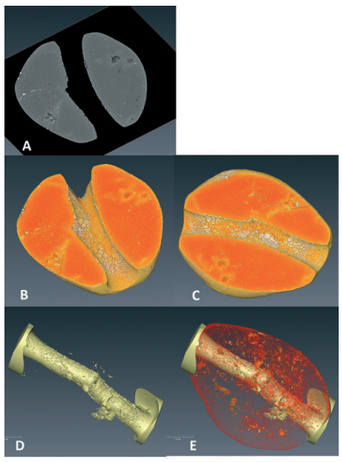
Archeologists from all over the world will be able to consult our virtual collection on line for artefacts comparison and further morphometric analysis. Lengthy demands and long travels to inspect the collections will not be needed anymore. This will allow a better understanding of various aspects of our cultural heritage such as intra-cultural exchanges along ancient trading routes or the materiality of past funerary practices. Material scientists will be able to use our digital collection as a laboratory to quantify material degradation rates at a very long time scale. Museums will be able to access our collection and, for their young visitors, develop with the gaming industry educative games based, for example, on pattern recognition intra- or inter-collections. Semi-transparent multi-colour 3-D prints of the ornaments can be produced from the mesh of the inner and outer surfaces of the micro-CT models for a better understanding of the art of making glass and jewels. The creative industry interested in reviving old local jewelery styles and capturing cultural diversity in Europe can also use our virtual collection as source of inspiration. In brief, our digital collections can be exploited by many! ■

References

Due to lack of space we left out the references. You can request the references by Dominique or the Natural Resource Committee.



▲ *Figure3: Bead 1058 is a 14 mm long hollow cylinder with an external diameter of 7.7 mm (A and B). Its tapered shaft has a diameter varying from 2.7 to 3.7 mm (F and G). Bead 1058 was first formed by rolling a glass wire or folding a plate or ribbon (A) around a tapering stick; this becomes clear from the vortex-like feature in cross-section (C). It was then re-heated- hence the presence of non-deformed glass bubbles (F)-, and a decorative glass wire was attached to the outside while both were hot. This wire contains again many metal or metal oxide inclusions as opacifier and/or colorant (E). Some opaque objects have a curved or flat shell or a hollow shell form (F). The thin layer of high-density material (G) that coats the shaft of the bead looks also like metal or metal oxides. It may be material from the tapering stick itself (iron or copper?), or from a parting layer, possibly lead oxide. This would imply that the bead has not been worn much. From (Lauwerier et al., under preparation).*



► *Figure 4: Amber bead KH1982-162. Flat oblongue bead. A: slice passing through the middle of the bead which is 24.1 mm long, 18.4 mm wide and has a narrow shaft of about about 2.7 mm. B and C: Opaque volume rendering of the bead clipped by slice A. View on the 2 sided attack of the shaft. Half shafts are not co-axial. They show signs of wear and degradation. D: representation of the asymmetrical wall surface superimposed in E by a semi-transparent volume rendering of the bead (van Gijn & Ngan-Tillard, under preparation).*

Influence of fluvial sandstone architecture on geothermal energy production

By Cees Willems

Geothermal energy is a relatively new alternative energy source in the Netherlands. In 2007 the first geothermal project started in Bleiswijk which is approximately 10 kilometers away from Delft. From fluvial sandstone reservoirs at a depth of approximately 2 km 70°C water is produced from a production well in this first project. After the heat is extracted ~30°C water is re-injected in the injection well of the doublet. The injection and production well are drilled deviated from the same well-head location to ~1.5km spacing at the reservoir level. The reservoir surrounding the injection well is slowly cooled-down during production. The development of the 'cold-water plume' determines the life-time of the doublet. In this project the influence of reservoir architecture on the plume development is investigated. As a case study fluvial sandstones from the Lower Cretaceous Nieuwerkerk Formation are modeled. Using these reservoir models geothermal energy production is simulated to study the effect of reservoir architecture on cold-water plume development and life-time of a geothermal double

Geothermal energy in the Netherlands

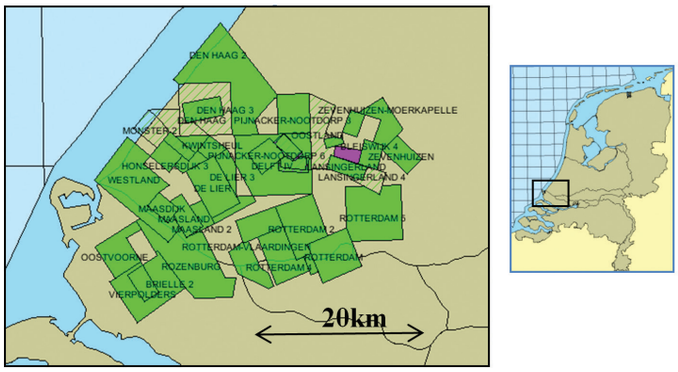
After the success of the Bleiswijk Geothermal project in 2007, 2-3 new geothermal doublets (injection and production well) are drilled each year. The main application for geothermal heat production in the Netherlands is currently heating in horticulture. In 2012 nine projects were installed in the Netherlands with a total capacity of approximately 40 MWthermal and a yearly production of roughly 200 GWh (heat) (Van Heekeren & Bakema, 2013). TNO estimated the total geothermal potential of the Netherlands in 2012 (Kramers et al., 2012). This was done by calculating the 'Heat In Place' from the sandstone bulk rock volume in the Netherlands and estimating a recovery factor of 30%. The result was a potential of 820,000 PJ of recoverable heat, an amount of energy equivalent to 70% of the energy of UR gas of the Slochteren gas field of Groningen. Geothermal energy is in an initial phase in the Netherlands compared to countries like Iceland, Germany and France. However, having an energy source comparable to the Groningen gas field gives the Netherlands a great potential of increasing alternative energy production.

West Netherlands Basin study area

This project aims to predict Lower Cretaceous reservoir architecture and reservoir properties in the West Netherlands Basin (WNB) for geothermal energy. The WNB is currently an area in the Netherlands with the largest geothermal development. 45 out of the 110 geothermal exploration licenses in the Netherlands are located in this basin. In addition currently six out of the total 12 geothermal doublet are realized in the WNB. They produce geothermal heat from Lower Cretaceous sandstone reservoirs. Five of the doublets in the WNB target the same fluvial sandstone: the Delft Sandstone Member. This member is part of the Lower Cretaceous Nieuwerkerk Formation. Many of the other exploration licenses target the same formation. Possible temperature- and pressure interference risks between the licenses are therefore a hot topic in the development of geothermal energy in the Netherlands at the moment. To efficiently produce geothermal energy from the Nieuwerkerk Formation, the distribution and internal architecture of the sandstone bodies must be better understood.

West Netherlands Basin

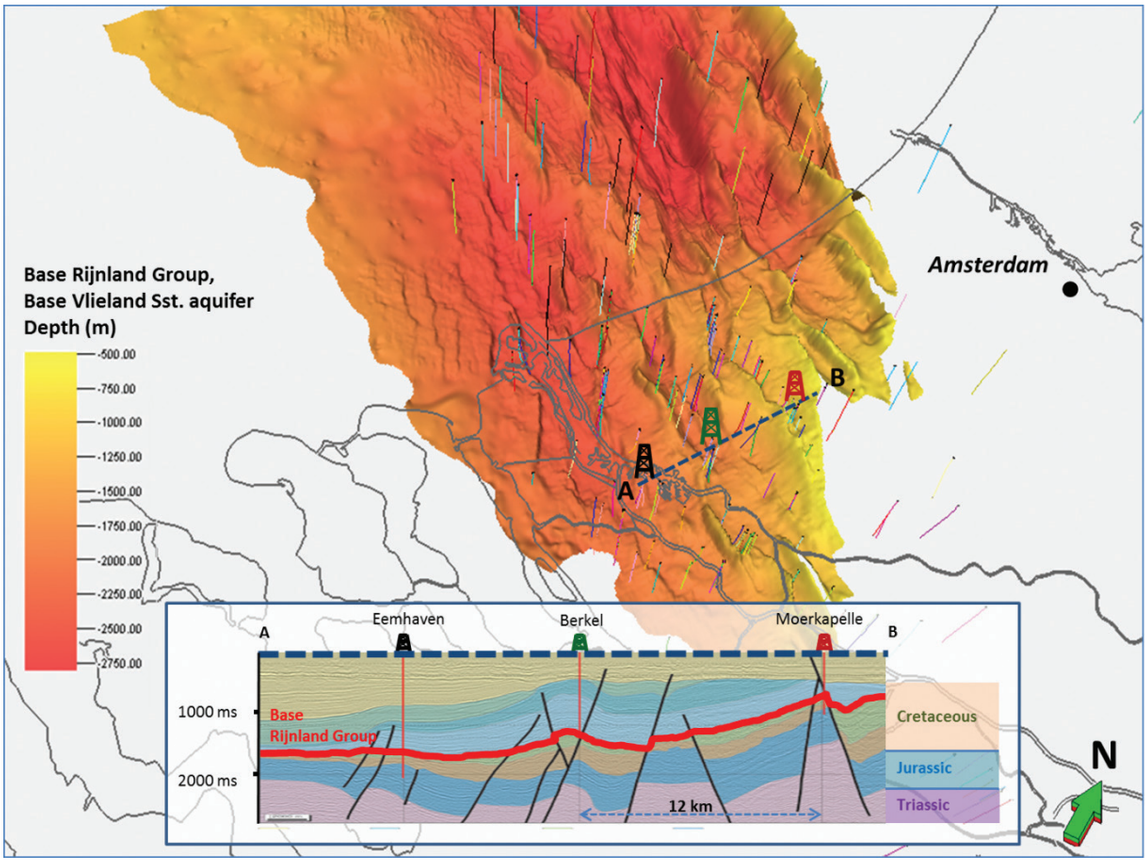
The West Netherlands Basin is one of the mature oil and gas basins in the Netherlands. Horst and pop-up structures were targets of oil and gas production in the past 60 years. For the recent upcoming geothermal energy production the focus lays on the deeper and warmer graben structures in between the oil and gas fields. The geology in the graben structures is similar to the horst and pop-up structures. The oil and gas production history therefore is an advantage for the development of Geothermal energy. It provides a large amount of geological data. However, sedimentation in the grabens was syn-tectonic. Therefore facies distribution is still uncertain for the grabens. In addition the basin was strongly inverted, therefore the burial history of all fault blocks is very different. This strongly influences reservoir properties and diagenesis processes. Reservoir property predictions like thickness and permeability are currently based on interpolations between oil and gas well measurements on horst and pop-up structures.



▲ *Figure 1: West Netherlands Basin geothermal license locations. Purple: production license; solid green: exploration license; dashed green: requested exploration license.*

Fluvial sandstone reservoir modelling

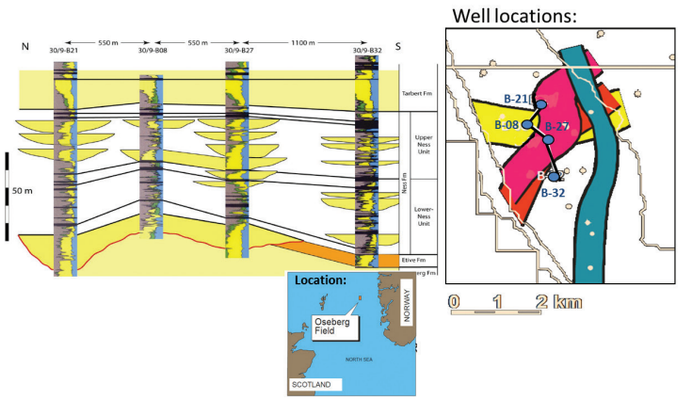
The Lower Cretaceous geothermal reservoirs in the West Netherlands Basin are mainly Fluvial Sandstones. Fluvial sandstone reservoirs are composed of stacked meander belt sandstones and floodplain fines. The net-to-gross, the orientation and the stacking pattern of the meander belts are of major importance for the connectivity between the injection and production wells in fluvial sandstone reservoirs. To show such a meander belt connectivity issue, an example is presented in Figure 3 from the work of Gozales et al. (1997). Wells B-21 and B-27 are situated 1100m apart. This distance is common between injection and production wells in the current Dutch geothermal doublets. Well B-21 and B-27 ►



◄ *Figure 2: Overview of the West Netherlands Basin. The colored lines indicate the oil and gas wells that target the structural highs of the basin. The orange to yellow surface in the map and the red line in the cross-section is the 'T-Cretaceous' surface . Graben blocks between the oil-fields are geothermal energy prospects.*

have a net-reservoir thickness of respectively ~30m and ~50m. In their interpretation, only a small part of the reservoir interval is directly connected, despite the close well spacing and the similar net-reservoir thickness. The fluvial Ness Formation, the reservoir in the Oseberg field, is an analogue of the Nieuwerkerk Formation in the WNB. If this example would be a geothermal reservoir, the connectivity would have a severe influence on the cold-water plume development. This would affect the life-time and the interference with the adjacent geothermal licenses.

Several studies described the effect of heterogeneities on cold water plume development. Mijnlieff & Van Wees (2009) simulated the efficiency of heat recovery of a geothermal doublet in a homogeneous 2D reservoir. The homogeneous base case was compared to the efficiency of heat recovery in reservoir models with heterogeneities. Two types of heterogeneities were considered. The first type is the anisotropic permeability distribution. This can be expected in fluvial reservoirs, which could have a preferred permeability and/or connectivity direction. The second type consists of zones of strongly enhanced or decreased permeability. Their directions can be both parallel and perpendicular to the production direction. They represented conductive or non-conductive fault zones. The efficiency of recovery could be decreased to up to 50% in some heterogeneous models. Therefore, they concluded that the distribution of the licenses should be carried out during development instead of during exploration since new subsurface data and production data will give more insight into optimal well placement. Smit (2012) simulated the effect of reservoir heterogeneities on the lifetime and on the Net Present Value of a geothermal doublet. For this study he used a 2D heterogeneous and a 2D homogeneous reservoir model. ►



▲ *Figure 3: Well log correlation (left) and meander belt stacking interpretation(right) in the Oseberg field, Norway. Edited after Gozalo et al. (1997).*

In this work a 3D static reservoir model of the Delft Sandstone in the WNB made by Gilding (2010) is used as an input for the 2D model. A random layer from this static model was chosen from which facies and properties formed the 2D heterogeneous reservoir of Smit (2012). Thermal breakthrough in the 2D heterogeneous model was 40% faster than the thermal breakthrough in the homogeneous model. Deo et al. (2013) assessed the potential of Great Basin sedimentary reservoirs. 2D vertical, multi-layered reservoir models with variations in reservoir temperature (i.e. conductive heat flow), permeability, and layer thickness were evaluated. They suggested that the lifetime of the doublets decreases, if permeability contrasts between stacked reservoir layers increase. The layers in the 2D reservoirs were assumed to have isotropic permeability and to be horizontally continuous.

In petroleum reservoir description it has long been recognized that modelling sedimentary deposits as totally homogeneous bodies, both with regards to sedimentological and structural heterogeneities, is a gross simplification of their potential flow behavior (Keogh et al., (2007). In their review paper Keogh et al.(2007) aim to outline the role of stochastic algorithms in building geologically-realistic and 3D fluvial reservoir models. They highlight the success of these developments with case studies from both producing fields and ancient outcrop analogue studies. In this work, we aim to evaluate the influence of the reservoir architecture in fluvial sedimentary reservoirs using a 3D modeling approach. Several geothermal production simulations are carried out with reservoir models with increasing geological detail. The obtained results are analyzed to study the effect of the reservoir architecture on the life-time of a geothermal doublet.

Cold-water plume development in fluvial sandstone reservoirs

In order to identify the most influential geological features controlling the flow and heat transfer in geothermal aquifers, several reservoir models of fluvial sandstones are constructed with increasing geological detail (Level 1-3). Geothermal energy production is simulated in these different models. Geometries in the models of level 2 and 3 are based on the results of geological fieldwork on the Huesca fluvial fan in Miocene, Ebro Basin, Spain. Several models with different geometry of the fluvial sandstone bodies, orientation of the channel belts and stacking patterns of the channel bodies are considered. A finite-element approach is utilized to study the geothermal energy production. The effects of different levels of architectural complexity on the geothermal energy production, by conducting several accurate numerical simulations, are discussed. The results show that utilizing simplified reservoir models can lead to a significant error in predictability of the heat recovery from deep fluvial sandstone formations.

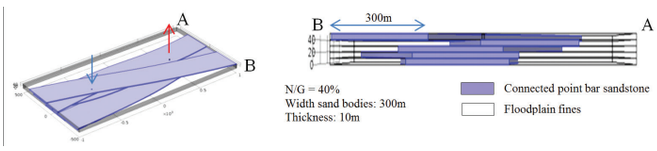
Level 1. Layered reservoir

The reservoir model of level 1 is composed of 5 layers and 10m thicknesses each. Every layer has a different permeability and porosity. The net-to-gross of the reservoir is 100%.

▲ *Figure 4: Level 1 reservoir model. The dots in the model on the left are the well locations. In the middle the reservoir property distribution is explained. On the right a cross-section with reservoir thickness is presented.*

Level 2. Layered reservoir with connected pointbars

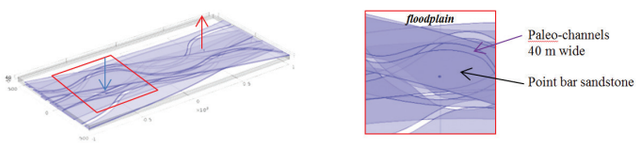
A layered reservoir with 300m wide and 10m thick meander channel sandstones surrounded by impermeable floodplain fines (based on Huesca fieldwork). The sandstone body in every layer has a different porosity and permeability.



▲ *Figure 5: Left) An overview of geological features in the model. Right) A cross-section A-B with a side view of the model.*

Level 3. Layered reservoir with connected point bars and paleo-channels

A layered reservoir with 300m wide and 10m thick sandstone bodies like in level 3. However in these models the channels are composed of meander point bars and paleo-channel deposits. ►



▲ *Figure 6: Left) Reservoir model level 4 overview. Right) Close-up of the top view of the geological features in the model.*

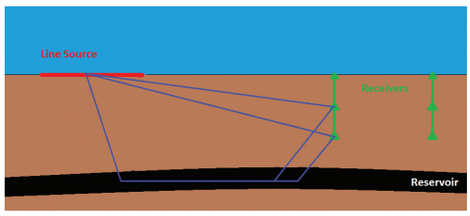
Preliminary production simulation results

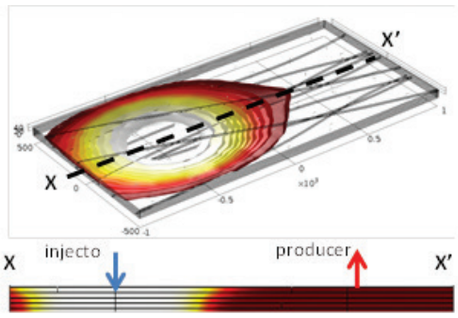
Fifty years of geothermal heat production at a rate of 200 m3/h is simulated in the different reservoir models. The reservoir has a temperature of 70 degrees. The injected water has a temperature of 30 degrees. The reservoir surrounding the injection well is slowly cooled-down during the life-time of the doublet. In Figure 7 the temperature breakthrough times at the production well is presented for the different models. This is the moment that the cold-water plume reaches the production well. The shape of the curve is determined by the reservoir architecture. The results show that modelling geothermal reservoirs in a simplistic way like with the level 1 model could lead to a significant overestimation of the doublet life time.

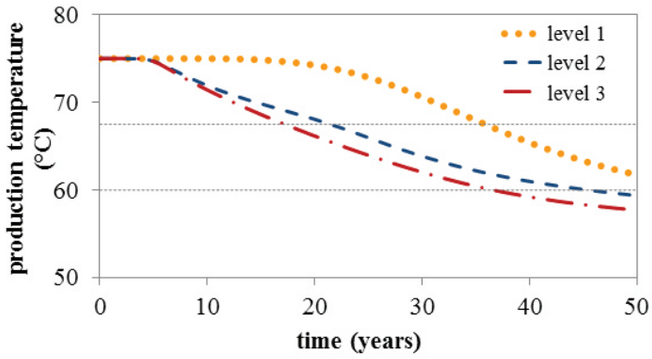
In Figure 8, the development of the cold-water plume is presented after 8.4 years of production in the level 1 and 3 models. The higher geological detail of level 3 models influences the simulation results compared to level 1 models. The water is injected into a smaller reservoir volume an therefore progresses faster towards the production well.

These preliminary results show the effect of the reservoir architecture on the doublet life-time. In these results conceptual reservoir models are used. In future work, reservoirs around existing doublets will be modeled with high geological detail. To obtain these models processed based facies modelling software will be used. This should give more insight in geothermal potential of the Nieuwerkerk Formation in the West Netherlands Basin.

Figure 8 Production simulation after 8.4 years. Isothermal contour lines are shown for comparison of the cold-water front movement in different models. For every reservoir level a vertical cross-section is presented through the center of the reservoir model, crossing the production and injection well. ■







▲ *Figure 7: Breakthrough curve comparison of reservoir models of level 1 to 4.*

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◀ *Figure 8: Production simulation after 8.4 years. Isothermal contour lines are shown for comparison of the cold-water front movement in different models. For every reservoir level a vertical cross-section is presented through the center of the reservoir model, crossing the production and injection well.*

Arctic Science A, University of Umeå, Sweden

By Adriaan van Natijne and Michiel Ooms

Early February, the undersigned left for the mining town of Kiruna. Not for mining this time, but for five days of in depth knowledge on Arctic Science. Organised by the University of Umeå the trip consisted of: auroral physics; arctic climate/weather and shear awesomeness.

On our way 2010 kilometers North we encountered Delft students at various points throughout the trip. In the airplane to Stockholm we met Dirk, and waiting on the train station in Stockholm we were greeted by Harm and Reinier. As the snow thickened outside during the sixteen-hour trip, an Ethiopian fellow traveller kept the spirits high with beer induced garlic farts.

As soon as we arrived in Kiruna the Dutch dominated the hostel, as 7 men en 3 women from different tracks at TU Delft and Utrecht University brought the typical Dutch 'gezelligheid' to the hostel and its sauna.

Directly on the first night we went aurora hunting, equipped with photo camera's we watched the sky above Kiruna on the world championship track for cross-country skiing. Minutes became hours and as the seconds passed by, the temperature dropped further and further till minus 18 °C, the absolute minimum temperature of that week. Eventually only clouds were observed, the only aurora we saw that night was in the amazing pictures Dirk and Arjan took the night before.

The next day we were expected at the IRF, the 'Institutet för Rymdfysik'. After a short introduction, the group toured the various laboratories for satellite construction and meteorological experiments. Surprisingly there was one lecture particularly interesting for us called: "How to survive in a cold climate?" We picked up a couple of ingenious tips that would help us survive the harsh conditions in our private expedition following this course.

The following day we left for Abisko, nowadays best known as a tourist destination. In 1903 a research station was build here, creating a detailed meteorological record for the last 100 years. Either man induced or not, the effects of climate change are visible in those records. Not only the change of temperature but also in relatively stable parameters like the depth of the (continuous) permafrost.

After a delicious lunch, that included pancakes and herring in one meal, we got some useful information on snow and associated risks like avalanches. As we made the trip up to the top of mount Nuolja by a 15 minutes long chairlift ride, we were greeted by an all covering fog that obstructed our aurora the nights before. We can confirm the cloud was white from the inside, too.

After two days of intense "studying" the group decided to go on their first nightly adventure, to the Swedish pub. The night resulted in one big snow fight in the city centre of Kiruna. The locals did not understand the fun of snow, but a Scandinavian trip was not complete without a snow fight for the Dutch, English and even Spanish visitors.
Every mining student knows that the best way of learning is by digging. Digging in the snow, this time. Guided by the municipality's snow expert we dug holes and analysed the different layers formed over the course of winter.

After three days in Kiruna, the capital of aurora, the clouds still blocked our view on the night's sky. We decided to go back to Abisko, where the weather forecast was more promising. In Abisko we finally saw it! Aurora! The auroral display was so bright we could already see it from the car as we approached the Torneträsk lake. The ice was filled with Asian tourists who spend more on their jackets than we spend on our whole trip. After the first show most of them left for the warmth of their beds. We stayed up for an extra two hours and got a never ending private display on a frozen lake in the heart of Sweden. The event where we all came for finally happened, satisfied with the unforgettable scenery we saw just a few moments ago, we headed home, back to Kiruna.

On the last day of our course we became tourists by visiting the IceHotel. Packed between two giant cold stores, is a ridiculously expensive 'fantasy world' overrun by tourists. It is such a popular tourist destination that it can only disappoint. It did not disappoint, disappointingly. With everything made out of ice, the temptation raised to try one of the icy beds covered with reindeer skin. After the check by four of us, we were the touristic highlight instead of the sculptures.

As everyone packed their stuff and prepared for leaving the next day, seventeen of us joined each other for our last Swedish dinner. Reindeer, Swedish meatballs similar to the ones from IKEA, broccoli and mashed potatoes. As most left back south, we would not return before reaching the most Northern tip of Europe the following week, as first expedition that winter. ■

▲ *Figure 1: Group picture of all the participants of the Arctic Science A course in front of the 'Institutet för Rymdfysik'.*

ISW Helsinki

By Kaj van der Waal

An ''International Student Week'', what is that? Well, we ''Mining engineers to be'' like to party and drink. Therefore the IFMMS (International Federation of Mining and Metallurgy Students) was established in the 1960's by the different Mining universities in Europe. Each university is supposed to organise such a week every 2 years, except for Delft, we organise an ISW every Lustrum and Half Lustrum. It is tradition to stay in student dorms of the hosting university, except for Helsinki. During this ISW, a bus trip is made through a big part of the country which took almost the whole week.

During such a week, about 20 students come together from all over Europe to experience the traditions of this particular Mining university and to attend some (local) company visits. Last February it was time for me, again, to join such an awesome week of partying with Miners from all over Europe. Together with Talitha Groenewold and Coco Antonissen I flew off to Helsinki.

When we arrived at the airport of Helsinki we were picked up by some old friends of me from another ISW organized by the Trondheim student society. We drove to the university and started drinking the typical Finnish beer, named Karhu. The funny thing about this beer is that the students take a ferry to Estonia to buy a van full of this liquid gold, since it is a lot cheaper than in Finland. Later we went to the ''W club'', this is an underground pub of which the location is a secret for all first years. It took until the next day for the whole group to be complete. Delft, Mons, Cambourne, Talinn, Miskolc and Helsinki were present, and after the first night of memory loss we started our bus trip which would take us up North, to Lapland.

The second night we arrived in Pyhäjärvi. The deepest metal mine of Europe is located here and produces zinc and copper. We went all the way down to 1500 meters below the surface to see the operation and we also sat in the world's deepest sauna. After this very nice visit we went to a holiday park next to a frozen lake.

But let us go back to the sauna's. If I had to describe the Finnish student culture in just one word I would say : sauna. Every evening, immediately after dinner, everybody took their clothes off and jumped in the deep snow, or in the sea if we were able to make a hole in the ice. Since the water is quite cold up there we needed a lot of the typical Finnish ''longdrinks''. These beverages helped us survive the cold, the hangovers and the heat in the sauna's. These drinks also helped the 70 year old professor that joined us forget what he did the night before. Let me just say that no clothes were involved but singing and lurching on the ground were.

The following night we drove to Ruukki close to Oulu. Ruukki is a big metal producer and we were guided along the processes associated to steel making. In the evening we were invited to have dinner with some company representatives and before dinner was served, the representatives were already dancing in the kitchen. On the shores of the lake next to the restaurant, we were invited to try a very typical ´´smoke sauna´´. Inside this sauna there was a real fire, but no ventilation gaps, and the temperature exceeded 100 degrees Celsius, drinking boiling beer is no good.

This evening we slept in a big student dorm of the student society run by the students of Oulu. This evening quickly escalated into a wild party with the local students and I do remember trying to reach the other side of the frozen lake while just wearing my flip flops.

The next morning we were still drunk when we started our tour in the next company. Unfortunately everybody fell asleep during the presentation and the company representatives decided to gives us our well-deserved break. After these killing days we drove back to Helsinki and had a walk through the city centre. On the last evening the traditional thanksgiving was held. The organizing board was thanked by the international students with giving them local booze they brought from their hometown. We, the Delft delegation, were so kind to offer the usual worn clog full of jenever. It seemed that the sweaty aftertaste was more intense than previous years.

Again, we showed how Delft Miners behave and we made a lot of new friends. In one year from now, we will organize an ISW in Delft. It will be legen – wait for it –. ■

Glück Auf and Kippis!

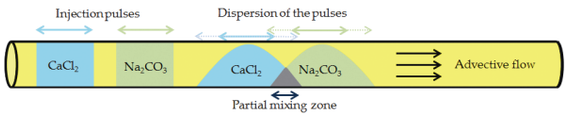
Controlled precipitation of calcium carbonate in spatial dimension with multiple calcium chloride and sodium carbonate pulses

By Barend Ubbink

Controlled calcium carbonate precipitation can be used for various applications. Calcium carbonate precipitation occurs when dissolved calcium and carbonate are mixed at concentrations which exceed the solubility of calcium carbonate. With alternate injection of pulses of calcium chloride and sodium carbonate solutions in time through a porous medium, dispersion will create a partial mixing zone in space, which moves through the whole system by advective flow. By means of dispersion and advection this should then create a homogeneous calcium carbonate deposit. By varying the concentration of the pulses, the size of the pulses, the distance between the pulses and the flow velocity it should be possible to control the location and distribution of the precipitated calcium carbonate to a certain extent. To investigate this principle a numerical model is developed, which is based on advective-dispersive-reactive transport equations for multiple dissolved and solid components using Matlab and Orchestra. Different ways of implementation have been tested and the performance of the model has been evaluated. With the final model seven different simulations were performed in which the system variables concentration, flow rate, pulse duration and pulse distance were varied. These simulations showed that controlled precipitation of calcium carbonate using alternating pulse injections is possible.

Introduction

In civil engineering controlled calcium carbonate precipitation can be used as ground improvement method in weak, instable grounds to prevent settlements, failure, cave-in and subsidence (De Jong et al, 2013; Van Paassen, 2009). In petroleum engineering, sand erosion can take place in wells producing oil from weak, loose sandstone or limestone reservoirs, which can be a significant problem for the production: it can plug the well or erode equipment.



▲ *Figure 1: schematic drawing concept of pulse injection in a porous medium*

Calcium carbonate precipitation occurs when dissolved calcium and carbonate are mixed at concentrations, which exceed the solubility of calcium carbonate. When mixing calcium and carbonate before injecting them into the porous media, the precipitation reaction starts almost instantaneously and consequently precipitation will accumulate mostly locally close to the injection well, which leads to clogging off the system and a non-homogeneous distribution of calcium carbonate and related engineering properties. Non-homogeneous distribution of the precipitated calcium carbonate has less effect as a ground improvement (van Paassen, 2009): a homogeneous distribution of the calcium carbonate is therefore desired. In order to achieve a homogeneous distribution over a long distance van Paassen (2009) sequentially flushed the contributing components for the precipitation of calcium carbonate through a porous medium.

Tartovsky et al, (2008) performed experimental and numerical work on the mixing of two simultaneously injected parallel pulses of calcium chloride and sodium carbonate. They showed that a thin calcium carbonate layer was precipitated between these two solutions. With the Tartovsky et al (2008) method of two simultaneously injected parallel pulses of calcium chloride and sodium carbonate, precipitation forms a thin layer parallel to the flow lines, which means that the precipitation starts from the injection location continuing further into the porous medium. Combining the van Paassen method of sequentially flushing the contributing components for the precipitation of calcium carbonate with Tartovsky et al, who injected pulses of calcium chloride and sodium carbonate, will give a method for calcium carbonate precipitation with calcium chloride and sodium carbonate where there should not be limitations in the spatial dimension. Therefore the objective of this study is to investigate whether distance-controlled homogenous calcification in a porous medium is possible by means of injecting multiple alternating pulses of calcium chloride (CaCl2) and sodium carbonate (Na2CO3) solutions. With alternate injection of pulses of CaCl2 and Na2CO3 solutions in time through a porous medium, dispersion will create a partial mixing zone in space, which moves through the whole system by advective flow (Figure 1). By means of dispersion and advection this should then create a homogeneous calcium carbonate deposit. By varying the concentration of the pulses, the size of the pulses, the distance between the pulses and the flow velocity it should be possible to control the location and distribution of the precipitated calcium carbonate to a certain extent.

To evaluate whether sequential pulse injection would lead to controlled precipitation a numerical model was developed. The model is based on advection-dispersion-reaction transport equations for multiple dissolved and solid components using Matlab and Orchestra. Different ways of implementation have been tested and the performance of the model has been evaluated using a model which included diffusion and reaction only without advection.

THEORY

Chemical reactions

When calcium chloride and sodium carbonate are dissolved in water, they dissociate in ions (charged molecules), which react with each other and with water to form a range of dissolved species and complexes, which vary depending on the alkalinity of the solution. Complexes are secondary species and alkalinity is the ability of a solution to convert acids and bases to an uncharged component. These speciation and complexation reactions are equilibrium reactions of the sort:

$$A + B \Leftrightarrow C + D \qquad [1]$$

In which the equilibrium constant, K, indicates at what concentration these reactions are at thermodynamic equilibrium: ►

$$K=\gamma_A C_A \gamma_B C_B / \gamma_C C_C \gamma_D C_D \qquad [2]$$

In which C is the concentration of a compound and γ is the activity coefficient. The relevant speciation and complexation reactions and their equilibrium constants for an aqueous solution containing calcium chloride and sodium carbonate are shown in Table 1. The quantity of a solid that can dissolve depends on the solubility product K_{sp} of the solid. When calcium (Ca^{2+}) and carbonate (CO_3^{2-}) become oversaturated in a medium and the ionic activity product (IAP) exceeds the solubility product, calcium carbonate ($CaCO_3$) can precipitate, according to van Paassen (2009):

$$Ca^{2+} + CO_3^{2-} \Leftrightarrow CaCO_3(s) \quad [3]$$

Name	Reaction equation	K value	Log K
Water dissociation	$H_2O \Leftrightarrow H^+ + OH^-$	$1.00693 \cdot 10^{-14}$	-13.997
Bicarbonate dissociation	$HCO_3^- \Leftrightarrow H^+ + CO_3^{2-}$	$2.13302 \cdot 10^{10}$	10.329
Carbonic acid dissociation	$H_2CO_3 \Leftrightarrow 2H^+ + CO_3^{2-}$	$4.79729 \cdot 10^{16}$	16.681
Calcium bicarbonate complexation	$CaHCO_3^+ \Leftrightarrow H^+ + Ca^{2+} + CO_3^{2-}$	$3.97188 \cdot 10^{11}$	11.599
Calcium hydroxide complexation	$Ca^{2+} + H_2O \Leftrightarrow H^+ + CaOH^+$	$2.00909 \cdot 10^{-13}$	-12.697
Calcium carbonate complexation	$CaCO_3 \Leftrightarrow Ca^{2+} + CO_3^{2-}$	$1.58488 \cdot 10^{3}$	3.200
Calcium carbonate precipitation	$Ca^{2+}CO_3^{2-} \Leftrightarrow CaCO_3(s)$	$3.01992 \cdot 10^{8}$	8.480
Sodium carbonate complexation	$NaCO_3^- \Leftrightarrow Na^+ + CO_3^{2-}$	$18.6207 \cdot 10^{0}$	1.270
Sodium bicarbonate complexation	$NaHCO_3 \Leftrightarrow H^+ + CO_3^{2-} + Na^+$	$1.19949 \cdot 10^{10}$	10.079

◄ *Table 1: Reaction equations and the K and log K values at 25oC. (Meeussen,2013).*

The relation between the ionic activity in the solution and its solubility product is at a thermodynamic equilibrium (van Paassen, 2009). The general notation of the relation is:

$$K_{sp} = IAP = \gamma_{Ca^{2+}}\gamma_{CO_3^{2-}} C_{Ca^{2+}} C_{CO_3^{2-}} \quad [4]$$

in which $\gamma_{Ca^{2+}}$ and $\gamma_{CO_3^{2-}}$ are the activity coefficients, $C_{Ca^{2+}}$ and $C_{CO_3^{2-}}$ are the concentrations. In this study we assume that calcium carbonate precipitates as calcite. The sodium carbonate (Na_2CO_3) and calcium chloride ($CaCl_2$) are dissolved in water and equation 5 shows the chemical reaction:

$$Ca^{2+} + 2\,Cl^{2-} + 2\,Na^+ + CO_3^{2-} = CaCO_3\,(s) + 2\,Na^+ + 2\,Cl^- \quad [5]$$

The precipitation rate of r_p, is often described using equation 6 (van Paassen, 2009):

$$r_p = \frac{\partial S_{CaCO_3}}{\partial t} = k_p (S-1)^n \quad [6]$$

in which S_{CaCO3} [mol/L] is the quantity of precipitated calcium carbonate,t [s] is the time, k_p [kmol·m^{-3}·s^{-1}] is the bulk kinetic constant, n [-] the kinetic order (in this study n is 2 (Söhnel and Mullin, 1982)) and S [-] the supersaturation. Furthermore, S can be described as equation 7:

$$S = \sqrt{\frac{IAP}{K_{sp}}} \quad [7]$$

Advective-dispersive-reaction flow through porous medium

Flow in a porous medium can only occur within the pore space. According to van Wijngaarden, the advection-dispersion-reaction equation that Zheng and Benett (1995) described for transport of a dissolved component in a porous medium for time-dependent porosity, when there will be internal no sink or source of the dissolved compounds and no interaction between the dissolved compounds and the grains in the porous medium, will be (van Wijngaarden et al., 2009):

$$\phi \frac{\partial C_i}{\partial t} = \nabla \cdot \left(\phi \mathbf{D} \cdot \nabla C_i\right) - \mathbf{q} \cdot \nabla C_i + \phi m r \quad [8]$$

in which φ [-] is the porosity, C_i [mol/L] is the concentration of the dissolved compound i, t [s] is the time, D [m^2·s^{-1}] is the dispersion tensor, and q [m·s^{-1}] the Darcy's velocity with, r [mol/L·s^{-1}] describes the reaction rate and m [-] is a stoichiometric constant, here 1.

The assumption is made that calcium carbonate does not transport and only will precipitate. That means that the quantity of calcium carbonate is only dependent on the rate that it precipitates in a time change $\Delta S_{CaCO3} = \varphi r \Delta t$. Therefore equation 8 can be written for calcium carbonate as:

$$\frac{\partial S_{CaCO_3}}{\partial t} = \phi r \quad [9]$$

The r of equations 8 and 9 is the same as the rp in equation 6. Therefore the advection-dispersion-reaction equations of the three components can be written as: ►

$$\phi \frac{\partial C_{CO_3^{-2}}}{\partial t} = \nabla \cdot \left(\phi \mathbf{D} \cdot \nabla C_{CO_3^{-2}}\right) - \mathbf{q} \cdot \nabla C_{CO_3^{-2}} - \phi \cdot k_p (S-1)^2 \quad [10]$$

$$\phi \frac{\partial C_{Ca^{+2}}}{\partial t} = \nabla \cdot \left(\phi \mathbf{D} \cdot \nabla C_{Ca^{+2}}\right) - \mathbf{q} \cdot \nabla C_{Ca^{+2}} - \phi \cdot k_p (S-1)^2 \quad [11]$$

$$\frac{\partial S_{CaCO_3}}{\partial t} = \phi \cdot k_p (S-1)^2 \quad [12]$$

Porosity

When calcium carbonate precipitates it will precipitate around the grains of the porous medium and therefore it will affect the pore volume of the porous medium. The change in pore volume Vpore is related to the quantity of precipitated calcium carbonate:

$$\Delta V_{pore} = \Delta S_{CaCO_3} \cdot \frac{m_{CaCO_3}}{\rho_{CaCO_3}} \qquad [13]$$

In which m_{CaCO3} is the molar weight of calcium carbonate and ρ_{CaCO3} the density of calcium carbonate. The reduction of the pore volume causes a reduction in porosity. The time-dependent relation of the porosity change with the quantity precipitated calcium carbonate can be derived from equation 13:

$$\frac{\partial \phi}{\partial t} = -\frac{m_{CaCO_3}}{\rho_{CaCO_3}} \frac{\partial S_{CaCO_3}}{\partial t} \rightarrow \phi(t) = \phi_0 - \frac{m_{CaCO_3}}{\rho_{CaCO_3}} \left(S_{CaCO_3}(t) - S_{CaCO_3,0} \right) \qquad [14]$$

Integrated over time and with the assumption that the initial quantity of precipitated calcium carbonate is 0, this will turn equation 14 into:

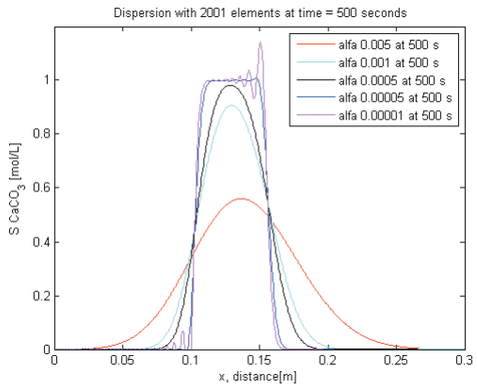
$$\phi(t) = \phi_0 - \frac{m_{CaCO_3}}{\rho_{CaCO_3}} S_{CaCO_3}(t) \qquad [15]$$

Model & Simulations

The following assumptions have been made to evaluate the hypothesis:

- The fluid is incompressible
- Capillary pressure is negligible
- Density differences between the participating fluids are negligible
- Viscosity differences between the participating fluids are negligible
- Speciation and complexation reactions (Table 1) occur instantaneously
- The precipitation reaction is kinetically controlled according to equation 6
- Calcium carbonate precipitates on the matrix of the porous medium and will not be transported.

Before the final model was evaluated, four implementation studies were carried out to evaluate the level of complexity that was required for the numerical model. The four implementation studies were: Coupling with Orchestra, Number of x-grid elements, Bulk kinetic constant and the longitudinal dispersion coefficient. With the coupling with Orchestra all the reactions of Table 1 are taken into account. Comparing the results with simulations that were done without the coupling with Orchestra no significant difference was visible. Therefore the coupling was taken out of the final model. Side effect is that a dynamic pH value could not be obtained anymore. The number of x-grid influenced the accuracy of the results, the storage and the numerical dispersion. The bulk kinetic constant k_pvalue influences the simulation running time. The longitudinal dispersion coefficient influences spreading over the porous medium of one single pulse and artificial oscillation (Figure 2) related to the Péclet number (Zheng and Benett, 1995). After the implementation study the parameters were set for the final model in such a way that accurate results were obtained with minimal running time and storage needed.



▲ *Figure 2: longitudinal dispersion variation at 500 seconds.*

Final model

For an one-dimensional problem the advection-dispersion-reaction equation 10 and 11 can be rewritten in equation 16 and 17:

$$\phi \frac{\partial C_{CO_3^{-2}}}{\partial t} = \phi D_{CO_3^{-2}} \frac{\partial^2 C_{CO_3^{-2}}}{\partial x^2} - q \cdot \frac{\partial C_{CO_3^{-2}}}{\partial x} - \phi \cdot k_p (S-1)^2 \qquad [16]$$

$$\phi \frac{\partial C_{Ca^{+2}}}{\partial t} = \phi D_{Ca^{+2}} \frac{\partial^2 C_{Ca^{+2}}}{\partial x^2} - q \cdot \frac{\partial C_{Ca^{+2}}}{\partial x} - \phi \cdot k_p (S-1)^2 \qquad [17]$$

$$\frac{\partial S_{CaCO_3}}{\partial t} = \phi \cdot k_p (S-1)^2 \qquad [18]$$

The domain for the one-dimensional evaluation is shown in Figure 3, the initial and boundary conditions are listed in Table 2 to evaluate the hypothesis. ►

IC and BC	$C_{CO_3^{2-}}$	$C_{Ca^{2+}}$
$C_i(x,0)$	$C_{CO_3^{2-}} = 0$	$C_{Ca^{2+}} = 0$
$C_i(0,t)$	$C_{CO_3^{2-}} = c_{in}$	$C_{Ca^{2+}} = c_{in}$
$C_i(L,t)$	$\frac{\partial C_{CO_3^{2-}}}{\partial x} = 0$	$\frac{\partial C_{Ca^{2+}}}{\partial x} = 0$

◀ *Table 2: initial and boundary conditions for the final model.*

Property of column	Value	unit
Length	5.00	m
Diameter	0.024	m
Area *A*	0.00045	m^2
Porosity ∅	0.35	[-]
Total volume V_t	0.00225	m^3
Volume liquid $V_{l\,m^3}$	0.00079	m^3
Volume liquid $V_{l\,L}$	0.79	L

Table 3: parameters of the porous medium. ▶

◀ *Figure 3: Configuration of the one-dimensional domain.*

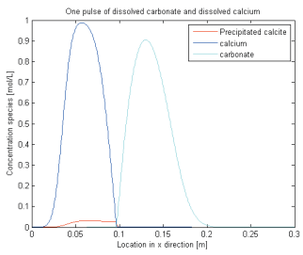
The parameters of the porous medium that is assumed to be a column are listed in Table 3.
In this study the porous medium is the same in each case at the start and the only variation will be on the injection of the dissolved carbonate and calcium, which will differ in three main aspects; pulses injection time, velocity and injected concentration.
For the pulse injection time the following notation is used, length of injection time dissolved component/length injection time between pulses. For example the notation 180/10 means that the time length of the injected dissolved component is 180 seconds and the time between the pulses of the two components is 10 seconds. Table 4 shows the different simulations which are performed.

Nr	Variable	c_{in} [mol L^{-1}]	Q [m s^{-1}]	D [m^2 s^{-1}]	Pulse/spacer time [s]	Nr of elements
1	Base case	1	$1.105 \cdot 10^{-4}$	$3.1578 \cdot 10^{-7}$	180/10	2000
2	Increase spacer time	1	$1.105 \cdot 10^{-4}$	$3.1578 \cdot 10^{-7}$	180/180	2000
3	Double pulse and spacer time	1	$1.105 \cdot 10^{-4}$	$3.1578 \cdot 10^{-7}$	360/10	2000
4	Nr of elements	1	$1.105 \cdot 10^{-4}$	$3.1578 \cdot 10^{-7}$	360/10	500
5	Concentration	0.5	$1.105 \cdot 10^{-4}$	$3.1578 \cdot 10^{-7}$	180/10	2000
6	Flow velocity	1	$2.2105 \cdot 10^{-4}$	$6.3156 \cdot 10^{-7}$	180/10	2000
7	Flow velocity+ spacer time	1	$2.2105 \cdot 10^{-4}$	$6.3156 \cdot 10^{-7}$	180/180	2000

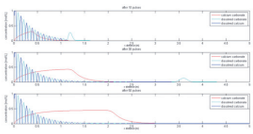
▲ *Table 4: Performed simulations.*

Base Case

In Figure 4 one pulse of both dissolved carbonate and calcium is shown. Figure 5 shows the transport of the pulses with dissolved calcium and carbonate and the development of precipitation throughout the column at different numbers of injected pulses. After injecting 10 pulses, most of the dissolved calcium and carbonate have disappeared, except for the first pulse containing carbonate at about 1.2 m, which has no calcium pulse in front of it and therefore did not completely react. The amount of precipitated calcium carbonate increases rapidly until about 0.4 m, while the concentrations of dissolved calcium and carbonate are rapidly decreasing, due to dispersion and reaction. After 0.4 m the amount of precipitated calcium carbonate starts to decrease again until it reaches almost 0 at 1 m from the inlet.
After injecting 30 pulses the first pulse of carbonate is transported about 3.6 m in the column. The amount of precipitated calcium carbonate reached a constant maximum value of about 0.5 mol·L^{-1} between 0.5 m and 1.2 m, after which it started to decrease again until about 2 m. With increasing distance from the injection, the dissolved concentration in each pulse is decreasing until about 1.6 m where the concentrations are close to zero.



▲ *Figure 4: One pulse of both dissolved carbonate and dissolved calcium.*

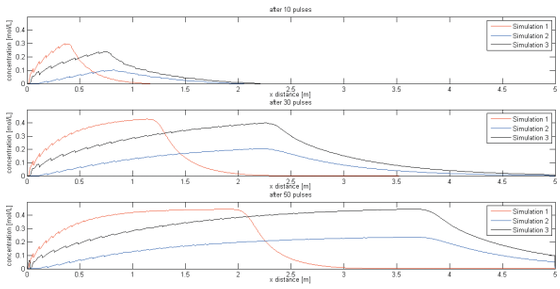


▲ *Figure 5: Results of the base case simulation.*

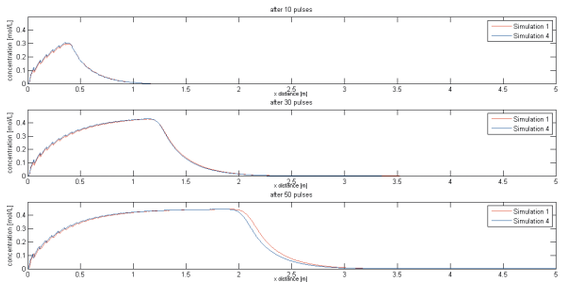
After injecting 50 pulses the maximum amount of precipitated calcium carbonate did not increase any further than 0.5 mol·L^{-1}, but the zone in which this maximum was reached extended from 0.5 m to 2.1 m, after which it decreased until about 3 m. The zone at which precipitation took place extended further than the pulses of dissolved calcium and carbonate reached, which seemed to diminish after 1.6 m.

Comparing the different simulations

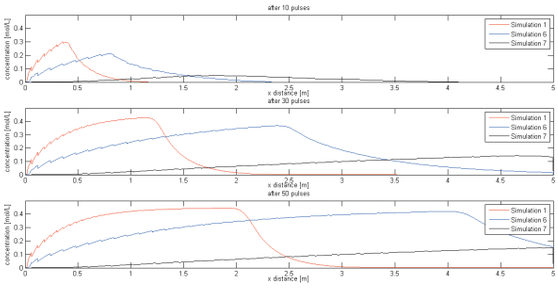
Figure 6 shows the comparison between simulation 1, 2 and 3. It clearly shows that an increase in spacer time from 10 s (simulation 1) to 180 s (simulation 2) does not increase the total amount of precipitated CaCO3, but the maximum concentration of precipitated calcium carbonate is reduced by a factor of two from 0.45 mol·L^{-1} to 0.22 mol·L^{-1}, while the distance over which it is distributed is doubled. Increasing the pulse length from 180 s to 360 s (while keeping the spacer short) results in twice the total amount of calcium carbonate, where the maximum concentration is about 0.45 mol·L^{-1} (similar to simulation 1) and the injection distance is more than 5 m (similar to simulation 2). ▶



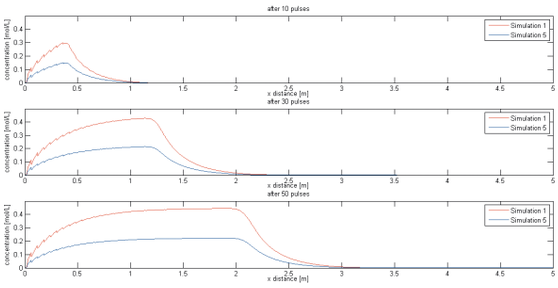
▲ *Figure 6: quantity of precipitated calcium carbonate of simulation 1, 2 and 3.*



▲ *Figure 7: quantity of precipitation of calcium carbonate of simulation 1 and simulation 4.*



▲ *Figure 8: quantity of precipitation of calcium carbonate of simulation 1 and simulation 5.*

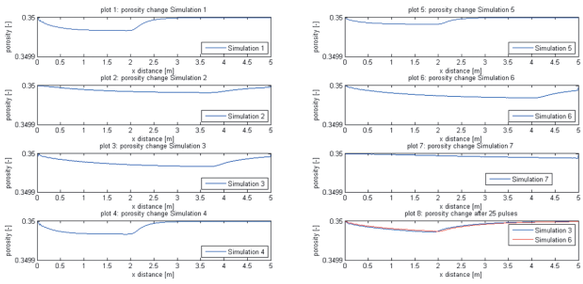


▲ *Figure 9 quantity of precipitation of calcium carbonate of simulation 1 simulation 6 and simulation 7.*

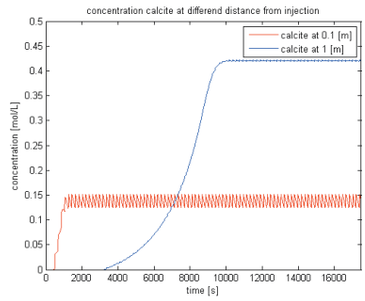
Figure 7 shows the comparison between simulation 1 and 4, in which the grid size or number of elements is varied. The results clearly show that reducing the number of elements from 2001 to 501 does not significantly affect the amount of precipitated calcium carbonate.
Figure 8 shows the comparison between simulation 1 and 5 in which the inlet concentration is halved. The amount of precipitated calcium carbonate of simulation 5 is half of the amount of simulation 1, which was expected because the inflow concentration c_{inflow} of simulation 5 is set to 0.5 instead of 1 mol·L^{-1}.
Figure 9 shows the comparison between simulation 1, 6 and 7, in which the flow rate is doubled. The quantity of precipitated calcium carbonate of simulation 6 looks that same as simulation 3 (Figure 6), due that in simulation 7 the length of between the pulses differ results in a very low quantity of calcium carbonate.

Porosity

In Figure 10 the change in porosity is plotted. The porosity change is calculated from the amount of precipitated CaCO3 using equation 15, the quantities of precipitated calcium carbonate after 50 pulses of the simulations and the expected quantities are listed in. Plots 1 to 7 of Figure 9 are plotted after 50 pulses of dissolved carbonate and calcium, plot 8 of Figure 10 simulation 3 and 6 are plotted after 25 pulses. Figure 10 shows that the change in porosity is not significant.
Conclusion & Discussion
The model used in this study gives a representation of an advection-dispersion-reaction simulation in a porous medium. ►



▲ *Figure 10: porosity change in the porous medium, where plot 1 till 7 is after 50 pulses and plot 8 after 25 pulses.*



▲ *Figure 11: saw tooth pattern due dissolution of calcium carbonate.*

The model is consistent:

- If the spacer time is increased the model reacts and the spatial distribution is further away from the injection point.
- If the injection time of the pulse is increased the quantity of precipitation can be controlled.
- If the velocity of the flow is increased the quantity of precipitation is more.

In Table 5 a negative part of the model is visible, that quantity of precipitated calcium carbonate is only 30%. This can be explained by the fact that the calcium carbonate dissolve if only one of the two dissolved component are at location x (Figure 11), at that moment S of equation 6 is smaller than 1 and calcium carbonate will dissolve. Only the rate that calcium carbonate dissolves is not equal to the rate that calcium carbonate precipitates (Krajl et al, 1997). Therefore the model needs improvement to retrieve the other 70%. Coupling with Orchestra is preferable for a more accurate model, but if the forming of complexes (Table 1) is negligible and the pH value not directly necessary it could be excluded. The pH in the model would help to validate the numerical model. The evaluation of the advection-dispersion-reaction model described in this article is a numerical evaluation, which is based on discretisation of time and space. To validate this numerical model an experiment is needed with the same parameter values the simulations. ■

Simulation nr	Precipitated [mol L^{-1}]	Precipitated [kg m^{-3}]	Injected [mol L^{-1}]	Percentage [%]
1	0.176	17.66	0.568	31
2	0.156	15.61	0.568	27
3 (47 pulses)	0.310	31.05	1.069	29
4	0.177	17.70	0.568	31
5	0.088	8.83	0.284	31
6	0.304	30.42	1.137	27
7	0.078	7.76	1.137	7

▲ *Table 5: quantity of precipitated calcium carbonate after 50 pulses of dissolved carbonate and calcium.*

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► *QR link to thesis on repository.*


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PALM

PhD Committee Update

By Twan Goense

After the 121st board of the Mijnbouwkundige Vereeniging set up the PhD committee, a lot of things have happened: activities reaching from ice skating to a pub crawl, and PhD- Barbara drinks to a harbor tour. In addition, some PhD students have left the committee and others joined the committee. That while the academic year is not over yet.. At the beginning of the year Randy Calis and Marieke Selles introduced the 122nd board of the MV to the PhD committee. It was a nice night in Het Noorden: we had an informal meeting, where everybody introduced himself and had some drinks. After the dinner we set up some plans for the upcoming year: what kind of activities do we want to organise? Luuk Mulder and I decided to participate in the committee as delegates from the MV, and started the PhD adventure with full courage.

Ice Skating

At a cold December night we decided to go ice skating in The Hague. All the MSc and PhD were invited to have dinner and some beers in 'Het Noorden'. After eating Chinese food and creating some 'Dutch courage' we left with a full stomach towards De Uithof. For some students it wasn't the first time they went ice skating, the MV only bought tickets for the 400 m track. For the advanced ice skaters: no problem. For the 'first-time-I-see-ice-skates-students': a real challenge. Some of the PhD students got a taste, and decided to start another 400m round just before the track closes. This resulted in a race against time. When the ice resurfacers started to do their work, there were still some students on the ice, which resulted in a funny situation.

PhD Harbor Tour

After the ice skating event, the PhD committee came with the idea to organize a cultural activity. Because there are a lot of foreign PhD students, we could show them the technological feats of the Netherlands. We decided to visit the Maeslant Storm Surge Barrier. After being received by a mining student, we got a 1,5 hour lasting guided tour about the construction and operation of the barrier. After a little delay we continued our trip to the Rotterdam Harbour. That little delay caused a delay for every passenger on the boat since the boat had to be held for us. Which led to a couple of angry looks, but that couldn't spoil the fun!

PhD Pub Crawl

I think the pub crawl was my favorite PhD activity of this year. Starting at 6 pm in 'Het Noorden' and ending at 11 o'clock in De Ruif. Below you can find a short point by point summary of the 5 intermediate hours (a summary would be to long):

- 5 pubs
- 17 PhD students, 3 groups
- Pasta pesto at 'Het Noorden'
- Just a beer at the 'Oude Jan'
- Wodka drinking at the 'Tango'
- Oldest Jenever in stock at 'De Klomp'
- A tequila pit stop at 'De Kurk'
- Award ceremony at 'De Ruif'
- Questionnaire with the subjects: St. Nicholas, St Barbara, Jenever & Delft
- Poetry writing students:

Round 1 – St. Nicholas – Question 2
When St. Nicholas is in the Netherlands, Dutch people make some poems for each other. Please write down a poem, with the next words included: St. Nicholas, mining, 'Het Noorden' and money.

St. Nicholas was sent from hell
He was not feeling very well
He went to 'The North'
Where there is a beer he can afford
He was begging for money
It wasn't too funny
So he got rich from mining
And the son is always shining
Now he is a big pimp
So he got lot of my…

After all the activities, I would like to thank all the PhD students who took part in the activities. And in particular the members of the PhD committee, who helped us organizing the activities and made them very enjoyable. ■

▲ *Figures 1 till 3: Pictures of the activities organized by the PhD Committee*

Studentlife in Arizona

By Corbin King

Its 8:30AM and I'm cruising down the Interstate 19 highway. I'm at the mine by 8:50, and I walk into the wet room to dress out for shift. Shift starts at 9AM, and we begin with a safety minute, and divide up the work for the day. It's just an average Saturday at the San Xavier Mining Laboratory. My name is Corbin King, and I am a Mining Engineering student in the United States of America. The school I attend is the University of Arizona (U of A) in Tucson, Arizona.

The state of Arizona, and the city of Tucson in particular, has a long history of mining that extends into the present day. The U of A was founded in 1885 with the primary goal of educating people in the fields of mining and agriculture to help the territory grow. Around the time the University was founded, 1 in 4 people in the state were miners. As a result, mining has had a huge impact on our history. It isn't unusual to go hiking in the desert, and stumble across the remnants of an old mine. There are some areas of Arizona that are covered with century-old mines that have long since been forgotten. About 48 kilometers north of Tucson itself, there's an area where some of my friends and I hunt, that is right next to the concrete foundations of an old smelter. Evidence of our past in mining is everywhere. Though mining isn't just in our past, it's a living, breathing industry alive in Arizona today.

Within an hour's drive from Tucson, there are at least six large open pit mines and one or two underground mines that are currently in operation. Having so many mines and mining companies close lends itself well to our studies.

Being able to learn about aspects of mining and then going and visiting multiple mines that employ those aspects really bring what you are learning to life. While being able to observe mining in action is good, our school puts an emphasis on hands-on experience and challenges, which we are able to encounter at one of our greatest assets at the U of A; the schools very own mine. Part of being a mining student at the U of A is that we have access to the San Xavier Mining Laboratory, a small underground mine that has been repurposed as a training facility. Our mine was originally started in 1878, and was the #6 shaft in a 9-shaft system. That I know of, it extended over a 13 square kilometer area, and was excavated extensively. It is part of the southern mining district of Arizona that has had major mining activity since the Spanish arrived in the 1500's, and small instances of mining by the native populations before that. The mine is now used as a research and test facility for both student and professor led research projects. On any given Saturday we have a variety of different people, from members of Government agencies to different departments from the U of A, out at the mine doing research.

One massive project that we just finished was by members of the College of Public Health using our 4 yard LHD to test the differing effects of biodiesel and diesel fuel on the human body. This was a two year project, and the results may change the way mining is done in the US to help underground miners live healthier lives. The mine itself is three levels; the Adit that you can walk into, the 30-meter level, and the 46-meter level which are both accessible via ladder systems. The workings that we continue to support probably cover around a .4 kilometers. Originally it extended down to 76 meters, with connecting man-ways down to 488 meters, but we only maintain to 46-meter level. The mine was leased in 1958 from the Anamax mining company, and in 1978 it was bought with $1 of state money under the contract that we cannot make a profit off of any metal that we pull out of the ground. Though research isn't the only thing we do; we also continue to mine and advance the 46-meter level. The mine is entirely student run; from the miners to the management. The only bit of faculty that is involved is the Director of the mine who is the face for the mine from the University. Freshmen (first-year students) start off as miners, and they are trained on all the equipment at the mine. Depending on the amount of time they put in, they can gain positions of leadership throughout their time in school.

Currently I am the Safety Foreman. My main responsibilities include leading teams of miners in underground excavation, as well as monitoring the level of safety on different projects throughout the property. The mine was originally opened to chase veins of silver. By the time the U of A acquired the mine, the silver had long been mined out. If you know where to look, though, there are still very small trace amounts of silver left. Most of what we mine then is copper. Our mine sits on top of, and descends into, a skarn deposit. Littering the surface of the mine is large quantities of Chrysocolla, representing our Oxide zone which extends in part into our 30-meter level. Once you reach the 46-meter level though, you are greeted by a healthy amount of Chalcopyrite, representing your arrival into the Sulfide zone. Since the 46-meter level is where we are advancing, sulfide minerals are primarily what we pull out of the mine. Though, since the Adit was dug by students, and is larger than the 46-meter level, most of our dump piles are filled with oxide minerals.

For our mining operations we use a 60-kilogram Jackleg drill to drill a blast pattern. After the pattern is completed, we load the holes with Emulsion explosives. Emulsion is a mixture of ANFO (Ammonium Nitrate and Fuel Oil) and other chemicals to help eliminate ANFO's vulnerability to water. After the blast we muck it all out using an Overshot Mucker that puts it into ore carts, which we haul to the surface via our shaft and hoist.

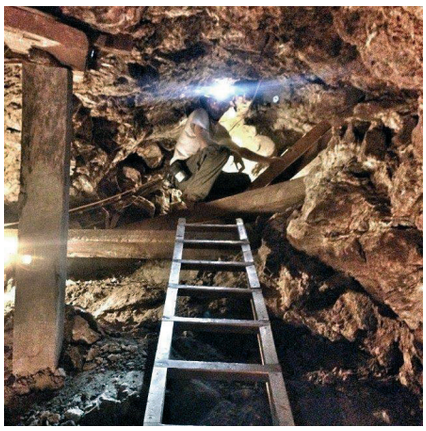
While some other US schools have student mines, we are the only school with a working shaft. Once we've cleared our way to the face, we bolt roof supports in and the process starts again. Although the actual mining practices that we use are antiquated compared to the modern mining industry, the key principals are still there. We still learn vital skills in how to approach a problem in mining as an engineer in a working mine setting. Aside from research and excavation, we have other mining activities that take place at the mine, including mine rescue teams. I currently lead the mine rescue program from the student end and work closely with our mine director who has 30 years of experience in mine rescue. The end goal for our mine rescue program is to create safety-minded engineers who would be able to work competently with rescue officials should they find themselves aiding a rescue effort. We will compete against other collegiate ►

mine rescue teams in the spring and hope to hone our abilities until then.

While the San Xavier Mining Laboratory is an excellent resource in our education, our department puts an emphasis on global and industry-related work experiences. Last summer I was able to attend the summer school of mining engineering in Krakow, Poland where I learned about the variations in mining taught in Poland, and met many international students. I was glad to have met the students from Delft; Stefan, Talitha, Lisann, Kathelijne, and Hubert. They were a great group of people and it was really interesting to compare what we were taught in Poland to what students are taught at Delft and what I have been taught in America. While there, we took classes, visited mines, tested with explosives, and explored the beautiful city of Krakow. It was an amazing experience that I would highly encourage mining students to pursue.

This summer I accepted an internship at Salt River Project (SRP), which is the primary power company that provides electricity to all of the Phoenix-metropolitan area; home to more than 4 million people. In America it is common for Mining Engineering students to get summer internships that give them mining-related work experience before they graduate. My job at SRP is to help secure fuel contract agreements between SRP and different mining companies. These contracts provide coal and uranium to the coal fired and nuclear power generating stations that SRP owns. It has been an awesome experience that has taught me a lot and allowed me to visit a number of different mines, including Black Thunder, the largest coal mine in the world.

I know that for mining students in Delft, studying abroad is a must as part of your degree requirements; I would encourage anyone who is interested to come and study at the University of Arizona. We have excellent mining and geology departments, and I know you won't be disappointed!
And as my friends from Delft taught me, Glück auf! ■



▲ *From upper left, clockwise:*
Figure 1: Myself, setting up the Jackleg drill during our Annual Drilling Competition on the U of A campus. Students have 2 minutes to set up and drill; the farthest depth wins. Photo Credit: Lisa Rzechula.
Figure 2: Friends from Delft! From left to right: Myself, Jacob (who is also from the U of A), Lisann, Stefan, Hubert, Talitha, and Kathelijne. Courtesy of Talitha Groenewold.
Figure 3: Myself, holding a stick of dynamite during explosives testing in Poland. You didn't think I was kidding did you?
Figure 4: Our Mine Rescue team just about to enter the underground and begin training. Photo Credit: Lisa Rzechula.
Figure 5 : A few steps into the adit, and you enter another world. Photo Credit: Lisa Rzechula.
Figure 6: Myself, descending into the 30-meter level. Man-ways can be tight! Photo Credit: Casey Camamo.

Remote Discoveries in Tibet

By Roderik Lindenbergh, Vu Phan Hien and Massimo Menenti

Tibet always has been a mysterious region. In the end of the nineteenth century Tibet was considered of strategic importance as it was situated between the empires of Russia, in the North, China, in the East, and India, in the South, where India at that time belonged to the British Empire. All these three superpowers were somehow afraid that one of the others would invade Tibet and would thereby close in. The fight for Tibet was part of a bigger conflict, the so-called Great Game, on supremacy in Central Asia. At that time, Tibet tried to defend itself by closing its borders and notably declaring its capital Lhasa as a city forbidden to foreigners. Exactly this triggered the interest of several adventurers, spies and surveyors that tried to enter Tibet to explore it, map it, and, in general, unveil its mysteries, (Hopkirk, 1982). This period was abruptly ended by British troops that invaded Tibet and occupied Lhasa with modern weapons in 1903-1904. As a result, Tibet was open to visitors in the first half of the 20th century. Notably all expeditions at that time to the highest mountain of the world, Mount Everest, or Chomolungma in Tibetan, approached the mountain from the Northern or Tibetan side, (Firstbrook,1999). These mountaineers provided the world with the first clear pictures of some of the Tibetan glaciers, compare Figure 1, that can now be used as benchmark to assess (local) glacial change. After the Second World War, the British lost their influence in the region, and China, led by Mao Zedong, took hold of the power in Tibet in 1951.

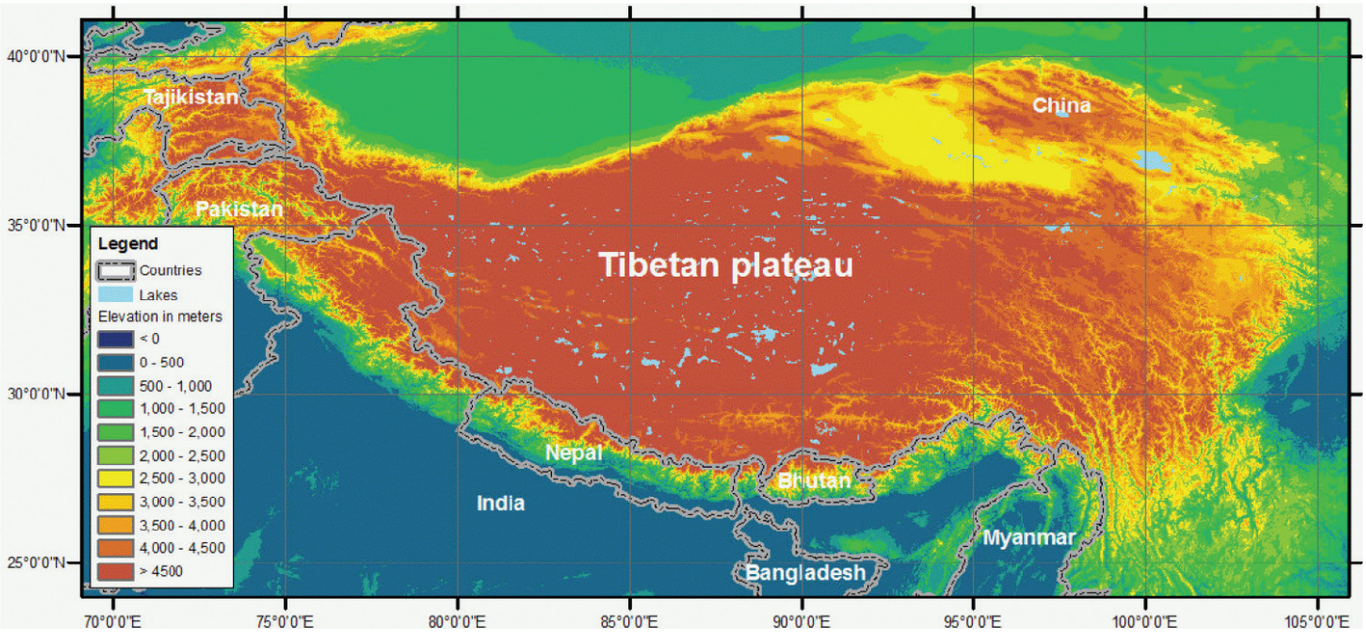
At the moment the Tibetan Plateau is again considered crucial, but now from a climate change perspective. All major South-Asian rivers, including notably Indus, Brahmaputra, Mekong, Yangtze and Yellow River, originate at the Tibetan Plateau. About 1.5 billion people directly depend for their water supply on these rivers and on the lakes and glaciers that are feeding them, (Immerzeel, 2010). In fact the Tibetan Plateau stores the largest amount of ice in its glaciers besides the Antarctica and Greenland ice sheets. For this reason it is also often referred to as the Third Pole. Not only is Tibet "exporting" water, it is also partly makes the regional weather. Indeed, the weather situation in Japan often finds its origin on the Tibetan Plateau. Even though Tibet plays this crucial role in physical geography, it is still among the least explored regions on Earth.

Main problem here is that it is almost completely situated above 4000m, compare Figure 2, combined with a harsh climate and sparse infrastructure. This, in combination with its large area, makes it very challenging to perform systematic measurements on the ground. Fortunately, there are more and more satellite missions that observe Earth including Tibet from Space. In this article we notably consider the possibilities of so-called space borne laser altimetry to monitor the possibly changing state of the many glaciers and lakes on the Tibetan Plateau. In theory, laser altimetry is able to obtain many accurate and precise elevations. If such measurements are somehow repeated, also changes in elevation, as for example caused by changing water levels or glacial melt could be obtained. Within the framework of his PhD project at Delft University of Remote Sensing, Vu Phan Hien used available laser altimetry elevations to study changes in glaciers and lakes. How this worked out in practice is explained in this article.

▲ *Figure 1: The Kyetrak Glacier, located on the northern slope of Cho Oyu (8201m) in Tibet, as photographed in 1921 (top) by Major E.O. Wheeler and in 2009 (bottom) by David Breashears. In the past 90 years, the glacier has retreated and melted so extensively that a lake has formed where once there was ice and snow. (Wheeler photo courtesy of Royal Geographical Society.) (Image Source and Caption: http://e360.yale.edu/content/images/0710-breashears-kyetrak-comp.html).*

ICESat Laser Altimetry

The main data source considered in this study is space borne laser altimetry. The principle of laser altimetry is straightforward, compare Figure 3. At the platform, which is in this case a satellite, a laser pulse is shot in the direction of the Earth. This pulse will eventually hit the Earth at a certain location and bounce back towards the satellite platform. The satellite measures the total travel time of the pulse. As the pulse traveled at the speed of light, the distance between satellite and ground is easily computed. Meanwhile the position of the satellite is known from a combination of GPS and star stracking. By combining this position with the orientation of the satellite, the angle at which the laser pulse was shot and the range distance from satellite to Earth, ►



▲ *Figure 2: Elevation map of the Tibetan Plateau. (Image Source: (Phan et al., 2012)).*

the 3D position is obtained of the point on Earth that was hit by the laser pulse.

The ICESat mission was the first and so far the last satellite mission on which laser altimetry was implemented. At least, as far as the Earth is concerned. The Earth atmosphere makes satellite laser scanning difficult: the atmosphere absorbs a large part of the emitted laser pulse, which makes it necessary to emit a quite strong signal to ensure that the return signal is even detectable. As a satellite can carry only a limited amount of batteries, ICESat could only measure elevations directly below its orbit, as shown in Figure 3, that also shows that consecutive pulses hit the Earth 175m apart. Sending also pulses sideways, which would result in a much better coverage, would simply require more batteries than ICESat can carry. ICESat was operational for seven years, between 2003 and 2009. The satellite actually carried three identical lasers, to ensure the mission could continue if a laser would break down. This was a good idea: after only three weeks the first laser already broke down.

Because of the battery problems and problems with the laser, ICESat was not measuring elevations continuously, but only during three approximately one month campaigns a year. The elevation profiles that ICESat measured during one such campaign, the L2D campaign, that took place in December 2008, are shown in Figure 4. The figure shows that actually only a small part of Tibet was sampled by ICESat elevation, simply because consecutive satellite tracks of ICESat over Tibet are around 70 km apart. In total, ICESat obtained measurements during 18 such campaigns.

Why are these ICESat measurements, will all their problems, still so unique and useful? A first highlight is the narrow bundle width of an ICESat laser pulse. Such pulse illuminates, on average, a spot with a diameter of only 70m, that is about the width of a football field. In comparison, radar altimetry, a measurement concept using radar signals, illuminates spots with a size in the order of a few kilometer. For such large spots, it is much more unlikely that there is such thing as one common elevation within the spot, especially as Tibet is covered by steep mountains. In addition, it has been shown, for example over The Netherlands, and over salt flats like the Salar De Uyuni in Bolivia, that the quality of the ICESat elevation is very high: from 600 km, ICESat managed to get elevation measurements with an error in the order of a decimeter over flat terrain. All in all, most ICESat elevations over Tibet are the best elevation measurements available for the location of the elevation.

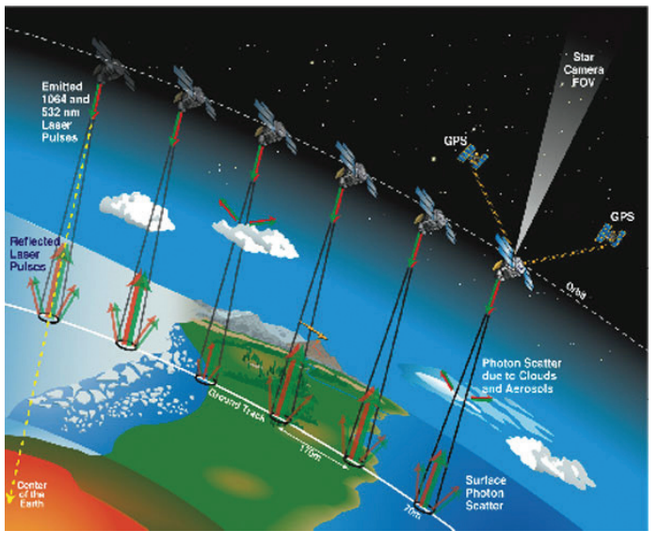
Lake Level Changes

Even with the high quality ICESat elevations, it is difficult to determine changes during its 18 one month campaigns. The ICESat tracks, as shown in Figure 4, are repeated during each campaign, but only in an approximate sense, which means that two repeated tracks can easily be one kilometer apart. In general this is a problem when considering changes in elevation in mountainous terrain. Fortunately, there is one type of very relevant terrain where it is not so important where exactly you measure its elevation. These are lakes. In Figure 4, about 900 Tibetan lakes with an area over 1 km2 are shown. The boundaries of these lakes are obtained from yet another type of satellite sensors, namely spectral cameras. The first instance of this particular lake mask has been created by a land cover classification procedure applied to spectral photographs obtained by the MODIS spectrometer, that is installed on both the Terra and Aqua satellites. As the initial water mask didn't distinguish between lakes, rivers and lakes that dry up in summer, we carefully checked it in Google Earth and by analyzing additional spectral data from the Landsat ▶

mission. This resulted in the final lake mask as shown in Figure 4.

Next it was considered for each of the 18 one month campaigns, which of its elevations where from within a lake. As Figure 4 shows, many lakes were hit by ICESat, but also many lakes were completely missed. Even if a measurement is over a lake, it still can be wrong. Maybe it was cloudy, and ICESat was measuring the top of the clouds instead of the lake. Or maybe, the lake changed its shape because it lost water. The good thing about measuring lakes in the way ICESat does, with consecutive pulses separated by 175m, is that in most cases you will not have only one lake elevation, but a whole series of elevations, that all should be the same, as they are all acquired at more or less the same moment. Using all good elevation from one pass a lake level at that time was computed for each lake measured by ICESat. As a result, for the first time, lake level variation of 154 lakes in Tibet could be estimated using the ICESat measurement, which is a huge improvement compared to the about 10 or 20 largest lakes that can be observed with the radar altimetry method with its large spot sizes. Still, these available radar elevations are very useful for validating the ICESat results. It is nice to come with a new type of measurements, but you have to somehow prove that these measurements indeed make sense.

The result in trends in lake level per lake are shown in Figure 5, where Tibet is divided into catchments, mostly corresponding to the large rivers mentioned above. On top of that, many lakes in Tibet have no discharge, but only loose water underground or via evaporation. These are the salty lakes, as the salt remains when the water evaporates. As can be seen from the figure, lakes behave quite differently. Some lake loose water, while others increase. On average, where the area of the lakes is taken into account af course, the Tibetan lakes measured by ICESat rose by 20cm/year between 2003 and 2009, (Phan et al., 2012b). The next step is to understand why the different lakes behave in the way they do. Was there locally more or less snow or rain? Are the glaciers indeed melting? Or do lakes loose the majority of their water through evaporation?



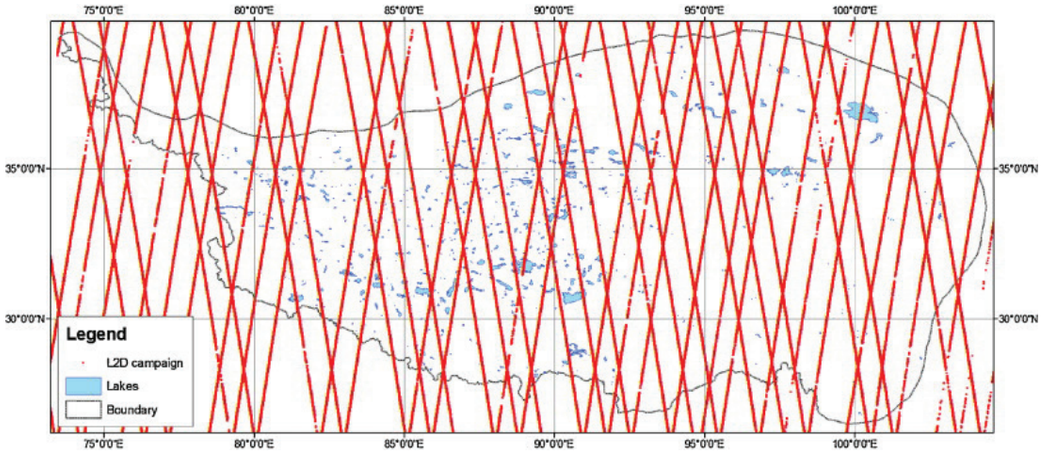
► *Figure 3: Principle of the ICESat mission (Image Source: NASA).*

Glacial Changes

As a first step to answer these questions it was decided to start to determine for each lake its potential inflow of glacial melt water. Again this is currently only possible in a remote way, as it is not feasible for obvious reasons to determine on location the actual runoff for all 37000 glaciers on the Tibetan Plateau. Still there are some ingredients that may help. First, we know the locations of the lakes, see Figure 4. In addition we know the elevations all over the Tibetan Plateau, see Figure 3, maybe not at the quality of the ICESat elevations, but the freely available digital elevation models obtained using radar (SRTM) or using photogrammetry (ASTER GDEM) have typical errors in the order of 10m, which is quite reasonable over mountainous terrain. In addition, also the locations of the glaciers have been determined by people, basically in the same way as the locations of the lakes: a combination of manual and automated classification of spectral satellite images.
Combining topography, lake and glacier locations can tell us actually which glaciers drain into which lakes. Starting from the glacier exit, its snout, the pathway of the outflowing water is estimated by constructing a path of steepest descent using the elevation data from the digital elevation model. We have done that systematically for the complete Tibetan Plateau and therefore we now know exactly which glaciers drain into which lakes, (Phan et al.,2013). Here, exactly is of course up to processing errors and errors in the different input data.

More difficult is to actually determine the amount of glacial change that is occurring on the Tibetan Plateau. Typically, so far people analyze if the outlines of the glaciers are changing, but that is somehow only half of the story, compare also Figure 1. In order to estimate the total volume of gained or lost ice, it is also important to know the thickness of the layer of ice. On top of that, see also Figure 1, it is quite difficult to distinguish between ice, debris on top of the ice and snow on top or not on top of the ice. Still, in 2012 an article appeared in Nature, (Kääb et al., 2012), that estimated glacial change in notably the Himalayas, the mountain range on the South border of Tibet, from different data sources including ICESat data. This triggered us to try something similar over the complete Tibetan Plateau as well.

In addition to the difficulties regarding what is changing, snow, ice or debris, there was this other problem with measuring elevation changes with ICESat: tracks are only repeated in an approximate way. This was no big problem over lakes, but is a problem over glaciers, compare again Figure 1. A partly solution to this is to not directly compare ICESat elevations from different campaigns, but to consider the differences between ICESat elevations and some reference surface. For this purpose we use the SRTM digital terrain model and group all resulting ►



◄ *Figure 4: ICESat tracks from one one-month campaign (Image Source: Phan et al., 2012).*

ICESat-SRTM elevation differences from a number of adjacent glaciers with similar orientations. This allows to, at least for some glacial regions, to get enough observations to estimate a change trend for that region. Preliminary results show that, as for the lakes, glaciers change in different ways in different regions, and on top of that, as can be expected, also change in a different way at different faces of a mountain ridge, (Phan et al, 2014). This can also be observed in the Alps: North facing slopes get less sun, and their ice and snow will therefore melt less fast. Therefore the qualitative result may not be so surprising, but what counts is, that in this way we are also able to quantify changes to some extent.

Conclusions

In this article we told about our remote discoveries at the Tibetan Plateau. In fact all the work described here was performed with freely available remote sensing data that is open to everybody with a sufficiently fast internet connection. You will also understand from this article that this work is not finished. Actually, our results on glacial change are still under debate, while it is expected that in the coming years many more articles will appear on these and similar topics. Also within TU Delft other colleagues are working on different topics related to the Tibetan Plateau, for example related to the amount of rain and snow. If you want to contribute in the form of a BSc or MSc thesis project, you are more than welcome. ■

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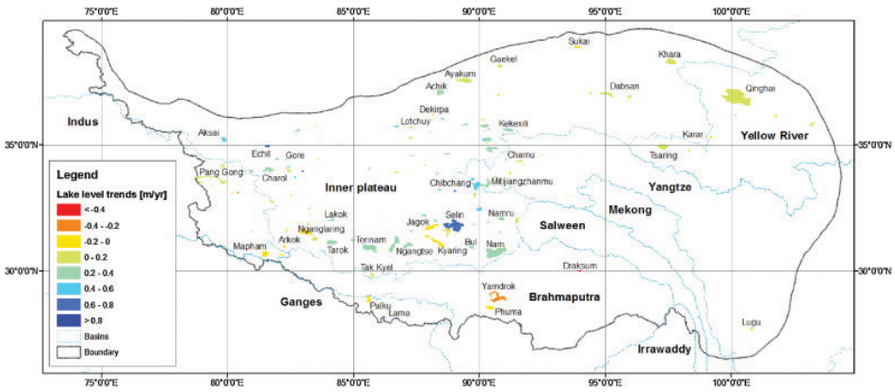


▲ *Figure 5: Lake level trends on the Tibetan plateau between 2003 and 2009 (Image Source: Phan et al., 2012).*

Bestuur Belicht

Naam:	Twan Goense
Leeftijd:	20 Jaar
Bestuursfunctie:	Penningmeester
Jaar:	2011
Hobby's:	Chillen, hardlopen, sport

Je hebt echt super hard hardgelopen op de Batavierenrace met een snelheid van 14,1 km/uur gemiddeld, hoe doe je dit in je bestuursjaar?
Ja, ik was inderdaad de snelste van alle heren. De avond ervoor had ik DSC gala, dus ik was nogal brak. Ik was al later aangekomen. Onderweg moest ik ook een sprintje trekken om de trein te halen, op Amersfoort. Dit was ongeveer 20 meter, en ik kwam uitgeput in de trein. Op dat moment dacht ik "Dit gaat helemaal niet goedkomen". Uiteindelijk ging ik rennen, ik voelde me inderdaad niet zo goed, maar ik dacht hoe sneller ik loop hoe eerder ik bij de finish ben en hoe eerder ik er vanaf ben.

Heb je overgegeven?
Nee, gelukkig heb ik alles binnengehouden.

Wat vind je het leuke aan je functie als penningmeester?
Het leukste vind ik dat je bezig ben met iets concreets. Je leert een echt vak in je bestuursjaar. Je bent bezig met het maken van begrotingen tot het spenderen van geld. Het leuke is ook dat bij de MV mogelijkheden zijn. Luuk haalt de sponsoring binnen, hoe meer sponsoring, hoe meer de MV kan besteden. Ik vind het erg leuk dat je druk bent met cijfers, je bent aan het boekhouden en je leert een vak. Daarnaast vind ik het ook leuk dat je later in het jaar steeds beter wordt in het boekhouden, dus dan komt het erop neer dat je meer tijd hebt voor andere dingen zoals het regelen van een tweedejaars excursie en nuldejaars excursie. Deze dingen erbij doen vind ik leuk.

Denk je dat je later een functie wil die met financiën heeft te maken?
Toevallig ga ik in september starten met de minor Finance bij wiskunde. Maar in principe wil ik later als ingenieur gaan werken en heel de wereld over gaan.

Heb je al een idee welke richting je op wil?
Petroleum engineer.

Hoe ziet jouw ideale Noorderfeestje eruit als je €122 zou besteden?
Laatst (tijdens de bananenbar) heb ik een stripper laten komen, maar die was 170 euro. Dat was heel leuk én het was één van de beste feestjes van het jaar. Ik zou misschien toch weer het bestuur 119 inhuren voor een bananenbar. En na een jaar penningmeester kan ik wel onderhandelen over het geld, en toch weer een stripper laten komen. Ik zal dan vragen of ze in plaats van 170 euro voor 122 euro wil komen.

Wie gaat er dan op tafel?
Uhm ja, dan kies ik toch wel mezelf uit om daar te gaan zitten.

Iets over je gewicht, mag je daar iets over verklappen?
Aan het begin van het jaar, rond oktober/ november, wilden we gaan wegen, want we kwamen toen toch wel veel aan. Wie van ons tweeën (Luuk en ik) ging als eerste de honderd aantikken? Het ging de goede richting op en kregen we een weegschaal. We gingen ons zelf elke dag wegen. Aan het begin hadden we een trendlijn die afnam, maar uiteindelijk ging die toch echt naar boven. Het ging de kant op dat we het zouden halen aan het einde van het jaar. Alleen rond maart hadden we een omslag punt en is de trend gaan afvlakken. We hebben ons pas nog gewogen en het zit er niet meer in om het te halen. We wegen ons ook met kleren aan, dus dan zelfs lukt het niet. Op de ALV zullen we onze grafiek laten zien.

Vind je het erg dat je bent aangekomen, of vinden mannen dat helemaal niet erg?
Nou nee, ik vind het nu niet zo heel erg. Als het over een jaar nog zo is dan gaat er het wel goed mis. Maar ik ben wel iemand die gewoon sport, dus in principe gaat het er wel weer vanaf, denk ik.

Als je bestuursgenoten verschillende kinderfilm personages zouden zijn, wie zou wie zijn en waarom?

Luuk is snorex uit pokemon, het uiterlijk werkt natuurlijk al mee. Verder vindt hij het niet erg om even lekker te gaan zitten en rond te kijken hoe het er allemaal aan toe gaat.

Ik vind Suus Guus Geluk van Donald Duck. Suus heeft altijd wel geluk. Als Suus bijvoorbeeld wordt aangehouden bij een lichtcontrole en ze heeft geen licht dan wordt de boete uitgeschreven en uiteindelijk rijdt de politie weg omdat ze een noodoproep hebben. Suus heeft dus gewoon geluk. Misschien dwingt ze het af, maar ze heeft wat meer geluk dan de ander.

Van Kabouter Plop dan Kwebbel, dat vind ik wel een Thaïsa. Thaïsa is iemand die vrolijk is, maar wel altijd praat en haar mondje bij heeft. Soms is het wel echt gekwebbel.

Mathijs is Goofy, hij is slim, maakt goede opmerkingen. Je zou het niet zeggen maar Mathijs vergeet ook wel eens wat. Dat is erg grappig. Hij doet dan alles heel goed, maar is wel verstrooid, bijvoorbeeld dan gaat die op tijd ergens naar toe en kom je hem 10 minuten later weer tegen omdat hij zijn portemonnee is vergeten. Zo goed voorbereid, maar dan helaas, zijn portemonnee vergeten.

En jezelf?
Dat is wel een hele goede…
Die van Wall Street. Als je het echt goed voor elkaar hebt, zo veel geld hebt dat het geld geen probleem meer is. Ik vind het wel grappig dat er dat soort mensen zijn. Dan kan ik genoeg bananenbar feestjes geven. ■

Weber puzzle

Solution of Tropical Hards Puzzle

The gist of this puzzle is to gather knowledge o f tropical diseases and ways to prevent contracting them. It's remarkable how much you can pick up from a brief search on Wikipedia.

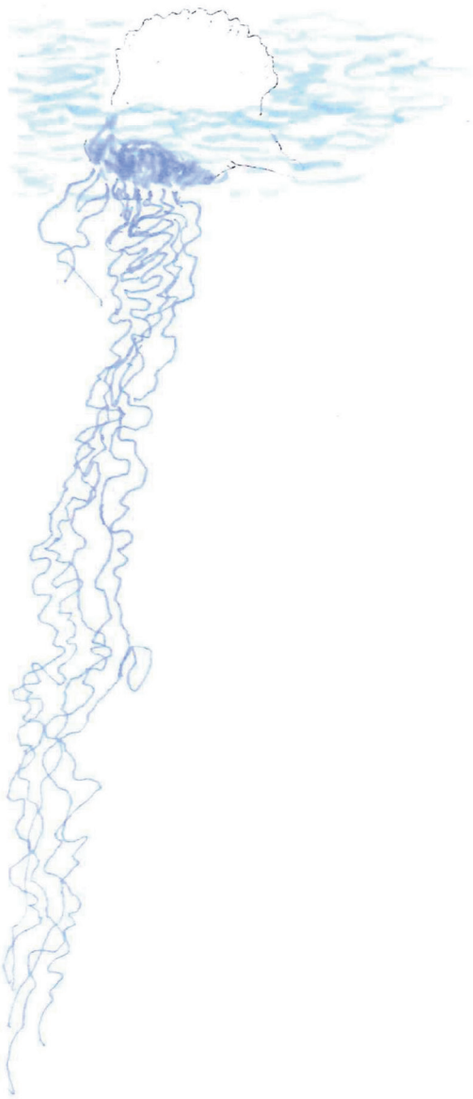
Snails invading the Assuan Dam Lake carry the bilharzias parasite and swimming there is not a good idea. Picking up stones in the desert by hand may wake up the scorpion(s) hiding underneath. They are more common than you think. Visitors to Egypt are not advised to take anti-Malaria pills, but on the Red Sea coast you will certainly need them. Finally in tropical seas one may encounter some strange jelly-fish like creature, named "Portuguese Man-O-War' (see picture). They have a whitish air-filled sack above water, but under the body very long tentacles are hanging, which can cause extremely painful nettle marks that are also quite dangerous.

In Nigeria we are in the 'steaming tropics' with an enormous variety of hazards from bacteria, viruses, worms, animal bites, parasites and an occasional armed robber. Even ice- cubes made from unboiled water can be infected. Because o f the 'Tsetse Fly' there are no cattle in southern Nigeria and ground grown fruit and vegetables are commonly fertilized with 'night soil'. Thus eating a watermelon can be dangerous. Nearly all of the local population carry various worm infections. Walking barefoot can lead to a hookworm infection. The larvae can penetrate your skin and work their way up to the lungs and various other organs!

Swimming pools in the tropics are often infected by fungea. After having taken a swim, you have to clean your ears thoroughly to prevent painful ear infections. A nasty insect in Nigeria is the Tumbu Fly. It lays its eggs on moist washing and all pieces of laundry have to be ironed with a hot iron. Towels in swimming pools are a favourite target. On touching your skin the eggs hatch immediately and the larvae enter your skin. You develop a hard boil inside which the maggot eats its fill. If you discover it in time, you smear Vaseline on the boil which closes o f the maggots breathing hole and next you massage the boil until the maggot pops out.

Sunning in the tropics is not good for white skinned people. Very many of my friends have developed skin cancers and one of them has even died of this! Wear a hat and a shirt except when swimming. Snakes are plentiful but people are rarely bitten by them. Nevertheless a green mamba dropped out o f a tree at less than a meter from where I sat and their bite is often deadly. Patting stray dogs is perhaps the most dangerous thing you can do. Rabies is still around in Africa and even a lick on your hand can transmit the disease.

If you add up all the hazards in the above stories you get: Bilharsia, scorpions, malaria, Portuguese Man-O- War, ice-cubes, watermelon, hookworm, Tumbu Fly, green mamba, ear infections, (infected)stray dogs and sun bums which makes a total of twelve hazards.



We would like to congratulate Richard Hontelez for his correct submission! We will contact you for the crate of beer you won. ■

On the wrong island

Most mining engineers are interested in biology and some are even birdwatchers. Having travelled far and wide, you must have seen a large variety of animals. Here you see an unusual view of a steaming jungle in New Guinea. The area is teeming with wildlife although in reality you would never see this many species so close together. However in this case there is an additional reason that the picture is unrealistic.

The older miners, like me, will remember the original Tarzan movies showing tigers and Indian elephants in Africa. Well, here there are also a number of animals that don't occur on New Guinea. Can you identify these lost souls? The corresponding picture can be found on the previous page.

You can submit your answer to Naturalresource-MV@tudelft.nl. ■

MV Calendar

Date	Event
Thursday 3 July	Eindejaarsbarbecue en Velzeboerbeker
Friday 4 July	Bacheloruitreiking
Wednesday 13 August	NGMSO barbecue
Saturday 16 August	Mijndoop Beringen
Sunday17 August	OWee kick-off
Wednesday 20 August	OWee Noordenavond
Wednesday 27 August	ALV en Bestuurswissel
Friday 5 September	Barbaraborrel
Wednesday 10 September	NoCo-wissel
Friday 3 October	Barbaraborrel
Friday 7 November	Barbaraborrel

Graduation Subjects

Name	Date	Subject
Daan van Berkel	April 11, 2014	An insight in the mass balance and reserve reconciliation of salt caverns in the Hengelo brine field (RE).
Resource Engineering	(RE)	

Colophon

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