Disposal Problems and Recycling Possibilities of Drilling Cuttings

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Affidavit

I declare in lieu of oath, that I wrote this thesis myself, using only literature cited in this volume.

Eidesstattliche Erklärung

Ich erkläre hiermit an Eides statt, dass ich die vorliegende Arbeit eigenhändig angefertigt habe, lediglich unter Verwendung der zitierten Literatur.

Leoben, March 2011

Karin Hofstätter

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Abstract (English)

The reason for this thesis work was a recent change in European law which brought new limits for landfills. One of those limiting parameters for waste is the TOC (=total organic carbon) content in solids and eluates. Due to organic polymers the TOC of the mud (and therefore also of the cuttings) is often very high. This means that most cuttings are not disposable in surface dumpsites in Austria anymore. Thus, the scope of this thesis was to find a practical, economic and environmentally friendly solution for handling drilling waste, namely cuttings.

In the first part of the thesis an overview of the Austrian law concerning the deposition and recycling of drilling waste is given. It discusses the legal situation before and after November 2009 and explains in detail under which circumstances the drilled material is defined as *general waste*, *mining waste* or *side-product*. Then an estimate of the annual amount of problematic waste in Austria is given, introducing the term *waste factor* and considering different *waste categories*.

The next part shows the documentation and interpretation of sample investigations of cuttings that were drilled with either bentonite or K_2CO_3-polymer muds. This analysis was done in cooperation with the Austrian operator RAG. The result was that cuttings drilled with a pure bentonite mud system can be deposited in the lowest landfill category in Austria whereas cuttings drilled with a K_2CO_3-polymer mud system cannot be disposed in surface dumpsites in Austria. Furthermore, experiments with retain samples were made in order to see whether dehydration or neutralization and exposure to natural or artificial sunlight would cause a reduction in TOC content and make the cuttings disposable. Dehydration did not show any downward trend but sunlight experiments showed a decrease in TOC of 40-50% in solids and 10-20% in eluate content for both light sources. However, the initial TOC values were so high that there was no change in dump category. A side observation that was made during the analysis was the inaccuracy of the TOC measurement technique.

Following this, another quality check experiment was conducted and several sources of error were identified, and the question was raised whether the usual TOC measuring devices are suitable for analyzing drilled cuttings and mud.

As a next step possibilities for cuttings recycling compared to cuttings deposition were discussed and a comparison of cost was conducted for three scenarios (combustion, mining backfill in a salt cavern in Germany, and recycling in the cement industry) which showed that recycling is an economically viable solution that means potential cost savings. Furthermore, the importance of recovery and reuse of mud as well as increased solids control efficiency was highlighted.

The conclusions were to minimize waste volumes and increase solids control efficiency, to minimize the use of mud additives, and to realize different recycling possibilities in Austria. As a long-term approach the author recommends to invest in research for new mud systems and TOC reduction possibilities.

Abstract (German)

Der Grund für diese Arbeit war eine kürzliche Gesetzesänderung auf europäischer Ebene, die neue Grenzwerte für Deponien einführte. Einer dieser begrenzenden Parameter für Abfall ist der TOC Wert (total organic carbon = gesamter organischer Kohlenstoff), sowohl im Feststoff als auch im Eluat. Der TOC Wert in der Bohrspülung (und daher auch im Bohrklein) ist oft sehr hoch, weil organische Polymere als Spülungsadditive verwendet werden. Das bedeutet, dass der Großteil des Bohrkleins in Österreich nicht mehr deponierbar ist (zumindest nicht auf Obertagedeponien). Das Ziel dieser Arbeit war es daher eine praktische, ökonomische und umweltfreundliche Lösung für das anfallende Bohrklein zu finden.

Der erste Teil der Arbeit gibt einen Überblick über die österreichische Gesetzeslage betreffend Deponierung und Verwertung von Bohrklein. Die rechtliche Situation vor und nach November 2009 wird diskutiert und es wird erklärt unter welchen Umständen Bohrklein als allgemeiner „Abfall“, als „Bergbauabfall“ oder als „Nebenprodukt“ definiert wird. Des Weiteren werden die jährlich anfallenden Mengen an problematischem Abfall (Bohrklein) in Österreich abgeschätzt, der Begriff „Abfuhrfaktor“ eingeführt und die verschiedenen Deponieklassen betrachtet.

Das nächste Kapitel dokumentiert und interpretiert Analysen von Bohrkleinproben, die entweder mit Bentonitspülung oder K_2CO_3-Polymer-Spülung verunreinigt sind. Diese Analyse wurde in Zusammenarbeit mit der österreichischen Erdölfirma RAG gemacht. Das Ergebnis zeigte, dass das Bohrklein mit Bentonitspülung in der niedrigsten Deponieklasse in Österreich deponiert werden kann, wohingegen das Bohrklein mit K_2CO_3-Polymer-Spülung nicht auf Obertagedeponien in Österreich deponiert werden kann. In weiterer Folge wurden Experimente mit Rückstellproben gemacht um zu sehen, ob eine Trocknung bzw. eine Neutralisierung und Bestrahlung mit künstlichem oder natürlichem Sonnenlicht zu einer TOC Reduktion führt und das Bohrklein so deponier gemacht werden könnte. Die Trocknung zeigte zwar keine TOC Reduktion, die bestrahlten Proben zeigten jedoch einen TOC Rückgang von 40-50 % im Feststoff und 10-20% im Eluat für beide Lichtquellen (natürlich und künstlich).

Da die ursprünglichen TOC Werte jedoch so hoch waren, konnte keine Änderung der Deponieklasse erzielt werden. Weiters wurde während der Analysen beobachtet, dass es eine hohe Ungenauigkeit in der TOC Messung gibt. Infolgedessen wurde ein Qualitätskontrollexperiment durchgeführt und die möglichen Fehlerquellen identifiziert, sowie die Frage gestellt, ob die üblichen TOC Messgeräte überhaupt für die Analyse von Bohrklein geeignet sind.

Als weiterer Schritt wurden die Möglichkeiten zur Bohrkleinverwertung den Möglichkeiten der Deponierung gegenübergestellt und ein Kostenvergleich für drei Szenarien (Verbrennung, Bergwerksversatz in einer Salzkaverne in Deutschland, Verwertung in der Zementindustrie) erstellt, welcher zeigte, dass die Verwertung eine ökonomisch praktikable Lösung ist, die Kosteneinsparungspotential zeigt. Außerdem wurde festgestellt wie wichtig Spülungsrückgewinnung und –wiederverwendung und eine effektive Feststoffkontrolle sind.

Fazit und Empfehlung sind die Minimierung von Abfallvolumen und die Steigerung der Effektivität der Feststoffkontrolle, die Reduzierung des Einsatzes von Spülungsadditiven, und die Realisierung verschiedener Verwertungsschienen in Österreich. Als langfristiger Lösungsansatz empfiehlt die Autorin in Forschung nach neuen Spülungssystemen und TOC Reduktionsmöglichkeiten zu investieren.

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1. Introduction

1.1. Problem Description

The oil and gas industry in Europe is recently facing the problem of the deposition of drilling waste (mud and cuttings). Until June 2009, drill cuttings and mud were disposable in dumpsites after some minor treatment. Due to a change in European law (DepoVO 2008) this drilling waste is not disposable anymore for several reasons. First, the new law stated that it is not allowed to dispose liquid and muddy materials in surface dumpsites anymore, and second, the law set up new limits for dumpsites, which cannot be met with most of the drilled material. This means that most drilling waste is no longer disposable in surface dumpsites and thus many European oil and gas companies are eagerly searching for an environmentally friendly, as well as economic, solution to this problem. This especially counts when considering new developments like shale gas, which will bring a greater number of wells and thus will cause more drilling waste. Furthermore, the oil and gas industry in Europe expects further emphasis on Environmentally Friendly Drilling in the near future and is willing to look ‘outside the box’ (outside the industry) and is interested in opportunities for avoidance, minimization, treatment and recycling of waste, and even new drilling mud compositions.

1.2. Thesis Objectives & Scope of Work

Although the problem description shows that drilling waste management is a topic that affects all countries in Europe this master thesis will focus solely on Austria.

The oil and gas companies in Austria have difficulties to handle the drilling waste problematic as the recent changes in law leave some room for interpretation. A simple and explanatory overview of the applicable laws is needed. Thus, the first objective of this thesis is to give an **overview of the Austrian law concerning the deposition and recycling of drilling waste** and show which laws apply when, which limits must not be exceeded for the disposal of cuttings in surface dumpsites in Austria, and which laws/limits and/or requirements are important in order to be able to use cuttings as a secondary raw material either in our own industry or in other industries.

In order to get an idea of the annual amount of problematic waste in Austria and the corresponding waste categories, the second objective of the thesis is to give a **quantification and classification of drilling waste industry-wide in Austria.**

When drilling a well in Austria primarily a freshwater-bentonite mud system is used for the first section, and water based K_2CO_3-polymer mud systems are used for the following deeper sections. In cooperation with the Austrian oil and gas operator RAG **representative cutting and mud samples should be taken for both mud systems and analyzed according to the Austrian Landfill Regulation (= Deponieverordnung 2008)**. An interpretation of the results should show whether a deposition of those cuttings on surface dumpsites in Austria would be legally possible or not. It is to be expected that most cuttings will have a TOC (= total organic carbon) content that is above the limits for deposition. Thus, the following step **discusses the TOC problematic, gives reasons for the high TOC value and thinks of potential ways to reduce the TOC content in the cuttings and tries to make them disposable**. However, treatment steps are often costly and therefore it is necessary to consider economic efficiency as well.

As an alternative to cuttings deposition the **possibilities for cuttings recycling in Austria** will be assessed as well. For each recycling path the idea behind it including pros and cons, the applicable laws, the technical, environmental and social requirements, necessary quality control, pretreatment and implementation steps, possible risks and problems, and the current legal situation in Austria will be addressed. Where information is available, **the costs/ton of cuttings should be roughly estimated and compared to other available options.**

An **overview plot** will be provided which shows the different possibilities how to handle drilling waste according to the conventional hierarchy of waste management. This means: **waste avoidance over minimization over recycling over disposal**. In this context not only surface deposition and recycling, but also subsurface deposition **(e.g. mining backfill),** as well as the **challenges with developing new mud systems,** that would not cause such a high TOC content in the cuttings, will be discussed briefly. Furthermore, the **importance of recovery and reuse of mud, as well as increased solids control efficiency, will be highlighted**.

1.3. Literature Review: Previous & Ongoing Research

This chapter gives a brief overview of some interesting literature and current research projects (including projects from related fields of activity) that show potential solutions for waste management, sustainability, and recycling.

1.3.1 'The Waste-Free Drilling Concept'

"In 2004 the authors H. Hofstätter and J. Aigelsreiter had published a paper called 'The Waste-Free Drilling Concept' in which they showed that with a K_2CO_3-polymer mud system a full recycling of mud and drilled cuttings is possible.

The disadvantage of the formerly used potassium chloride mud system was that the chloride content was very high and thus the cuttings were also contaminated by chlorides which made recycling impossible and required proper and expensive disposal.

The reason why they had developed the waste free drilling concept was that RAG's remaining capacity of their own mud deposits was predicted to only last for three to five more years and they believed that it would be unlikely for RAG to get the legal permit to establish a new waste site in the environmentally sensitive area where they operate. The problem was that most of their concessions are in groundwater protection areas and those areas were likely to be expanded in future. Furthermore, tourism plays an important role in those concession areas and as tourism is economically important for Austria this would undoubtedly cause a lot of local resistance when it comes to the construction of waste sites.

Since 2000 RAG is working on the realization of the waste free drilling concept which aims in a step by step manner at: A) 100% of mud volume should be recycled and therefore be stored in intermediate storage facilities for further use in subsequent wells and B) 100% of the drilled cuttings should be recycled.

In the past 10 years RAG performed a number of lab tests and field trials and tried to legally work out and implement different ways of recycling on a small scale." (1) (2)

1.3.2 ‘Economic Optimization of Waste Accumulation in Drilling’

“In June 2006 the authors L. Holleis and S. Staber carried out a feasibility study for the Austrian oil and gas operator OMV to find out about the ‘Economic Optimization of Waste Accumulation in Drilling’. In their work they tried to make a Break-Even-Analysis and compare the economic suitability of different measures that could be undertaken to avoid, minimize, recycle, and treat drilling waste. They pointed out how important it is to have high solids control efficiency and prevent dilution of problematic waste as this has a direct impact on costs.” (3)

1.3.3 ‘Development of Agriculture on *Welser Heide* (Upper Austria)’

“According to an article written by D. Bogner and published in the ‘Catalogs of the State Museum of Upper Austria’ the so called Welser Heide was described as mainly barren land before the 18th century. In 1750, intensive agricultural activity started and therefore huge amounts of marl (=limey clay, main component of the Molasse in Austria) were brought from the North (from the area ‘Hausruck’) to the Welser Heide and distributed onto the barren land in order to enhance the soil properties. The process was as follows: The marl was dug out in chunks and due to sun and cold it became loose. It was then brought to farms where it was stored in pits, covered by dung piles, and manure was put onto it which was leaking through the marl/dung mixture. This way, the underlying marl was enriched with organic fertilizer and was then distributed onto the fields. The reclamation of the Welser Heide was an age-long process and is the reason why the land is fertile today.” (4)

1.3.4 ‘Recycling of Excavation Material from Tunneling’

“Since November 2008 a research project called ‘Recycling of Excavation Material from Tunneling‘ under the direction of DI Michael Pauser and Univ.-Prof. DI Dr.mont. Robert Galler investigates the recycling of excavation material from 11 planned future tunneling projects in Austria - considering different geologic areas in Austria and different tunneling techniques (e.g. blasting, drilling with bentonite mud, tunneling with different machines).

This current research project is based on a trial in Switzerland (Gotthard- and Lötschberg-Basistunnel) which had shown that up to 35 % of excavation material could be recycled and used as concrete aggregate (=Betonzuschlagstoff). Up to now, excavation material was mainly deposited or used as land fill material.

The advantages of recycling excavation material would be the reduction of dump volume and thus less cost for deposition and construction of additional dumpsites, as well as shorter routes of transport. However, the savings/profit must be contrasted with additional expenditure that may arise from e.g. the construction and operation of a material preparation plant.

The goals of the project are A) maximum recycling (Ideally, 100 % of the concrete needed for the tunneling process on the construction site should be made out of the excavation material; only cement should be added in addition. The rest of the excavation material should be used for recultivation and other recycling possibilities.), B) optimum economic efficiency, and C) minimization of environmental impact caused by material transport and necessary pre-processing for recycling.

The different recycling possibilities are mainly dependent on:

- *rock properties (grain size, grain shape, etc.)*
- *demand of mineral resources nearby the tunnel project*
- *other mining operations for consolidated and unconsolidated rock nearby*
- *the tunneling technique*
- *technical requirements for recycling*
- *economic efficiency of pretreatment steps*
- *distance of transport*
- CO_2 *balance.*

For the 11 planned future projects a total excavation volume of 12.7 MM m^3 *was calculated (no swell factor considered). Considering an average rock density of 2.5* t/m^3 *the total anticipated weight sums up to 31.7 MM tons. If it is assumed that 35 % can be recycled this means a resource of 11 MM tons. For comparison: Austria needs 100 MM tons of such mineral resources per year.*

Initial investigations had shown that for all projects the excavation material can be used as concrete aggregate, at least partially. Additional applications may be:

- *lime as resource in metallurgical industry, as filler material and in feed industry*
- *unconsolidated sediments as raw material for the brick making industry*
- *stone dust (powdered rock) for amelioration of agriculturally used soil/land*
- *mica for use in the color and paint industry.*

Grain shape and grain size have a major influence on green concrete properties as well as hardened concrete properties. Grain size and shape are dependent on properties of the rock as wells as the tunneling technique. E.g. fine material without preprocessing would mean a higher water requirement and this means a higher shrinkage of hardened concrete which in turn would require a greater amount of binding material to be added.

To avoid requirements for huge surface storage areas on site a continuous quality control is necessary. Therefore, on-site quick tests should be conducted in order to allocate material to a certain application. Additionally, a petrographical assessment will be accomplished on site.

The environmental impact of recycling will be assessed with the method of life cycle assessment, short LCA. The LCA will be done for the base case of deposition and will be compared to the different LCA outcomes of all other recycling possibilities. This will allow an evaluation of the different recycling possibilities." (5) (6)

1.3.5 'The Environmentally Friendly Drilling Systems Program'

"The objective of the EFD program is to identify, develop and transfer critical, cost effective, new technologies that can provide policy makers and industry with the ability to develop reserves in a safe and environmentally friendly manner. The program is managed by the Houston Advanced Research Center (HARC) and has been funded by the US Department of Energy, the Research Partnership to Secure Energy for America (RPSEA), and Industry. The EFD team includes academic institutions, national laboratories, research organizations and small businesses under the guidance of industry, environmental organizations and government agencies.

In 2010, the EFD program expanded to Europe as a means of 'identifying and applying best practices in Europe as well as to identify new innovations and applications'. The European chapter is under the direction of Univ.-Prof. Dipl.-Ing. Dr. mont. Gerhard Thonhauser of Austria's University of Leoben. Having both a US and a European EFD program enables all operators and regulators to learn about technologies being developed and implemented throughout the world.

The EFD has examined a variety of technologies ranging from site access to modular, low-impact rig technologies – the latter, including alternate power sources, integrated waste minimization and reduced emissions. The eventual aim of these studies is to devise wellsite pads much smaller than conventional locations and capable of drilling multiple wells from one location. That work, investigators envision, hopefully will extend to water-intensive and controversial hydraulic fracturing operations in the shale gas plays.

Recently, HARC developed the EFD scorecard which is currently in its testing phase and should help to assess drilling operations and technologies with respect to air, site, water, waste management, biodiversity and societal issues. The scorecard enables issues to be identified and measured so that they can be discussed and dealt with. Land owners, regulators, and the general public can use the scorecard to objectively assess operator's environmental performance. Operators, meanwhile, can evaluate their own operations and compare them with industry best management practices.

Thomas Williams, managing director of Houston's Nautilus International and one of the creators of the EFD initiative said: 'The EFD scorecard will get employees and senior management on the same page so they all understand the benefits. With this, we can spell out that there are some things we can do to reduce the environmental footprint, an in the end it will be cost-effective, and at the end of the day we can all reward ourselves for doing the right thing.' " (26) (27)

Author's comment: In the meanwhile, the Drilling and Completion Chair of the University of Leoben has established its own EFD workgroup under the supervision of *Univ.-Prof. Dipl.-Ing. Dr. mont. Gerhard Thonhauser*. This thesis at hand evolved in the course of such an EFD project.

2. Status Quo: Drilling Waste in Austria

2.1. Explanation of the Term 'Drilling Waste'

In this thesis the term *drilling waste* only refers to flocculated material, cuttings and non-recyclable mud which are produced as a result of the actual drilling progress. All other kinds of waste that accumulate on a rig site during drilling a well (e.g. domestic waste, garbage from workshops and repair jobs, broken machines, packaging, etc.) were not considered in this thesis and therefore are excluded.

2.2. Applicable Laws for Drilling Waste in Austria

2.2.1 European Laws

2.2.1.1 General Remarks and Explanations

The European Union sets up (framework) directives which are guidelines for the national laws. Those (framework) directives do not include any specific information, e.g. limits. For such information it is required to refer to national laws.

According to the internet source Wikipedia, **directives** are explained as follows:

*"A **directive** is a legislative act of the European Union, which requires member states to achieve a particular result without dictating the means of achieving that result. It can be distinguished from regulations which are self-executing and do not require any implementing measures. Directives normally leave member states with a certain amount of leeway as to the exact rules to be adopted. When adopted, directives give member states a timetable for the implementation of the intended outcome. Occasionally the laws of a member state may already comply with this outcome and the state involved would only be required to keep their laws in place. But more commonly member states are required to make changes to their laws (commonly referred to as transposition) in order for the directive to be implemented correctly."* (9)

*"A **framework directive** establishes a framework or template for subsequent legislation in an area."* (10)

2.2.1.2 The Mining Waste Directive (Bergbauabfall-RL 2006/21/EG)

The goals of this directive are: enhancement of safety and environmental protection standards by reducing the hazardousness and amount of mining waste, prioritizing recycling, treatment of mining waste near the place of generation, and safe disposal.(11) The Mining Waste Directive was fully implemented in the Austrian MinroG.(11)

2.2.1.3 The Waste Framework Directive (Abfall-RRL 2008/98/EG)

The goals of this directive are: establishing a recycling society, decoupling of waste generation from economic growth, reduction of waste volumes as well as enhancement of recycling and reuse rates, creation of a modern waste management, and clearness and simplification in law-making.(12) It has to be mentioned that *mining waste* IS NOT within the scope of the Waste Framework Directive (because there is already a separate Mining Waste Directive existing at EU level).(12) On the other hand, material that accumulated directly in the course of a mining activity may not always be defined as *mining waste*; in certain circumstances it may be general *waste* and then the Waste Framework Directive would still be valid (see Figure 1). However, many directives and regulations refer to the definitions in the Waste Framework Directive for the explanation of terms like *waste, hazardous waste, treatment, recovery, end of waste, product, side-product, re-use, recycling, disposal, ban on the mixing/diluting of hazardous waste, waste management/prevention plans*, etc.

*“ **waste** means any substance or object which the holder discards, or intends to, or is required to discard” (19)*

*“ **hazardous waste** means waste which displays one or more of the hazardous properties listed in Annex III of the Waste Framework Directive” (19)*

*“ The **reclassification of hazardous waste as non-hazardous waste** may not be achieved by diluting or mixing the waste with the aim of lowering the initial concentrations of hazardous substances to a level below the thresholds for defining waste as hazardous.” (19)*

*“ **re-use** means any operation by which products or components that are not waste are used again for the same purpose for which they were conceived” (19)*

*“ **treatment** means recovery or disposal operations, including preparation prior to recovery or disposal”* (19)

*“ **recovery** means any operation with the result that waste is serving a useful purpose by replacing other materials which would otherwise have been used to fulfill a particular function, or waste is being prepared to fulfill that function, in the plant or in the wider economy. Annex II of the Waste Framework Directive sets out a non-exhaustive list of recovery operations”* (19)

*“ **preparing for re-use** means checking, cleaning or repairing recovery operations, by which products or components of products that have become waste are prepared so that they can be re-used without any other pre-processing”* (19)

*“ **recycling** means any recovery operation by which waste materials are reprocessed into products, materials or substances whether for the original or other purposes. It includes the reprocessing of organic material but does not include energy recovery and the reprocessing into materials that are to be used as fuels or for backfilling operations”* (19)

*“ **disposal** means any operation which is not recovery even where the operation has as a secondary consequence the reclamation of substances or energy. Annex I of the Waste Framework Directive sets out a non-exhaustive list of disposal operations”* (19)

*“ A **side-product** is a substance or object, resulting from a production process, the primary aim of which is not the production of that item, may be regarded as not being waste referred to in point (1) of Article 3 of the Waste Framework Directive but as being a by-product only if the following conditions are met: (a) further use of the substance or object is certain; (b) the substance or object can be used directly without any further processing other than normal industrial practice; (c) the substance or object is produced as an integral part of a production process; and (d) further use is lawful, i.e. the substance or object fulfils all relevant product, environmental and health protection requirements for the specific use and will not lead to overall adverse environmental or human health impacts.”* (19)

*“ **end-of-waste status**: Certain specified waste shall cease to be waste within the meaning of point (1) of Article 3 of the Waste Framework Directive when it has undergone a recovery operation, including recycling, and complies with specific criteria to be developed in accordance with the following conditions: (a) the substance or object is commonly used for specific purposes; (b) a market or demand exists for such a substance or object; (c) the substance or object fulfills the technical requirements for the specific purposes and meets the existing legislation and standards applicable to products; and (d) the use of the substance or object will not lead to overall adverse environmental or human health impacts.”* (19)

2.2.2 National Laws before November 2009

2.2.2.1 Overview

Before November 2009 all aspects concerning drilling waste in Austria were regulated in the **General Waste Management Law (Abfallwirtschaftsgesetz, AWG)** and in the **Law Concerning Cleanup Operations (Altlastensanierungsgesetz, ALSAG)**. The only exemption was uncontaminated rock. But when using a mud system for drilling there is always some sort of contamination; so this exemption was not valid for drilled cuttings. The two ways of handling drilling waste were either deposition or recycling.

2.2.2.2 Scenario 1: Deposition of Drilling Waste according to AWG

According to the AWG drilled cuttings and mud were defined as *waste* as soon as the owner wanted to dispose the material or if its accumulation, storage, transportation and treatment as *waste* was necessary to protect public interest.(18) This was true for both the deposition of cuttings and mud on a landfill which belonged to the mining business itself or the deposition on an external landfill.

For both cases the waste owner was charged a fee according to ALSAG. This fee could be between 7 Euro and 87 Euro per ton of waste depending on the type of waste.(20) Exemptions: No ALSAG fee must be paid for uncontaminated rock/soil or for mud and liquid residues which accumulate in the course of a mining activity AND which are reinjected into the original formations.(20)

Furthermore, for *waste* according to AWG all other regulations that have their legal foundation in the AWG needed to be followed as well. For dumping drilling waste the applicable regulations were: the **Waste Catalog Regulation (Abfallverzeichnis-VO)**, the **Waste Documentation and Tracking Regulation (Abfallnachweis-VO)**, the **Annual Waste Balance Regulation (Jahresabfallbilanz-VO)**, and the **Landfill Regulation (Deponie-VO)**. Additionally, the **Federal Waste Management Plan (Bundes-Abfallwirtschaftsplan, BAWP)** needed to be considered as well. Note: The BAWP is published in 5 year intervals and shows how EU programs are realized and how effective those implemented measures are.(21) It presents best available technologies, which are necessary in order to protect public interest.(18, 21)

a. **New Landfill Regulation (Deponie-VO 2008)**

On 1st March 2008 the New Landfill Regulation became effective.(14) The transition period ended on 1st July 2009.(14) The essential changes concerning drilling waste were the following:

- For the categorization of waste (category of landfill) the total content of harmful substances as well as the eluate content needs to be determined.(14) Especially the TOC content in the eluate is a new limiting parameter; so far the focus was only on the TOC content of solids.
- New categories of landfill were introduced with comprehensive lists of limiting parameters for each category.(14) In Table 1 the Austrian categories of landfill (and their English translation) as well as the associated TOC limits are shown.
- The dilution and mixing of waste is not allowed if the acceptance criteria of a certain category of landfill can only be met by such a mixing or dilution action.(13)
- Waste with a TOC content of solids >5 % and a TOC content in the eluate >2500 mg/kg dry matter must not be deposited in surface dumpsites anymore.(13)

- The dumping of liquid, muddy or fine-grained materials is not allowed if the functioning of the drainage system is affected or if the stability of the landfill body is not guaranteed.(13)

Table 1: Categories of Landfill and Associated TOC Limits(13)(14)

Deponieklasse		Category of Landfill	TOC Limit for Solids	TOC Limit for Eluate
			[mg/kg dry matter]	
1	Bodenaushubdeponie	Excavation soil landfill	90,000	200
2	Inertabfalldeponie	Inert waste landfill	30,000	500
3	Deponie für nicht gefährliche Abfälle	Landfill for nonhazardous waste		
3a	Baurestmassendeponie	Demolition & construction waste landfill	30,000	500
3b	Reststoffdeponie	Residual substance landfill	50,000	500
3c	Massenabfalldeponie	Mass waste landfill	50,000	2,500
4	Deponie für gefährliche Abfälle (nur als Untertagedeponie)	Landfill for hazardous waste (only subsurface landfill)	If the limits above cannot be met, a subsurface deposition may be possible in Germany (but: export license needed)	

So, after July 2009 the problem concerning drilling waste can be defined as follows: All landfills – even the ones that are belonging to the mining business itself (company internal landfills) – were granted under AWG and thus must comply with the New Landfill Regulation and its new limits. So essentially, most drilling waste could not be deposited on surface dumpsites in Austria anymore as the TOC content of the eluate was often above the limit for the highest landfill category. An alternative solution was needed. The oil and gas companies in Austria thought of the following possibilities:

1. Drilling waste export and subsurface deposition on a landfill for hazardous waste in Germany
2. Combustion of drilling waste
3. Find a cost efficient way (some sort of treatment) to reduce the TOC content in the drilling waste in order to make the material disposable on surface dumpsites in Austria
4. Avoid such a high TOC content in the cuttings by finding an alternative mud system that does not cause such a high TOC
5. Cuttings reinjection
6. Recycling of drilling waste

The different solution approaches and their pros and cons are discussed in more detail in Chapter 4 but in essence the following can be summarized: Approach 1 would be possible but should not be a long-term solution. Approach 2 would be very expensive. Solutions 3 and 4 would need further investigations as simple preliminary experiments were without great success. Solution Approach 5 has never been tried in Austria before. So, at this stage the most promising solution for Austria seemed to be cuttings recycling.

2.2.2.3 Scenario 2: Recycling of Drilling Waste

In accordance with EU law the AWG states that recycling would mean the end of waste characteristic. The exact wording according to AWG is:

"As long as no other regulation says something else, existing substances are defined as waste until they are (as a whole or only certain substances of it) directly used as a substitution for raw materials or used for products that are made out of primary raw materials."(18)

This meant that if a material was not defined as *waste* any longer, the AWG and its associated regulations would not apply. Furthermore, for something that was not considered waste, no ALSAG fee must be paid.

On the other hand, when it comes to recycling, other limits (= technical limits defined by the companies that are willing to recycle the material), and other laws (=laws applicable to the special industries in which the material is used), need to be followed. For more information on recycling see Chapter 4.3.

Authors comment: Besides finding an alternative solution to cuttings deposition, the oil and gas industry in Austria was also trying to get in touch with the responsible legislative institutions, and was discussing and questioning the new TOC limits that were hitting the Mining Industry when the new Landfill Regulation became effective. Subsequently, a task group was initiated including representatives of the Federal Government and of different professional associations of the Mining Industry. Together they tried to work out a viable solution for the Mining Industry in Austria and consequently some new national laws were implemented. See next Chapter 2.2.3.

2.2.3 National Laws after November 2009

2.2.3.1 Overview

In order to summarize the current legal situation regarding drilling waste in Austria, the following laws must be considered:

- **BBA-G**
- **BBA-VO**
- **MinroG**
- **AWG**

The **Guideline for Mining Waste** helps with the interpretation.

In November 2009 there was an amendment of the **Mineral Resources Law (Mineralrohstoffgesetz, MinroG)** and an amendment of the **General Waste Management Law (Abfallwirtschaftsgesetz, AWG).** The main statement of those changes was that all waste that is directly related to the drilling activity (no matter if rocks, mud, cuttings, flocculated material, surface soil, stone dust, humus, excavation material, fines, …) is now regulated in the new **Mining Waste Law (Bergbauabfallgesetz, BBA-G)** which became effective on 18th November 2009. The exact wording was as follows:

"The new BBA-G changes the AWG as follows: The AWG is not valid for waste that accumulates directly from exploration, production, processing and storage of mineral raw materials (=mining waste), as long as those activities are subject to the MinroG and as long as this waste is used or stored within the mining business; if waste cannot be referred back to those activities, it is not defined as mining waste." (25)

Before that amendment the exemption from the AWG was only for uncontaminated rock. Now the exemption is also valid for cuttings, mud, etc.

Moreover, the new BBA-G demands the establishment of a *waste management plan* (2.2.3.5) and focuses on regulations for *waste disposal facilities* (2.2.3.6) concerning approval requirements, safety issues, and public involvement in approval procedures.

A few months later, on 1st May 2010 the new **Mining Waste Regulation (Bergbauabfallverordnung, BBA-VO)** came into effect. It contains supplementary instructions to the BBA-G and regulates the following:

a. The construction and operation of waste disposal facilities

b. Protective measures for backfilling excavation voids with waste material

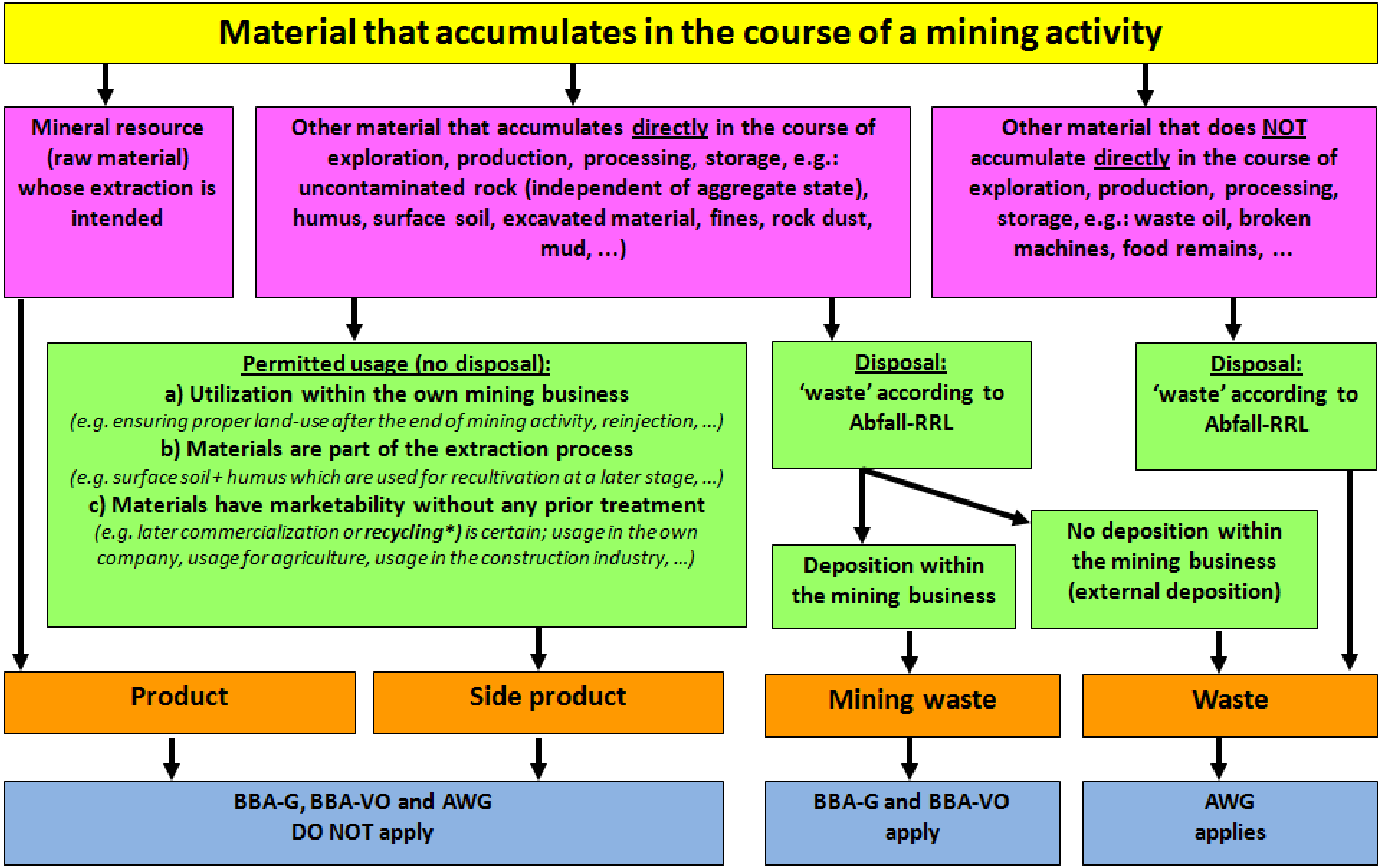
c. Safety management

d. Emergency plans (internal and external) and how to inform the public in case of emergency

e. The realization concerning the new classification of waste disposal facilities, inert waste, and the characterization of waste.

Then, in December 2010 the **Guideline for Mining Waste (Leitfaden Bergbauabfall)** was published upon approval by the Austrian Mining Authority (Montanbehörde). This Guideline should assist in interpreting and easier usage of the BBA-G and BBA-VO. It was developed together with the professional associations of the petroleum industry, stone and ceramic industry, mining and steel industry, and the federal guild for construction-related trade. It is to be mentioned that the Guideline for Mining Waste has no legal obligation.(11)

Figure 1 shows a decision tree (translated from the Guideline for Mining Waste), which should help to determine in which cases drilled cuttings are defined as general *waste*, as *mining waste* or as *side-product* and should show which laws apply when. For more detailed information on this differentiation please refer to the following three scenarios (Chapters 2.2.3.2, 2.2.3.3, and 2.2.3.4).



*) *__recycling__: If mineral resources (raw materials) and/or side products are stored for later use, then they are NO (mining) waste. This is true also if they are stored for longer than the time limits mentioned in § 119a MinroG.*

Figure 1: Decision Tree for Material that Accumulated in the Course of a Mining Activity (11)

2.2.3.2 *Scenario 1: Deposition of Drilling Waste according to AWG 'Waste')* (11)

Materials or residues are defined as *waste* according to AWG if

- they are related to a mining activity but are NOT DIRECTLY accumulating in the course of exploration, production, processing or storage and if they should be disposed of (e.g. waste oil, broken machines, food remains,…) or
- they are DIRECTLY related to a mining activity but should be *disposed outside the mining business* and dumped according to the AWG & the Landfill Regulation.

For those cases the AWG and its associated regulations (including the New Landfill Regulation and its TOC and other limits) apply and the ALSAG fee must be paid.

2.2.3.3 *Scenario 2: Deposition of Drilling Waste according BBA-G ('Mining Waste')* (11)

Whether something is *mining waste,* or not, has to be determined in two steps:

1. *Is it waste according to the EU Waste Framework Directive?*

   This can be answered with "Yes", if there is an intention to dispose the material (= subjective waste definition) or if the collection, storage, transport and treatment as waste (=objective waste definition) is necessary in order to protect public interest.

2. *Is it waste that accumulated DIRECTLY in the course of exploration, production, processing or storage according to MinroG?*

   Please note: the construction of mining streets, ramps, mining stockpiles - even if outside of the immediate mining area - are included here.

If both questions are answered with "Yes", the MinroG (BBA-G) and the BBA-VO apply. The AWG and its associated regulations, do not apply (this means that the New Landfill Regulation with its TOC & other limits does not apply) and no ALSAG fee must be paid.

If the answer to the first question is "Yes" but to the second question is "No", then it is defined as general *waste* (see 2.2.3.2).

If *mining waste* is present it needs to be characterized according to § 4 Z 1 BBA-VO as the waste properties determine the *type of mining waste* (see Figure 2) and define whether the waste is privileged (which means that simplifications and exemptions from the legal requirements can be granted) or not. *Hazardous waste* cannot be privileged.

Author’s comment: Please note that cuttings with a very high TOC content fall under the category *hazardous waste*.

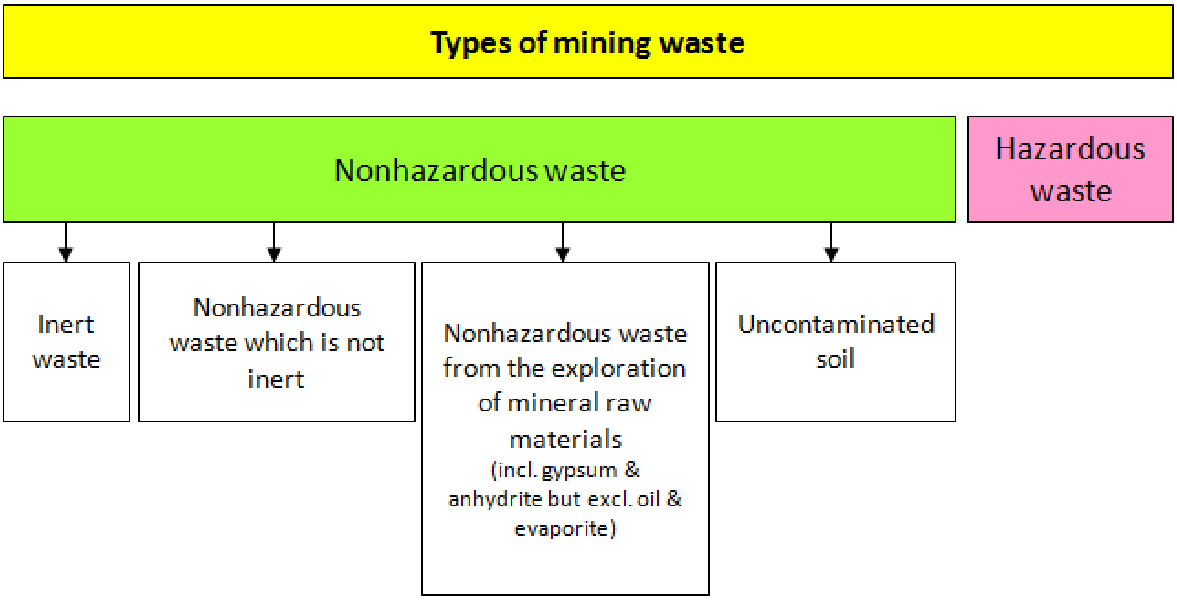


Figure 2: Different Types of Mining Waste (11)

2.2.3.4 Scenario 3: Recycling of Drilling Waste (‘Side-Product’)

For the existence of *side-products* the following criteria must be met: (11)

1. The further use of the material is certain as e.g. a market exists for it.
2. The material can be used directly without any further treatment that exceeds the usual industrial practices.
3. The material is specifically generated as an integral part of a production process.
4. The further use of the material is permitted; the material/substance is harmless for the meaningful purpose; no protected property is affected and the procedure complies with all relevant laws.

In the case of a product, or side-product, the BBA-G, BBA-VO and AWG (incl. the New Landfill Regulation with its TOC and other limits) do not apply and no ALSAG fees must be paid. Furthermore, according to the AWG, and in accordance with EU law, *recycling means the end of waste characteristic* and thus all laws applicable to wastes would not be relevant any more.

But on the other hand, when it comes to recycling, other limits (= technical limits defined by the companies that are willing to recycle the material), and other laws (=laws applicable to the special industries in which the material is used) need to be followed. For more information on recycling see Chapter 4.3.

2.2.3.5 The Waste Management Plan (11)

In the absence of 'mining waste':

A notification to the authority is required which should explain why NO *mining waste* will accrue and thus no waste management plan will be required. E.g. an example for such a notice could be:

"The material that accumulates from mining and production does not require waste management measures as these are mineral materials which are legitimately used for backfilling and construction (recultivation) or used as side-products without any prior processing."(11)

In the presence of 'mining waste':

In this case the creation of a *waste management plan* for the minimization, treatment, recycling and disposal of mining waste is mandatory.

The *waste management plan* should include considerations about the amount of mining waste that will accumulate; its properties and conditions; best practices for a safe waste management; and precautionary measures that are taken to avoid negative effects on the environment (water, soil, flora, fauna) and the health of human beings during the whole life cycle of the facility, and especially after abandonment.

The waste management plan is therefore a requirement for the approval and startup of a *waste facility according to MinroG.*

The *waste management plan* is not subject to approval but must be presented to the authority at least two weeks before starting the operation. The *waste management plan* must be checked and if necessary revised every 5 years. Changes to the plan must be notified to the authority. For more information about the content of the waste management plan see MinroG and BBA-VO.

2.2.3.6 Waste Facilities, Transitional Provisions & the Backfilling of Excavation Voids (11)

Waste Facilities

"*Waste facilities according to § 119a MinroG are facilities for collecting or storing certain mining waste which can be solid, liquid, dissolved or in suspension and which furthermore fulfills the time periods for storage mentioned in Figure 3.*"

These waste facilities can be surface or subsurface waste facilities whereby both are subject to approval according to §119a MinroG.

The categorization of waste facilities depends on its associated risk. Thus a distinction is made between a *Waste Facility* and a *Waste Facility of Category A* (Figure 3).

If *mining waste* has a shorter storage time than mentioned in Figure 3 then the regulations for waste facilities (§ 114 Abs. 2, 119a und 119b MinroG) do not apply.

If mineral *raw materials* or *side-products* are stored intermediately for later usage, then they are neither defined as *mining waste* nor as *waste* according to AWG and thus the regulations for waste facilities are not applicable. This is also true if the intermediate storage is for longer than the intervals mentioned in §119a MinroG (Figure 3), given that recycling is certain.

Waste Facilities of Category A

This facility contains *hazardous waste* as defined in Annex III of the Mining Waste Directive (Bergbauabfall-RL) and as defined in the commission's decision 2009/337/EG. For a waste facility of Category A special regulations apply concerning:

- Financial security (acc. to § 119a MinroG)
- The prevention of accidents and spreading information (acc. to § 119b MinroG provided that the Seveso II regime does not apply)
- Requirements for its construction and operation (acc. to § 5 BBA-VO).

If the mining operator is not sure whether his waste facility is Category A or not, he has to file a petition to the BMWFJ, which then will decide about it upon notification.

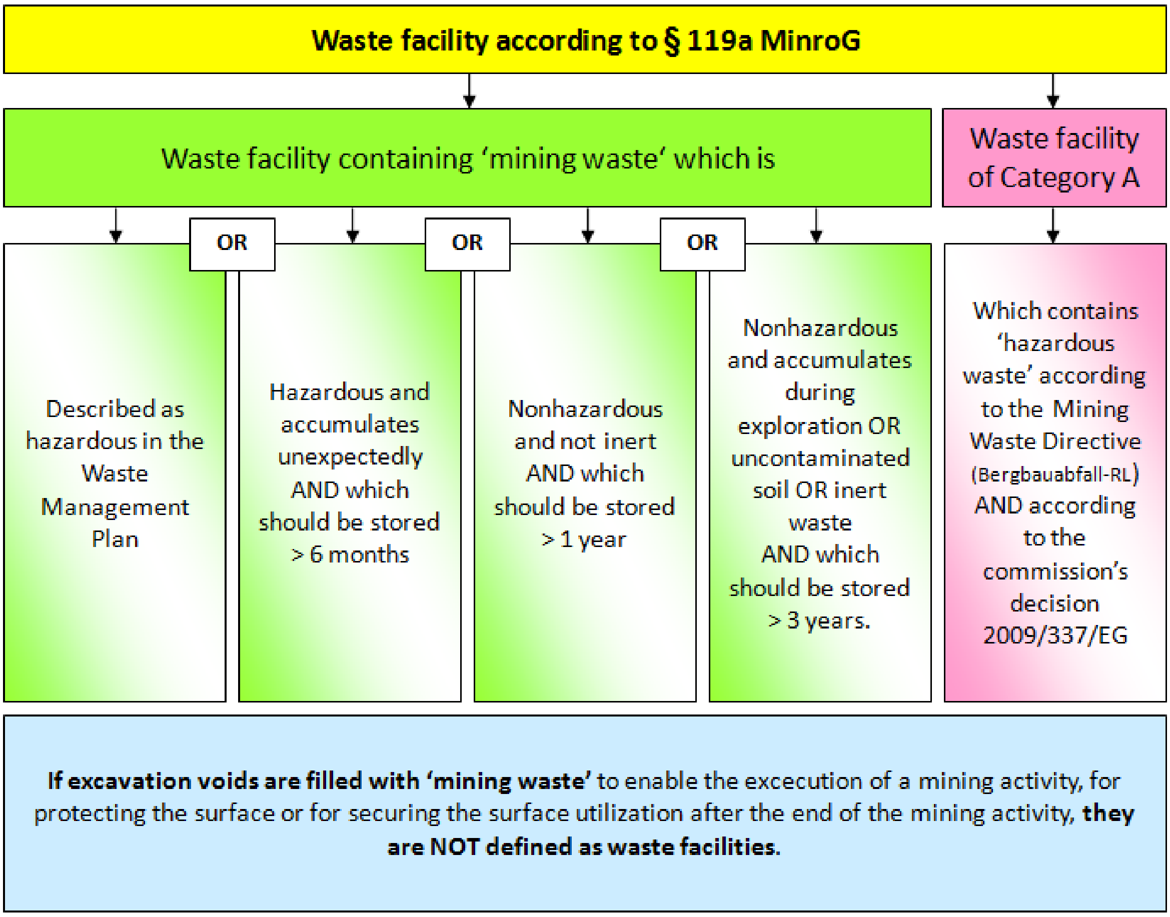


Figure 3: Different Types of Waste Facilities according to § 119a MinroG (11)

Transitional Provisions for Existing Waste Facilities

Existing waste facilities (according to § 223 Abs 17 MinroG), which are approved or in operation on 18th November 2009 have to comply with the regulations for waste facilities until 1st May 2012 at the latest. The regulations concerning financial security must only be met on 1st May 2014 at the latest.

Author’s comment: If the currently existing waste facilities, that are granted under AWG, and owned by oil and gas operating companies in Austria, were transferred into waste facilities according to MinroG, then these facilities would be of Category A.

Backfilling of Excavation Voids

As already mentioned at the bottom of Figure 3: if *excavation voids* are filled with *mining waste* to enable the excecution of a mining activity, for protecting the surface or for securing the surface utilization after the end of the mining activity, they are NOT defined as waste facilities (MinroG § 119a).

> Author’s comment: If material from mining is meant for recultivation or backfilling from the beginning then the **Regulations for Backfilling Excavation Voids** are not applicable because in this case the material is by definition not *mining waste* (it is a *side-product*). The Regulations for Backfilling Excavation Voids are only relevant, if there was an intention for discharge at first and thus the waste characteristic was fulfilled, but later the decision for recycling (e.g. recultivation) was made.

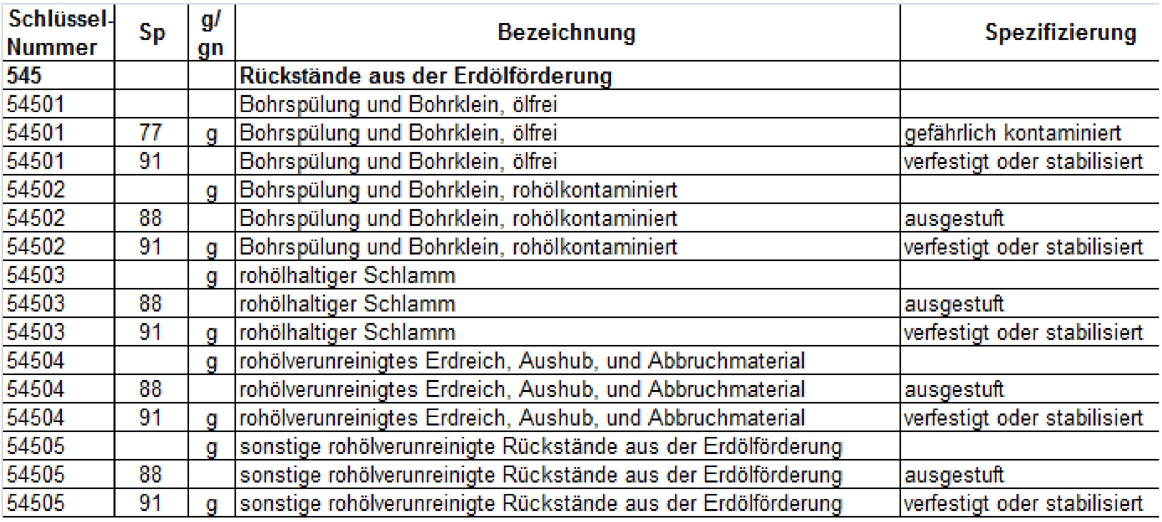
Excavation voids include voids from surface mining and voids from underground mining (e.g. from exploration, production, storage and processing). Also voids that develop due to the converging of a natural terrain and a mining activity are included. This incorporates also measures for increasing the hydrocarbon yield, and the construction and maintenance of access roads, delivery ramps, dividing walls, safety barriers, and slopes.

If *excavation voids* are backfilled with *mining waste,* measures for the stabilization of waste, for the prevention of surface- and groundwater pollution, and for monitoring (which includes regular measurements, cleaning and maintenance, and reporting to authority) must be undertaken.

2.3. Drilling Waste Categories in Austria

The **Waste Catalog Regulation (Abfallverzeichnis-VO)** was amended in 2008 (BGBl. II Nr. 498/2008). The main content of this amendment was, that Austria decided to neglect the **European Waste Catalog**.(17) Austria's waste categories refer to the Austrian standard **ÖNORM S 2100**.

Table 2: Austrian Waste Catalog for Residues from Oil Production according to ÖNORM S 2100 (GERMAN)(15)



Schlüssel-Nummer	Sp	g/ gn	Bezeichnung	Spezifizierung
545			**Rückstände aus der Erdölförderung**	
54501			Bohrspülung und Bohrklein, ölfrei	
54501	77	g	Bohrspülung und Bohrklein, ölfrei	gefährlich kontaminiert
54501	91		Bohrspülung und Bohrklein, ölfrei	verfestigt oder stabilisiert
54502		g	Bohrspülung und Bohrklein, rohölkontaminiert	
54502	88		Bohrspülung und Bohrklein, rohölkontaminiert	ausgestuft
54502	91	g	Bohrspülung und Bohrklein, rohölkontaminiert	verfestigt oder stabilisiert
54503		g	rohölhaltiger Schlamm	
54503	88		rohölhaltiger Schlamm	ausgestuft
54503	91	g	rohölhaltiger Schlamm	verfestigt oder stabilisiert
54504		g	rohölverunreinigtes Erdreich, Aushub, und Abbruchmaterial	
54504	88		rohölverunreinigtes Erdreich, Aushub, und Abbruchmaterial	ausgestuft
54504	91	g	rohölverunreinigtes Erdreich, Aushub, und Abbruchmaterial	verfestigt oder stabilisiert
54505		g	sonstige rohölverunreinigte Rückstände aus der Erdölförderung	
54505	88		sonstige rohölverunreinigte Rückstände aus der Erdölförderung	ausgestuft
54505	91	g	sonstige rohölverunreinigte Rückstände aus der Erdölförderung	verfestigt oder stabilisiert

Table 3: Austrian Waste Catalog for Residues from Oil Production according to ÖNORM S 2100 (ENGLISH translation)(15)

545			**Residues from oil production**
54501			**Drilling mud and cuttings, oil-free**
	77	**g**	
	91		
54502		**g**	**Drilling mud and cuttings, crude oil contaminated**
	88		
	91	**g**	
54503		**g**	**Slurry containing crude oil**
	88		
	91	**g**	
54504		**g**	**Crude oil contaminated soil, excavated material, and mining material**
	88		
	91	**g**	
54505		**g**	**Other crude oil contaminated residues from oil production**
	88		
	91	**g**	

Explanation of Codes:

g … hazardous waste *88 … reclassified*

77 … dangerously contaminated *91 … compacted or stabilized*

Table 2 and Table 3 show the drilling waste categories in Austria. Marked in yellow is the category which is considered in this master thesis for disposal and recycling. It is called 'drilling mud and cuttings, oil-free'. All other categories are somehow contaminated by crude oil. Each main category can have additional codes, e.g.: 77 means *dangerously contaminated*, 88 means *reclassified*, 91 means *compacted or stabilized* and the letter g means *hazardous waste*.

> *"A '**reclassification'** means that a hazardous waste is defined as non-hazardous. This can only happen if a request for reclassification (of a certain amount of waste or a consistent type of waste from a certain process) together with the proof of non-hazardousness (must be verified by an external authorized expert), is sent to the Federal Ministry of Agriculture, Forestry, Environment and Water Management (BMLFUW). The BMLFUW then - as a countermove - reconfirms (=reclassifies) the non-hazardousness."*(18)

The Austrian waste categories do not yet conform to EU standard, with the only difference that the names and numbers of the categories are not the same. Table 4 shows the EU compliant waste code numbers and designations taken from German legislation.

Table 4: European Waste Codes and Designations for Drilling Mud and other Drilling Wastes(16)

01 05	Bohrschlämme und andere Bohrabfälle	Drilling mud and other drilling wastes
01 05 04	**Schlämme und Abfälle aus Süßwasserbohrungen**	**Mud and waste from sweet water wells**
01 05 05 *	**Ölhaltige Bohrschlämme und –abfälle**	**Oil containing drilling mud and drilling wastes**
01 05 06 *	**Bohrschlämme und andere Bohrabfälle, die gefährliche Stoffe enthalten**	**Drilling mud and other drilling wastes containing hazardous substances**
01 05 07	**Barythaltige Bohrschlämme und -abfälle mit Ausnahme derjenigen, die unter 01 05 05 und 01 05 06 fallen**	**Barite-containing drilling mud and drilling wastes other than those mentioned in 01 05 05 and 01 05 06**
01 05 08	**Chloridhaltige Bohrschlämme und -abfälle mit Ausnahme derjenigen, die unter 01 05 05 und 01 05 06 fallen**	**Chloride-containing drilling mud and drilling wastes other than those mentioned in 01 05 05 and 01 05 06**
01 05 99	**Abfälle anderweitig nicht genannt**	**Wastes otherwise not mentioned**
** bedeutet gefährlicher Abfall*		** means hazardous waste*

The following information was provided from the Austrian *Lebensministerium* (Abteilung VI/3 Abfallbehandlung und Altlastensanierung, DI Mathilde Danzer):

"The first year for reporting annual waste balance sheets to the BMLFUW is the year 2010. The deadline for handing in the reports is the 15th March 2011. Thus, the waste balance sheets are neither complete nor comprehensive, yet."

"No waste was deposited under the waste code 54501 and 54502 in the previous years. The waste amounts defined as 54503 88 and 54504 88 are varying significantly each year. The amounts of hazardous waste are comparatively small."

Author's Comment: Please note that a mining company only needs to report annual waste balances if its material is defined as 'waste' according to AWG. Only then the **Annual Waste Balance Regulation (Jahresabfallbilanz-VO)** applies. So, to get an idea about the annual drilling waste volumes in Austria one cannot count on the annual reports which are handed in to the BMLFUW. Instead, the annual drilling waste volume is estimated with the calculations shown in Chapters 2.4 and 2.5.

2.4. Case Studies: Actual vs. Theoretical Waste Volumes

2.4.1 Explanation of the Term 'Waste Factor'

In Chapter 2.4 several example wells were investigated and the actual waste volumes were compared to theoretically calculated waste volumes. (Please note that the actual borehole geometry was not taken into account.) From this, a so called *waste factor* could be generated which was then used in Chapter 2.5 for projecting the annual amount of drilling waste in Austria for the years 2008 and 2009. The *waste factor* accounts for:

- Possible hole enlargement
- Crushing and decompacting the rock
  (=*swell factor* due to the cutting action of the bit)
- Adhering liquids like mud, water, and flocculants.

2.4.2 Storage and Production Wells (Austria)

Four example wells from the two Austrian Oil and Gas Operators (OMV and RAG) were taken and analyzed and a *waste factor* was obtained in each case.

For Example Well 1 and 2 waste water and contaminated mud were not gathered separately and are therefore included in the given data. The density of the cuttings that was used to calculate the theoretical hole volume was 2,300 kg/m³ = 2.3 t/m³. The first well showed an overall *waste factor* of 3.1, the second well a *factor* of 3.0. Both wells were over 3,300 meters long and had 3 sections whereof the first section was drilled with bentonite mud and the 2nd and 3rd section with potassium carbonate polymer mud. Generally, the *waste factor* increases with depth as the cuttings become finer and more mud adheres; also, the finer the cuttings the more flocculation is required, which again increases the waste volume.

Table 5: Waste Factor Calculation for Example Well 1 (Waste Water and Contaminated Mud Included)

OH diameter [in]	OH radius [m]	Length of section [m]	Theoretical weight [t]	Actual weight [t]	Factor	Mud system
17 ½	0.22225	375	134	446	3.3	Bentonite
12 ¼	0.15558	1,575	275	760	2.8	K2CO3 Polymer
8 ½	0.10795	1,430	120	405	3.4	K2CO3 Polymer
		3,380	***530***	***1,611***	***3.0***	

Table 6: Waste Factor Calculation for Example Well 2 (Waste Water and Contaminated Mud Included)

OH diameter [in]	OH radius [m]	Length of section [m]	Theoretical weight [t]	Actual weight [t]	Factor	Mud system
17 ½	0.22225	401	143	360	2.5	Bentonite
12 ¼	0.15558	1,249	218	593	2.7	K2CO3 Polymer
8 ½	0.10795	1,653	139	623	4.5	K2CO3 Polymer
		3,303	***501***	***1,576***	***3.1***	

The data in the next two tables (Example Well 3 and 4) excludes waste water and contaminated mud and therefore gives smaller *waste factors*. However, in order to make those wells comparable to the previous ones, the amount of waste water and contaminated mud was included in an additional calculation and a new overall *waste factor* was calculated which gave 2.6 for the first case and 2.9 for the second case. The *waste factor* increases with depth, which can also be seen here. The density of the cuttings was again assumed to be 2,300 kg/m³ = 2.3 t/m³.

Example Well 3 had only two sections and a total depth of ~2,200 meters and was drilled with bentonite and potassium carbonate polymer mud. Example Well 4 had three sections and was drilled with bentonite and potassium chloride polymer mud.

Table 7: Waste Factor Calculation for Example Well 3 (Waste Water and Contaminated Mud Excluded)

OH diameter [in]	OH radius [m]	Length of section [m]	Theoretical weight [t]	Actual weight [t]	Factor	Mud system
12 ¼	0.15558	501	88	112	1.3	Bentonite
8 ½	0.10795	1,726	145	337	2.3	K2CO3 Polymer
		2,227	***233***	***449***	***1.9***	

waste water = 66 t, contaminated mud = 97 t → overall factor = 2.6

Table 8: Waste Factor Calculation for Example Well 4 (Waste Water and Contaminated Mud Excluded)

OH diameter [in]	OH radius [m]	Length of section [m]	Theoretical weight [t]	Actual weight [t]	Factor	Mud system
17 ½	0.22225	410	146	157	1.1	Bentonite
12 ¼	0.15558	2,341	409	860	2.1	KCl-Glycol
8 ½	0.10795	629	53	141	2.7	KCl-Glycol
		3,380	***609***	***1,158***	***1.9***	

waste water = 259 t, contaminated mud = 358 t → overall factor = 2.9

According to Ottmar Polczer, authorized signatory of the waste management company *J. Ehgartner GmbH* in Southern Bavaria (Germany), an average storage well with ~2,500 meters total depth, having a 17 ½ inch and a 12 ¼ inch section, causes about 1,200 tons of drilling waste. *“These numbers are based on practical experience as the company Ehgartner is regularly in charge of disposing drilled cuttings from storage and geothermal wells in Bavaria. In the past, all the drilling waste from Bavaria (except cuttings drilled with a pure bentonite mud system) was transported to Stassfurt in Saxony-Anhalt (Germany) where the cuttings were injected into a salt cavern”*, said Ottmar Polczer.

2.4.3 Geothermal Wells (Bavaria, Germany)

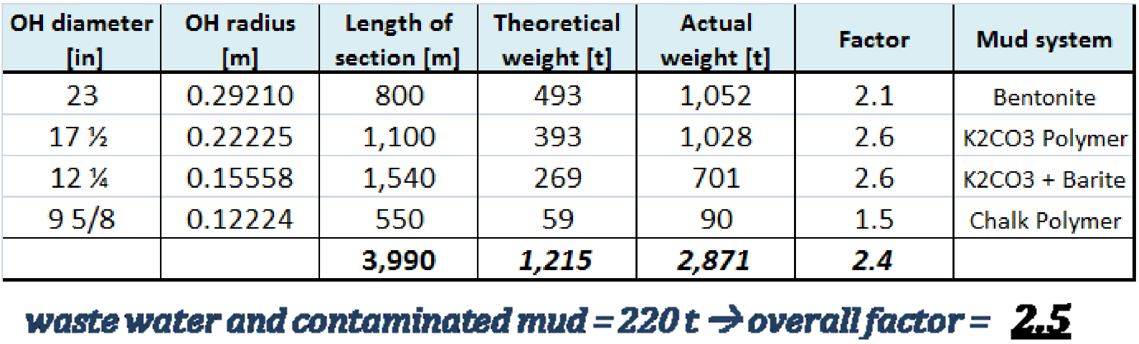
The following data was provided from a German waste management company called *J. Ehgartner GmbH*. Table 9 shows an example of a geothermal well drilled in Southern Bavaria (Germany) with four sections and a total depth of almost 4,000 meters.

The density of the cuttings that was used to calculate the theoretical hole volume was 2,300 kg/m^3 = 2.3 t/m^3. The data in the table excludes waste water and contaminated mud (e.g. cement slurry residue mixed with mud, sludge from cleaning tanks and pits). The final calculation, which included the 220 tons liquid waste, gave an overall *waste factor* of 2.5.

Please note that the 3rd section of the geothermal well was drilled with a weighted mud system (barite = barium sulfate = weighting agent) and the 4th section with a so called formation-friendly mud system which is based on chalk (=calcium carbonate). The reason for its ‘friendliness’ is that the invaded zone of the formation can be easily acidized at a later stage when chalk was used previously as the mud system in drilling.

Please note: When drilling a *geothermal well doublet* (= two wells) the actual amount of drilling waste from the table must be roughly multiplied by two. However, it should be considered that one well is often a few hundred meters shallower than the other one. Ottmar Polczer of the company J. Ehgartner GmbH says: “Based on my experience a *geothermal well doublet* drilled in Bavaria causes about 4,000 tons of drilling waste that needs to be disposed.”

Table 9: Waste Factor Calculation for Geothermal Well (Waste Water & Contaminated Mud Excluded)



OH diameter [in]	OH radius [m]	Length of section [m]	Theoretical weight [t]	Actual weight [t]	Factor	Mud system
23	0.29210	800	493	1,052	2.1	Bentonite
17 ½	0.22225	1,100	393	1,028	2.6	K2CO3 Polymer
12 ¼	0.15558	1,540	269	701	2.6	K2CO3 + Barite
9 5/8	0.12224	550	59	90	1.5	Chalk Polymer
		3,990	***1,215***	***2,871***	***2.4***	

waste water and contaminated mud = 220 t → overall factor = <u>2.5</u>

2.4.3.1 Excursus on ‘Geothermal Well Doublets’ (22, 23, 24)

Thermal water can either be utilized for the supply of heat or if it has a temperature above 100°C it can also be used for power generation. One possibility to utilize geothermal energy is by means of a so called *geothermal well doublet*. This means that two wells are drilled – one producer and one injector well.

First, the hot water is produced through the production well (that can be up to 6,000 meters deep) via a submersible pump. Once on surface, the water is used thermally (a heat exchanger causes a decrease of water temperature) and then the cooler water is reinjected into the same thermal aquifer from which it was produced. For this procedure it is very important that the quality of the water is neither altered nor contaminated on surface.

The reason why the water needs to be reinjected into the aquifer is that it often has a very high mineral content and thus cannot be drained into rivers, lakes or the sewerage system.

In order to cover peak loads and to ensure a constant heat supply via the district heating network geothermal plants are usually equipped with a gas-fired boiler in addition to the heat exchanger (which usually covers the base load).

Some examples of working geothermal energy plants in Bavaria are the plants in Erding, Straubing, Simbach-Braunau, Unterschleißheim, Riem and Pullach, which are all exclusively used for heat supply.

The main thermal aquifer in Bavaria is the so called ‘Malmkarst’ of the South German Molasse Basin.

In order to exclude a thermal or hydraulic short-circuit between producer and injector well in the long term the wells need to keep a minimum distance from each other. Practical experience had shown that a horizontal distance of 1,500 to 2,000 meters is sufficient.

Usually, the two geothermal wells have a vertical section first and are then inclined in opposite directions. Figure 4 shows two schematics of geothermal well doublets.

In the past, geothermal power generation was not put into practice very often in Germany. One reason for that is the very low net efficiency of the geothermal power generation plants (only 10 – 13 %) and another problem arises due to the immense cooling water requirement which often causes negative effects on groundwater resources.

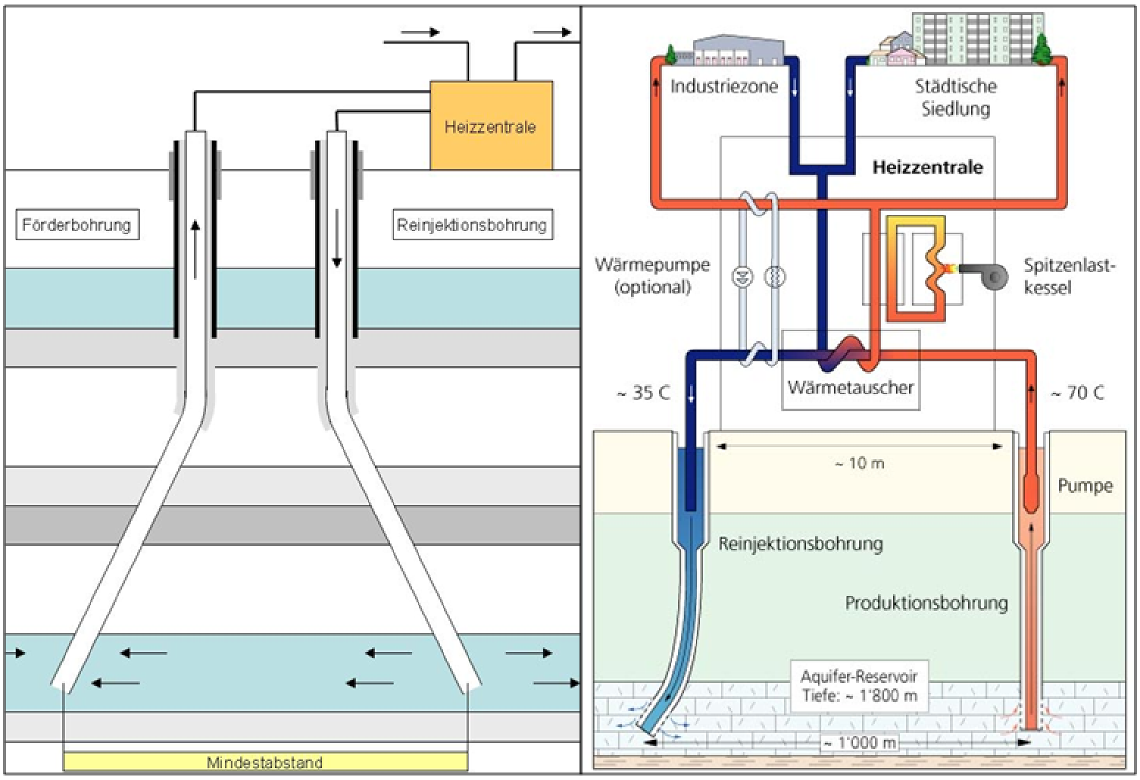


Figure 4: Schematics of Geothermal Well Doublets (22, 23)

2.5. Annual Amount of Drilling Waste in Austria

2.5.1 Summary: Year 2008

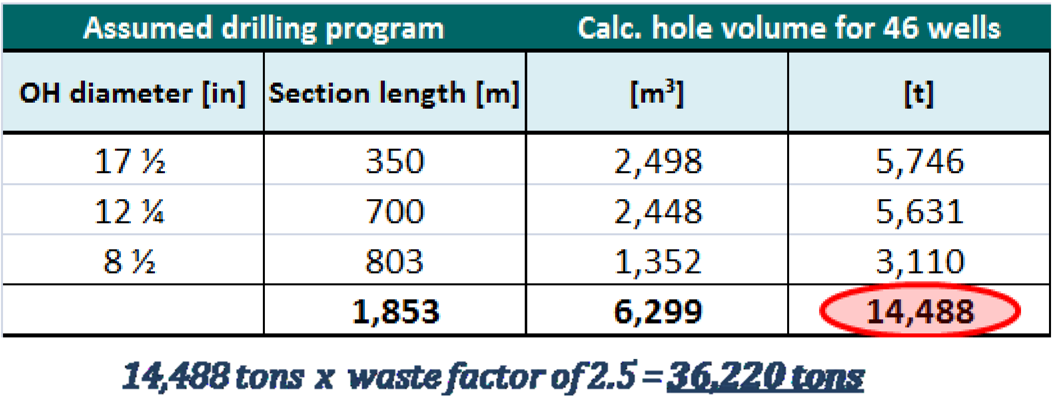
To get an impression of the annual amount of drilling waste in Austria, the following figures were taken from the **Austrian Mining Handbook (issue 2009 about the year 2008):**

"In 2008, 46 wells were drilled to TD which corresponded to 85,256 meters. If ongoing drilling activities were included there were in fact 95,307 meters drilled. The average length of borehole was 1,853 m." (7)

Table 10 shows an assumed drilling program for the average well with three sections and OH diameters of 17 ½, 12 ¼ and 8 ½ in. A theoretical borehole volume in m³ was calculated for 46 wells and converted into tons with an assumed bulk density of 2,300 kg/m³. Thus the theoretical amount of **drilling waste for 2008** summed up to **~14,500 tons**.

In order to get an assumption of the actual waste volume one would need to include the waste factor into the calculation. According to the case studies in Chapter 2.4 this *waste factor* lies between 2.5 and 3.0. Assuming a waste factor of 2.5 for the year 2008, the **actual annual amount of waste** was then **~36,000 tons** for 46 wells which means an average of ~780 tons actual waste per well drilled. As mentioned in Chapter Geothermal Wells (Bavaria, Germany)2.4.3 a geothermal well doublet causes about 4000 tons of drilling waste which means an average of ~2000 tons per well. This would mean that the geothermal wells from Bavaria (Germany) cause 2.5 times more waste than the storage and production wells from Austria.

Table 10: Annual Amount of Drilling Waste in Austria for the Year 2008



Assumed drilling program		Calc. hole volume for 46 wells	
OH diameter [in]	**Section length [m]**	**[m³]**	**[t]**
17 ½	350	2,498	5,746
12 ¼	700	2,448	5,631
8 ½	803	1,352	3,110
	1,853	**6,299**	**14,488**

14,488 tons x waste factor of 2.5 = 36,220 tons

2.5.2 Summary: Year 2009

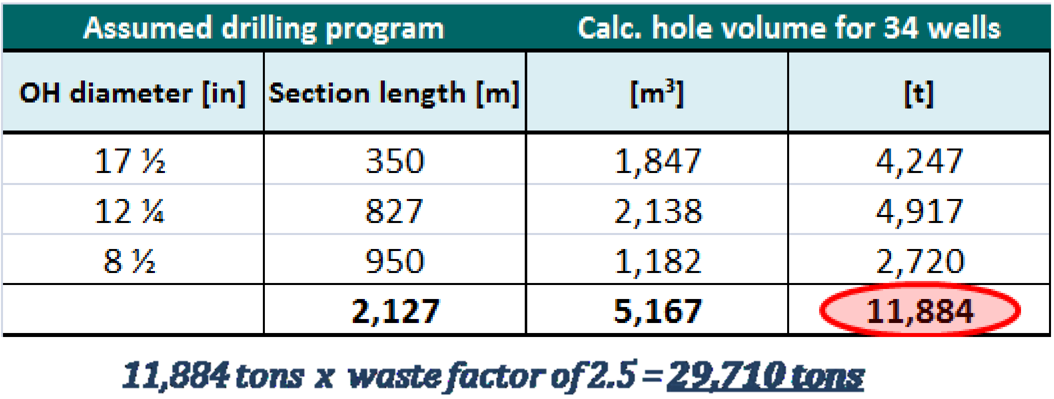
According to the **Austrian Mining Handbook (issue 2010 about the year 2009)** the following data was provided:

“In 2009, 34 wells were drilled to TD. This corresponded to 72,324 meters drilled to TD. If ongoing drilling activities were included there actually were 81,471 meters drilled. The average length of borehole was 2,127 m.” (8)

For subsequent calculations OH diameters and section lengths for an average well needed to be assumed (please refer to Table 11). Next, a theoretical borehole volume in m³ was calculated for the 34 wells and converted into tons with an assumed bulk density of 2,300 kg/m³. For the year 2009 the **total amount of drilling waste** summed up to **~11,900 tons**.

Again, a waste factor of 2.5 was assumed (based on the case studies in chapter 2.4) and the **actual annual amount of drilling waste** was calculated which gave approximately **30,000 tons** for the year 2009.

Table 11: Annual Amount of Drilling Waste in Austria for the Year 2009



Assumed drilling program		Calc. hole volume for 34 wells	
OH diameter [in]	**Section length [m]**	**[m^3]**	**[t]**
17 ½	350	1,847	4,247
12 ¼	827	2,138	4,917
8 ½	950	1,182	2,720
	2,127	**5,167**	**11,884**

11,884 tons x waste factor of 2.5 = 29,710 tons

3. Analysis of Cutting Samples

3.1. Introduction

In the following the geology, mud system and solids control system for the sample wells are described in detail.

3.1.1 Geology

Molasse Basin: RAG's concession area in Upper Austria and Salzburg is in the Molasse Basin (see Figure 5). "The Molasse lies between the Flysch in the South and the Crystalline in the North. Geographically, this is in the foothills of the Alps. The Molasse Basin consists of tertiary sequences (Upper Eocene to Late Miocene) which are mainly marine sediments. Gravel, sand, and clay were sedimented in different depositional environments like deltas, shore lines and shelves but also sediments from deep marine basins can be found. Most typical for the Molasse Basin is silty/sandy marl. The tertiary sediments are mostly covered by glacial sediments which function as groundwater bearing strata."(34) Figure 6 shows the typical lithology of a Well in Upper Austria.

Mineralogy: "The drilled formations mainly consist of alternating layers of often dispersing clays, sands and conglomerates. In order to know more about those clays and to achieve an optimum inhibition, representative core samples had been taken from the Molasse Basin in the past and were analyzed in the MI Technical Center in Stavanger. The results showed the following composition:"(33) (2)

Table 12: Mineral Composition of Core Samples from the Molasse Basin(33)

Mineral	Weight %
Calcite	14.1
Dolomite	13.1
Quartz	18.6
Siderite	1.3
Feldspar	6.7
Kaolinite	20.1
Illite	25.4
Smectite	0.7

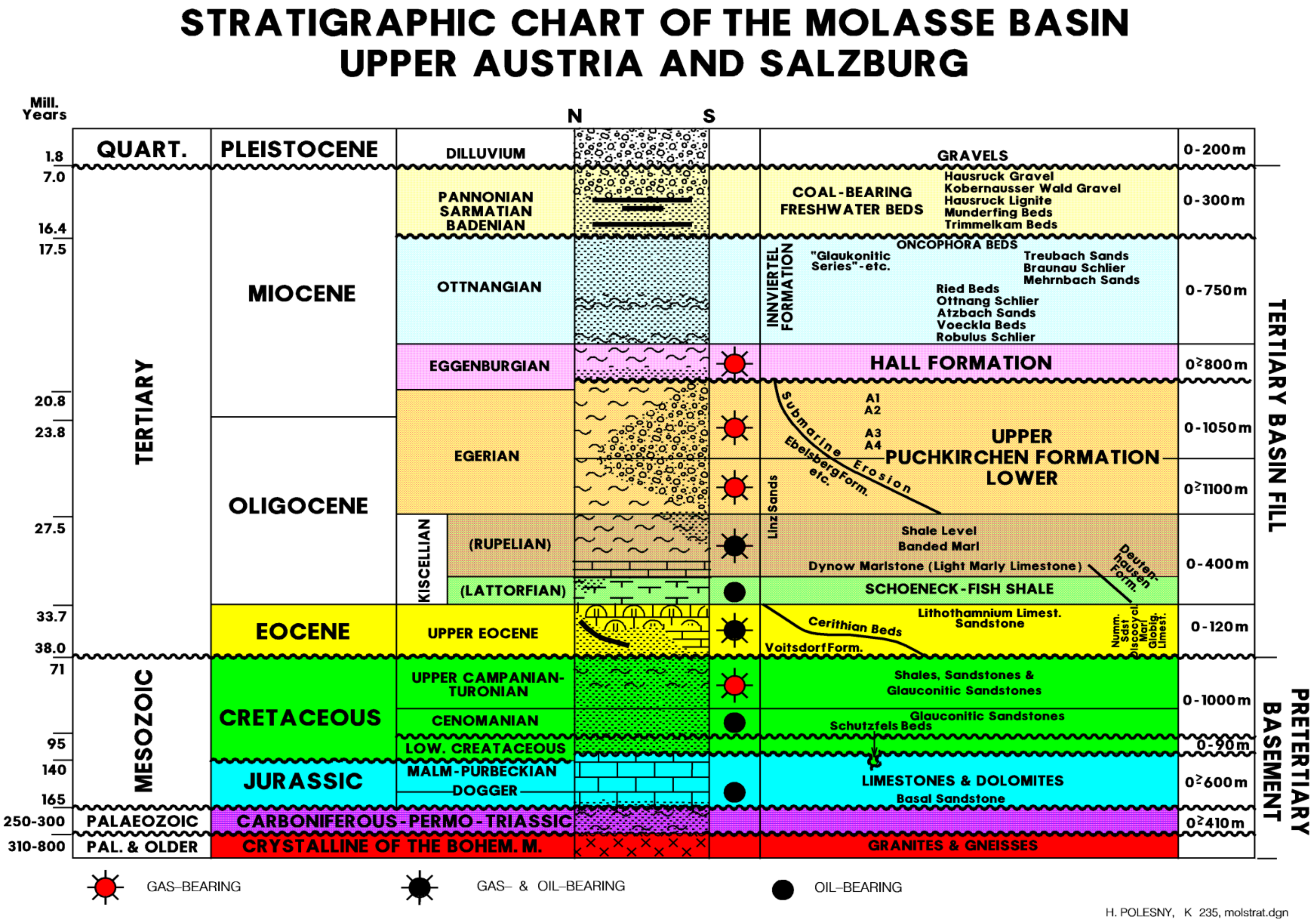


Figure 5: Stratigraphic Chart of the Molasse Basin – Upper Austria and Salzburg[33]

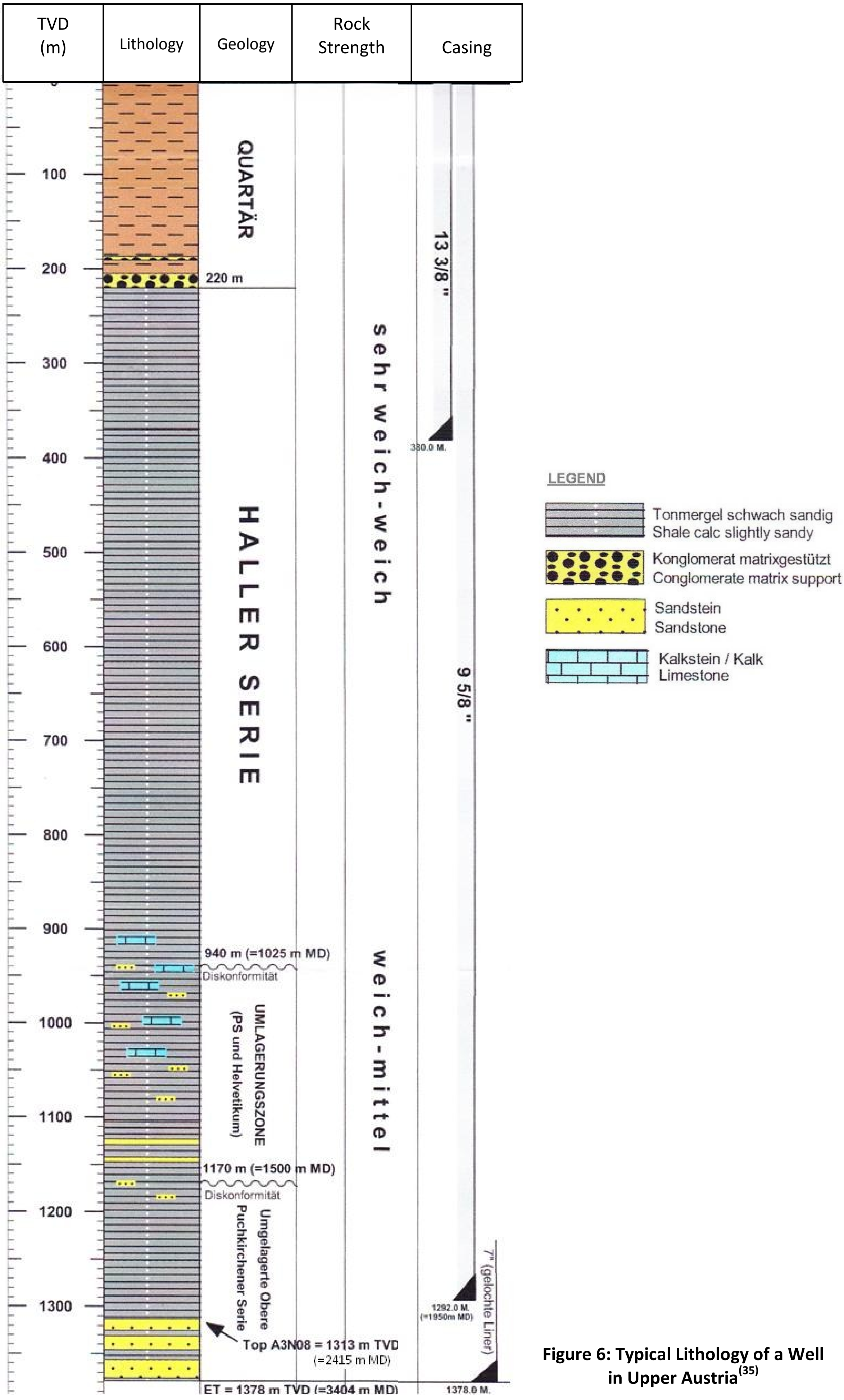


Figure 6: Typical Lithology of a Well in Upper Austria(35)

3.1.2 The Mud Systems in Use

3.1.2.1 General Functions and Desired Properties of Mud Systems (28)

The drilling fluid’s **primary functions** are to:

- Stabilize the wellbore and control subsurface pressures
- Transport cuttings and sloughing to the surface
- Suspend solids when circulation is halted
- Cool and lubricate the bit and drillstring
- Assist in gathering and transporting formation-evaluation data to the surface
- Assist in suspending the weight of the drillstring and casing
- Transmit hydraulic horsepower to the drillbit
- Minimize formation damage caused by drilling operations

There are several factors that should be taken into consideration when **selecting a drilling fluid**:

- Fluid compatibility with the producing reservoir
- Presence of hydratable or swelling formation clays
    - In general, inhibitive fluids (calcium, sodium, potassium, oil-based fluids) aid in preventing formation swelling.
- Fractured formations
- The possible reduction of permeability by invasion of nonacid soluble materials into the formation

Factors affecting the **removal of cuttings** from the wellbore include:

- Drilling fluid density and rheology
- Annular velocity
- Hole angle
- Cuttings slip-velocity

Circulating rates must be sufficiently high to override the force of gravity acting upon the cuttings. If the annular velocity is less than the slip-velocity the cuttings settle and may cause problems such as bridging, fill-up, and stuck pipe.

The rate of fall of a particle through a column of drilling fluid is dependent upon the density of the particle and the fluid, the size of the particle, the viscosity of the fluid, and the thixotropic (gel-strength) properties of the fluid. High gel strengths also require high pump pressure to break circulation.

In order to **ensure that subsurface geological information (cuttings, mud pulse data, wireline logs) can be properly transported and evaluated**, the following fluid properties must be considered:

- Salinity of the fluid
- Filtrate invasion depth
- Pressure induced fractures
- The nature of the continuous phase of the fluid (oil or water)
- The stability of the fluid properties

Hydraulics optimization is important in order to obtain the best hole cleaning and drilling performance. The rheological properties of the drilling fluid have an influence upon hydraulics, and should be monitored at all times.

A **water based fluid** is one that uses water for the liquid phase and commercial clays (bentonite, attapulgite, or sepiolite) and often polymers for viscosity. The continuous phase may be fresh water, brackish water, seawater, or concentrated brines containing any soluble salt (e.g. sodium or calcium). The use of other components such as thinners, filtration-control additives, lubricants, or inhibiting salts in formulating a particular drilling fluid is determined by the type of system required to drill the formations safely and economically.

Many materials (**additives**) used to change or modify the characteristics of the mud are added at the surface. For example:

- Weighting agents (usually barite) are added to increase the density of the mud, which helps to control subsurface pressures and build the wall cake.
- Viscosifying agents (clays, polymers, and emulsified liquids) are added to thicken the mud, which increases its ability to clean the hole.

- Dispersants or deflocculants may be added to thin the mud, which helps to reduce surge, swab, and circulating-pressure problems.
- Clays, polymers, starches, dispersants, and asphaltic materials may be added to reduce filtration of the mud through the borehole wall. This reduces damage to drilled formations, differential sticking problems, and problems in wireline or MWD log interpretation.
- Salts are sometimes added to protect downhole formations or to protect the mud against future contamination, as well as to increase density.
- Other mud additives may include: lubricants, corrosion inhibitors, chemicals that tie up calcium ions, and flocculants that aid in the removal of cuttings at the surface. Caustic soda is often added to increase the pH of the mud, which improves the performance of dispersants and reduces corrosion. Preservatives, bactericides, emulsifiers, and temperature extenders may all be added to make other additives work better.

3.1.2.2 Pure Bentonite Mud

In RAG wells in Austria the first section of a well is drilled with a bentonite mud system consisting only of freshwater and bentonite (without any other additives) in order to protect near surface strata and freshwater bearing horizons. As the first meters to drill is hard formation consisting of gravel (glacial sediments from the Quaternary) a very thick viscous bentonite mud is used.

“Bentonite itself is a viscosifier that aids in removing cuttings from the wellbore and keeps them in suspension during periods of noncirculation. Bentonite consists of fine-grained clays containing not less than 85 % montmorillonite, which belongs to the class of clay minerals known as smectite. Bentonite increases hole-cleaning capability, reduces water seepage or filtration into permeable formations, forms a thin and low-permeable filter cake, promotes hole stability in poorly cemented formations, and avoids or overcomes loss of circulation. Bentonite hydrates (=attracts and holds liquid) in fresh water muds to approximately 10 times its dry volume.” (28)

3.1.2.3 Potassium Carbonate-Polymer Mud

The second section of RAG wells in Austria is drilled with a K_2CO_3-Polymer mud system (sometimes weighted with barite). The main formation to be drilled with this system is called the Haller Series which consists primarily of shale sediments. Therefore, shale stabilization is very important for this well section.

"Potassium carbonate (K_2CO_3) is a white salt, soluble in water (insoluble in alcohol), which forms a strongly alkaline solution. Other names for potassium carbonate are: potash, pearl ash, salt of tartar, salt of wormwood, dipotassium salt, dipotassium carbonate, and carbonate of potash."(36)

The potassium salt is also known as an effective shale stabilizer. (28) "The K^+ ions attach to clay surfaces and lend stability to shale exposed to drilling fluids by the bit. The ions also help hold the cuttings together, minimizing dispersion into finer particles. The presence of Na^+ ions counteracts the benefits of K^+ ions and should be minimized by using fresh water (not sea or salt water) for make-up water. Potassium chloride, KCl, is the most widely used potassium source."(37)

"In former times, RAG used a KCl-Polymer mud system to prevent swelling and dispersing of clays but the chlorides in the mud made recycling of cuttings impossible. For this reason a freshwater based mud system was developed in which the KCl is fully replaced by K_2CO_3."(34)

The K_2CO_3 mud system used at RAG is obtained by mixing the following components:

- Freshwater
- Potassium carbonate (for shale stabilization; increases pH)
- Citric acid (to reduce the pH)
- Antisol FL 100 (to reduce filtration)
- Antisol FL 30000 (to increase viscosity)

Antisol is a polyanionic cellulose polymer. Formerly, Poly Pac LV (FL 100) and Poly Pac UL (FL 30) were used instead of the Antisol products. The Antisol and Poly Pac products are the same; only the names are different as they come from different suppliers.

The benefits of the K_2CO_3-Polymer mud system are: (34, 35)

- K_2CO_3 can be used as weighting agent. Lab tests have shown that freshwater can be weighted with K_2CO_3 up to a specific gravity of 1.53 kg/l. Figure 8 shows the solubility graph gained from the lab tests. Furthermore, field experience had shown that a specific gravity of 2.10 kg/l could be achieved easily when barite was added. So far, there was no need of even higher mud weights.
- K_2CO_3 has corrosion inhibiting properties. Different mud systems were investigated and their corrosion rates were compared (see Figure 7). It turned out that the K_2CO_3 mud system showed almost no corrosion.
- Practical experience showed that even in geologic sections with abnormal stress regimes the caliper logs proved a dimensionally stable borehole.
- K_2CO_3 mud can be reused and the cuttings can be recycled as the system is not contaminated from chlorides.

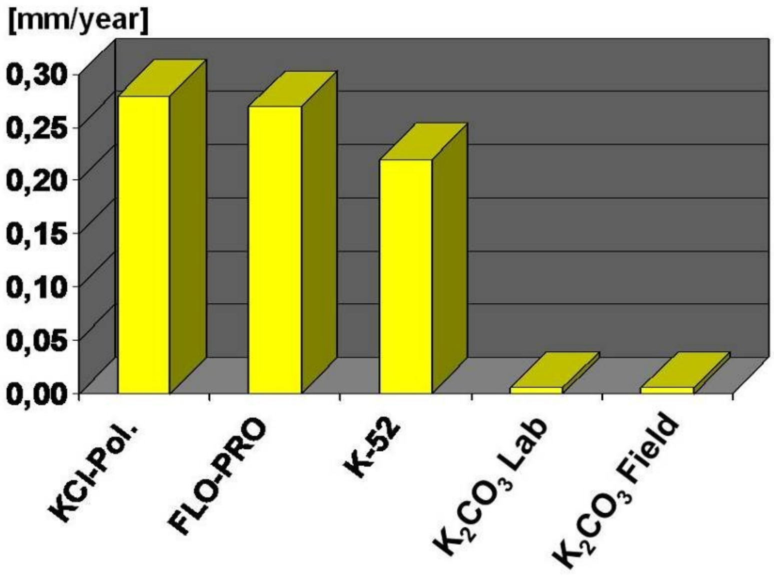


Figure 7: Comparison of Corrosion Rates for Different Mud Systems(34, 35)

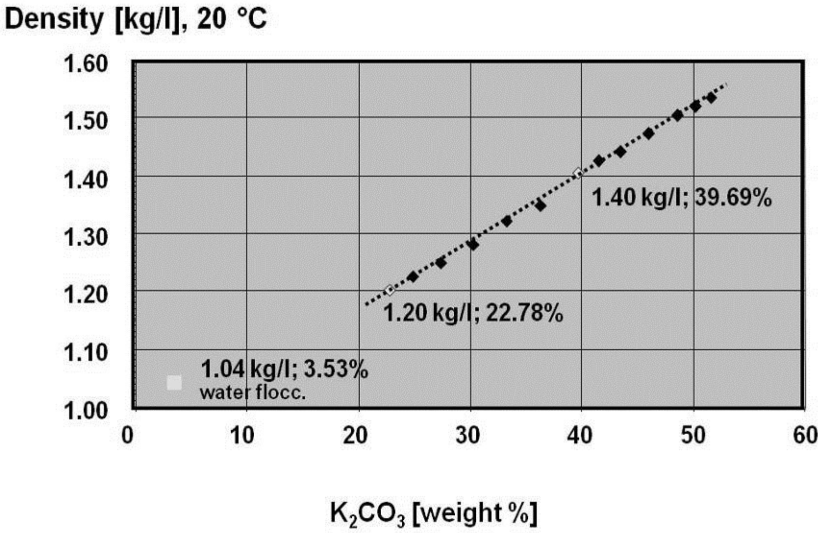


Figure 8: Solubility of K_2CO_3 in Freshwater(34, 35)

3.1.2.4 Potassium Carbonate-Polymer Mud with Additive Mix II

Usually, the last section (reservoir section) of RAG wells is drilled with the K_2CO_3-Polymer mud system as explained before (see Chapter 3.1.2.3). However, sometimes an additional additive called MIX II is added to this system. This is the case when RAG has problems with lost circulation or when they are drilling storage wells where the reservoir section already is at low pressure (depleted horizon) and it is important to protect the storage horizon and have a minimum zone of invasion so that maximum injection and production rates can be ensured later on during storage cycles.

"The additive MIX II is a plugging agent consisting of cellulose fiber used to bridge and seal permeable formations. Thus, it reduces differential pressure sticking, controls lost circulation and provides filtration control. MIX II is available in fine (original), medium and coarse grades. Each grain size has a specially selected particle size distribution optimized to seal a wide range of formations. It is an inert material which is compatible with all mud systems and other lost-circulation materials. MIX II fiber residue can be partially removed using standard treatments such as hydrochloric acid or alkaline hypochlorite solutions. One disadvantage of MIX II (especially with the medium and coarse grades) is that it is discharged at the shale shakers and solids control equipment and thus MIX II must be added frequently when a certain concentration in the mud should be maintained. As it is a cellulose polymer MIX II is biodegradable and subject to bacterial degradation. If fermentation is indicated, a biocide should be used."(38)

3.1.3 The Solids Control System

The following figure shows the general configuration of a mud circulation system on a drilling rig.

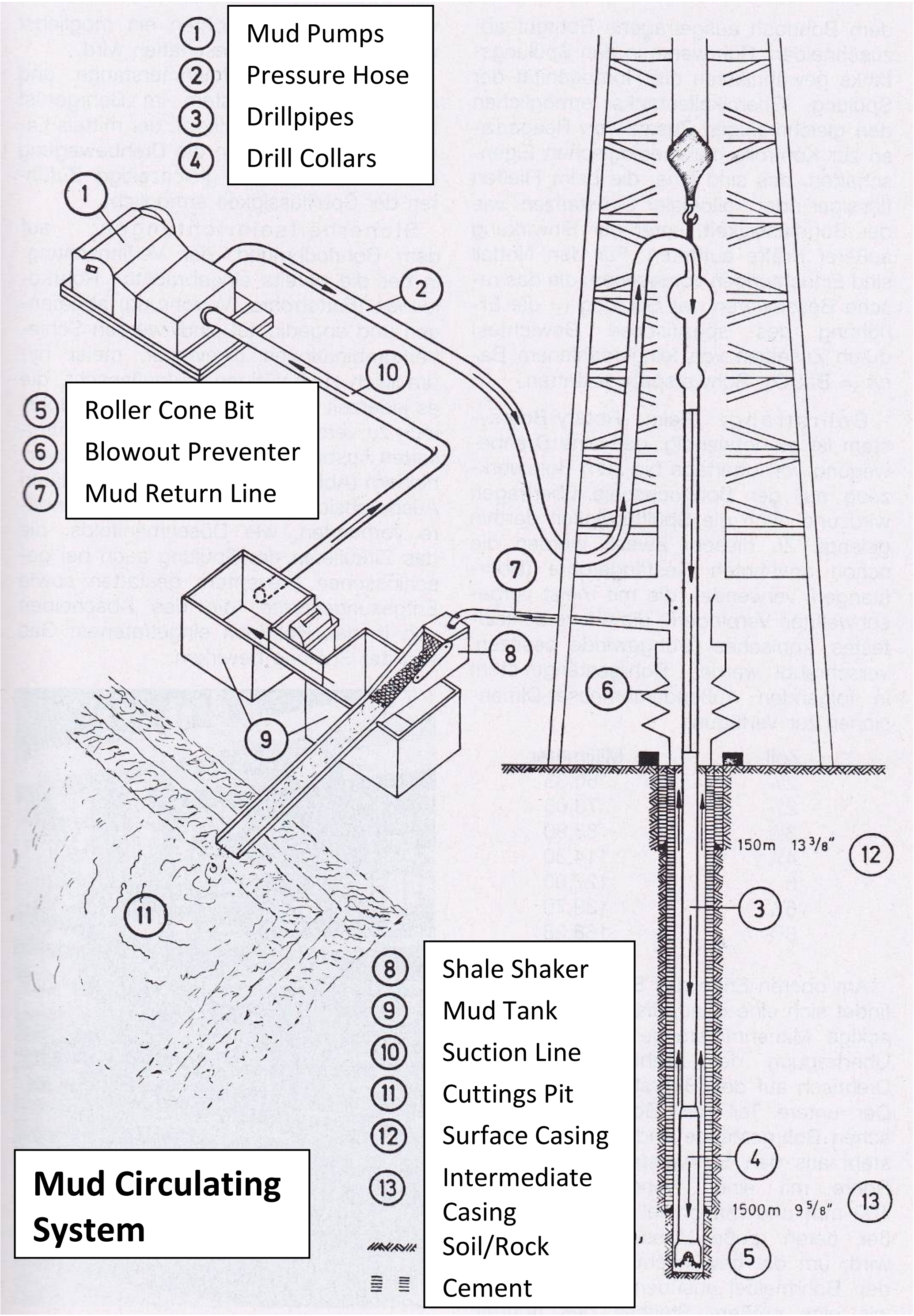


Figure 9: General Configuration of a Mud Circulation System(29)

The next figure shows a general schematic for a solids control system. In this system the mud, which contains the drilled solids, first flows over the shale shakers (which can be equipped with different mesh sizes depending on the well section that is drilled) where the larger particle solids (> 70 microns = sand limit) are removed and flow into the cuttings box. The mud that has passed the sieves now enters the hydrocyclones (desanders and/or desilters) where finer solids (> 40 microns for desilter) are removed from the mud. The “clean” overflow of the hydrocyclones directly goes back into the active mud tank, the discharge of the hydrocylones enters the decanter (=centrifuge). Before the decanter a flocculant may be added to the underflow in order to be able to remove the finest solids (>5-10 microns) from the mud.

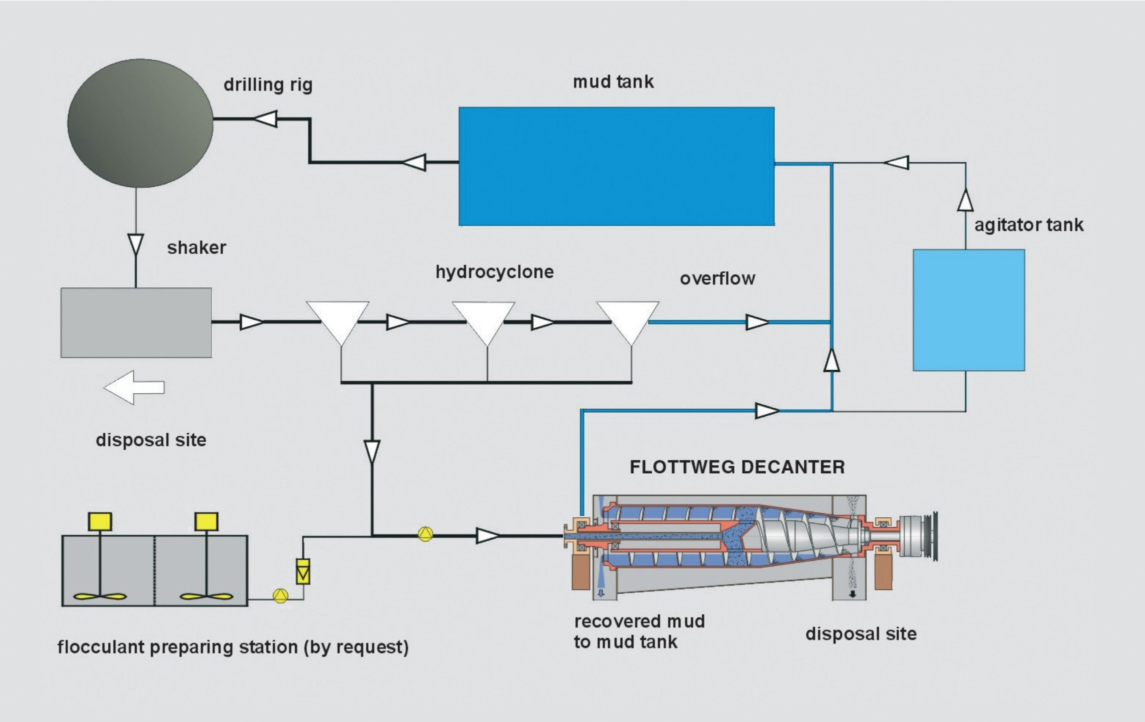


Figure 10: Solids Control System incl. Shale Shakers, Hydrocyclones & Flocculation Unit(45)

The solids control system of the RAG rig looks similar. It is equipped with 2 shale shakers with exchangeable screens, (no desander), 1 desilter unit, and 2 centrifuges whereof one is run without flocculant and the other one can be additionally fed by flocculant if necessary. The total maximum tank volume is 96 m³ (= 8 tanks à 12 m³ whereof 2 tanks are reserve tanks). The two cutting boxes have a total capacity of 70 m³ (= 2 boxes à 35 m³). Figure 11 shows the flow schematic that is usually in use; Figure 12 shows the flow schematic when barite is recovered from the mud.

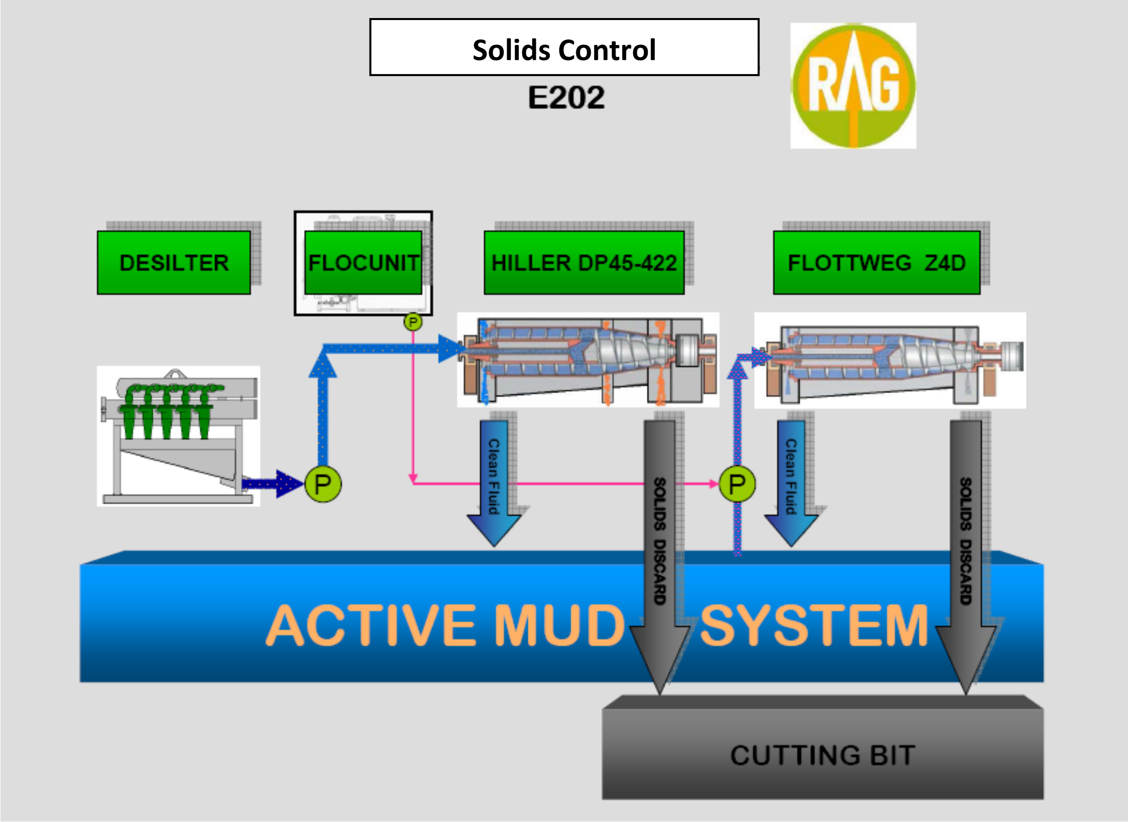


Figure 11: Solids Control System of the RAG Rig E202

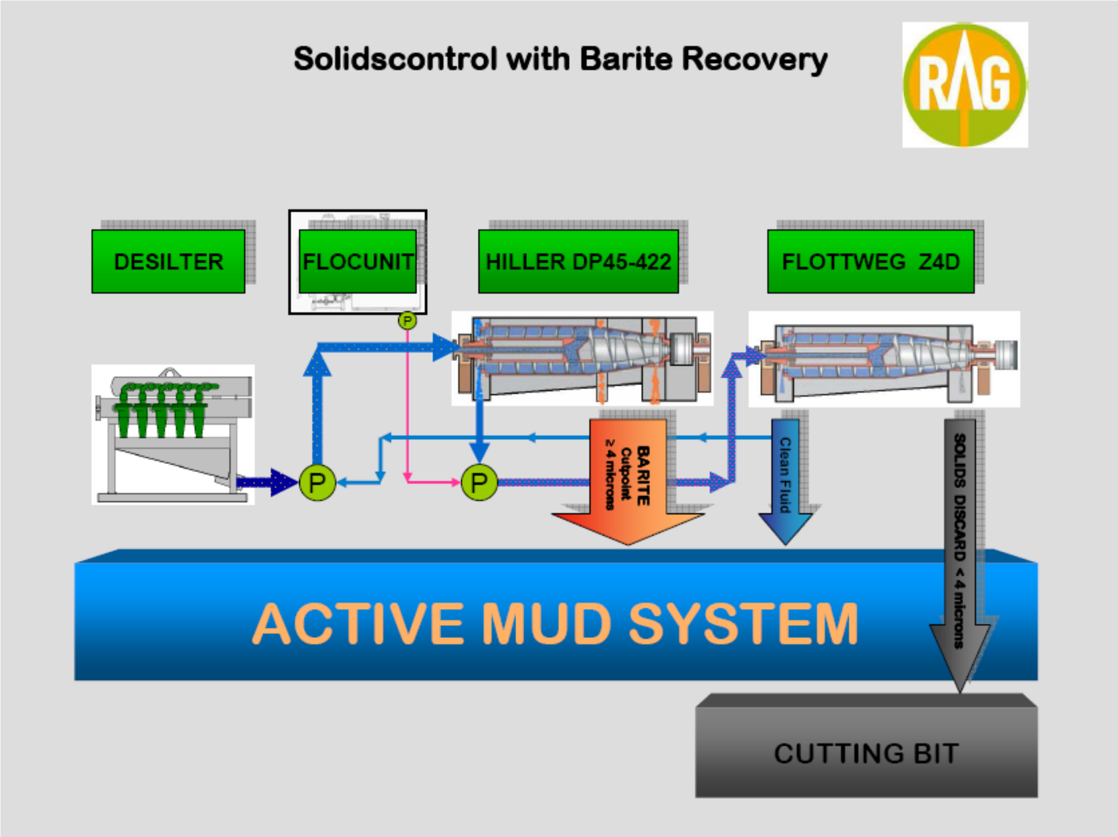


Figure 12: Solids Control System of the RAG Rig E202 with Barite Recovery

Figure 13: Pictures of the Cutting Boxes (Left Picture - Outlets of Shale Shakers, Right Picture – Outlets of Centrifuges)

*“**Shale Shakers:** The primary and probably most important device on the rig for removing drilled solids from the mud. A wire-cloth screen vibrates (linear, elliptical, or circular movement) while the drilling fluid flows on top of it. The liquid phase of the mud and solids smaller than the wire mesh pass through the screen, while larger solids are retained on the screen and eventually fall off the back of the device and are discarded. Obviously, smaller openings in the screen clean more solids from the whole mud, but there is a corresponding decrease in flow rate per unit area of wire cloth. Hence, the drilling crew should seek to run the screens (as the wire cloth is called), as fine as possible, without dumping whole mud off the back of the shaker.”*(49)

*“**Hydrocyclone:** An item of solids-control equipment consisting of an inverted cone, the mud being fed tangentially into the upper (larger diameter) part. The resulting spinning effect forces solids to the wall of the device and they exit from the bottom (apex) of the cone, while the cleaned liquid exits at the top. Hydrocyclones are classified by the size of the cone as either desanders (typically 12 inches in diameter) or desilters (4 to 6 inches in diameter) and will separate particles in the medium-, fine- and ultrafine-size ranges.”*(48)

*“**Flocculant:** A chemical that causes a dispersed colloidal system (such as clay) to coagulate and form flocs. Most flocculants are either multivalent cations such as calcium, magnesium and aluminum, or long-chain polymers.”*(46)

*“**Centrifuge:** An item of solids-removal equipment that removes fine and ultrafine solids. It consists of a conical drum that rotates at 2000 to 4000 rpm. Drilling fluid is fed into one end and the separated solids are moved up the bowl by a rotating scroll to exit at the other end.”*(47)

3.2. Execution & Objectives of the Sample Investigation

The primary goal of this investigation was to find out whether the different waste fractions (mud, unflocculated cuttings, and flocculated material) from RAG wells are disposable in surface dumpsites in Austria; and if not, whether RAG should further enforce their recycling paths. During an internship on a RAG drilling rig in Upper Austria cuttings and mud samples were taken in three phases:

a) during wiper tripping the 12 ¼ inch hole section of well X
b) during drilling the 8 ½ inch reservoir section of well X
c) during drilling the 17 ½ inch top hole section of well Y

The reason for taking samples from three different sections and two different wells was that in each case a different mud system was used. Thus, the aim was to investigate how the different mud systems affect dumping capability. In each phase mud samples, cutting samples and samples of flocculated material were taken at the different solids control outlets: Cuttings (=coarser grained and unflocculated) were taken directly from the shale shakers. Flocculated material (=fine solids and flocculants) was taken at the centrifuge discharge, and mud samples were taken directly after the mud had passed the shale shakers (at the sieve underflow). A representative sampling procedure was planned (according to ÖNORM S2123) and documented. At the end of each phase one representative sample for cuttings, one representative sample for mud and one representative sample for flocculated material was at hand and sent to an accredited laboratory. All samples had been homogenized before they were sent to the lab. Furthermore, retain samples were kept as well. All samples were assigned to the lithology and mud systems used (see Table 13).

The laboratory conducted a full analysis according to the Austrian Landfill Regulation 2008 for the Sample Numbers 1 to 6, and a TOC (total organic carbon) and LOI (loss on ignition) analysis for the sample numbers 7 to 9.

By comparison of the measured parameters and the limits mentioned in the Austrian Landfill Regulation 2008 the landfill category for the investigated mud and cuttings samples could be determined. During interpretation of the results it was important to consider the properties of the raw materials which were used to mix the mud in the first place. It was to be expected that the TOC content would be elevated. Thus, the secondary aim was to identify where the high TOC value was coming from (mud additives, coal, etc.). A so called LECO measurement was done which showed the rock inherent TOC content. Furthermore, the natural degradation of the TOC content was discussed and possibilities for accelerating the TOC degradation were mentioned. Thus, experiments with dehydration and sunlight were conducted. For those possible treatment steps it was important to think of economic efficiency as well. In addition, the TOC measuring technique was questioned and possible sources of error were identified.

Table 13: Sampling Overview – Numbers and Names of Samples Sent to Laboratory for Analysis

No.	Laboratory Sample	Sampling Date	OH Size	Geology	Mud System	Performed Analysis
1	Mud wiper tripping run	16th and 17th May, 2010	12 ¼ in	Haller Series*) and Zone of Resedimentation	K_2CO_3 polymer mud (freshwater, K_2CO_3, citric acid, Antisol)	Full analysis according to Landfill Regulation 2008
2	Cuttings wiper tripping run					
3	Flocculated material wiper tripping run					
4	Mud reservoir section	25th, 26th and 27th May, 2010	8 ½ in	Haller Series*) and Sandstone (gas bearing)	K_2CO_3 polymer mud with MIX II	
5	Cuttings reservoir section					
6	Flocculated material reservoir section					
7	Bentonite mud	13th, 14th and 15th July, 2010	17 ½ in	Quaternary and Upper Part of Haller Series	Pure bentonite mud (freshwater + bentonite)	TOC (=total organic carbon) and LOI (=loss on ignition)
8	Cuttings bentonite mud					
9	Flocculated material bentonite mud					
*) The Haller Series consists primarily of sandy clay marl. From 900 m downwards a Zone of Resedimentation (Umlagerungszone) exists in which lime and sandstone layers may occur.						

3.3. Sampling Procedure

As there was no API recommended practice available for the sampling of cuttings and mud, the decision was to use the Austrian standard ÖNORM S2123 'Sampling Plans for Waste' instead. Most consideration was given to part 2 (S2123-2 'Sampling of solid waste from containers and transport vehicles') and part 4 (S2123-4 'Sampling of liquid or paste-like waste') of this standard. The planning of the sampling procedure is discussed in the following Chapter 3.3.1.

3.3.1 Planned Sampling Procedures

3.3.1.1 General Sampling Procedures and Definitions for Sampling

Before the actual sampling took place, a so called sampling plan had to be created. According to ÖNORM S2123 a sampling plan must contain the following:(30)

- Evaluation of homogeneity or heterogeneity
- Determination of mass (estimation of volume or density if required)
- Defining the number of samples required
- Defining the minimum sample quantity
- Considering Legal guidelines

The legal guideline in this case was the Austrian **Landfill Regulation 2008 (Appendix 4).** In the following some important terms used in sampling standards are explained.

"Representative Sampling (Repräsentative Probenahme): *For sampling in general it is important that the taken samples show the properties of the given underlying population. Thus, a representative sample is a sample whose properties are consistent with the mean properties of the object that should be sampled and investigated."(31)*

"Homogenous Waste: *Waste is homogenous if based on given information (about the production process, source, waste properties, results of preliminary investigations, etc.) and visual inspection it can be assumed that the waste has a constant and consistent composition."(30)*

*“**Heterogeneous Waste:** Waste is heterogeneous if previous information or executed visual inspections or preliminary investigations have shown that there are doubts about the waste composition being consistent.”*(30)

*“**Liquid Waste:** Liquid Waste is generally homogenous. Heterogeneity is only present if the liquid contains different phases (e.g. solids and liquid). Such liquids may segregate or solids may settle down. In such cases agitation is necessary in order to ensure homogeneity.”*(30)

*“**Increment (Stichprobe):** This is a sample which is taken at a certain location at a specific point in time. The increment is part of a composite sample.”*(30)

*“**Composite Sample (qualifizierte Stichprobe):** This is a sample that consists of several increments and which can be assigned to a certain sampling location (e.g. borehole) and a certain waste type.”*(30)

*“**Collective Sample (Sammelprobe):** This is a sample that consists of several composite samples which had been taken over time and/or at different locations and which then were merged into a collective sample.”*(30)

*“**Individual Sample (Einzelprobe):** This is a single sample which is taken at a certain location at a specific point in time and which fulfills the minimum requirements (minimum sample quantity) of a composite sample and which is prepared and used as a field sample for further investigation.”*(30)

*“**Field Sample (Feldprobe):** This is the sample from which the laboratory sample (which used for subsequent investigation in the lab) is derived. The field sample can either be an individual sample, a composite sample or a collective sample.”*(30)

*“**Laboratory Sample (Laborprobe):** This is a sample that is obtained from the field sample after preparation, homogenization, diminution, and conservation and that is used for laboratory tests.”*(30)

*“**Retain Sample (Rückstellprobe):** This is an aliquot of the field sample which is kept for at least six months.”*(30)

Figure 14 shows a schematic of how the previous terms and definitions are used:

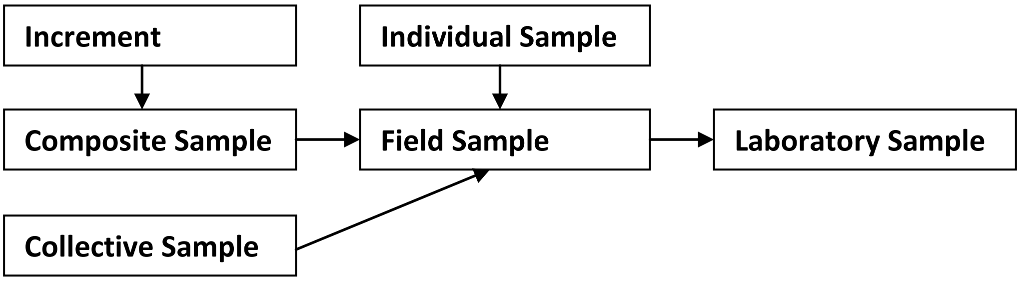


Figure 14: Overview of Sample Defintions(30)

Figure 15 shows a general flowchart for conducting a waste analysis.

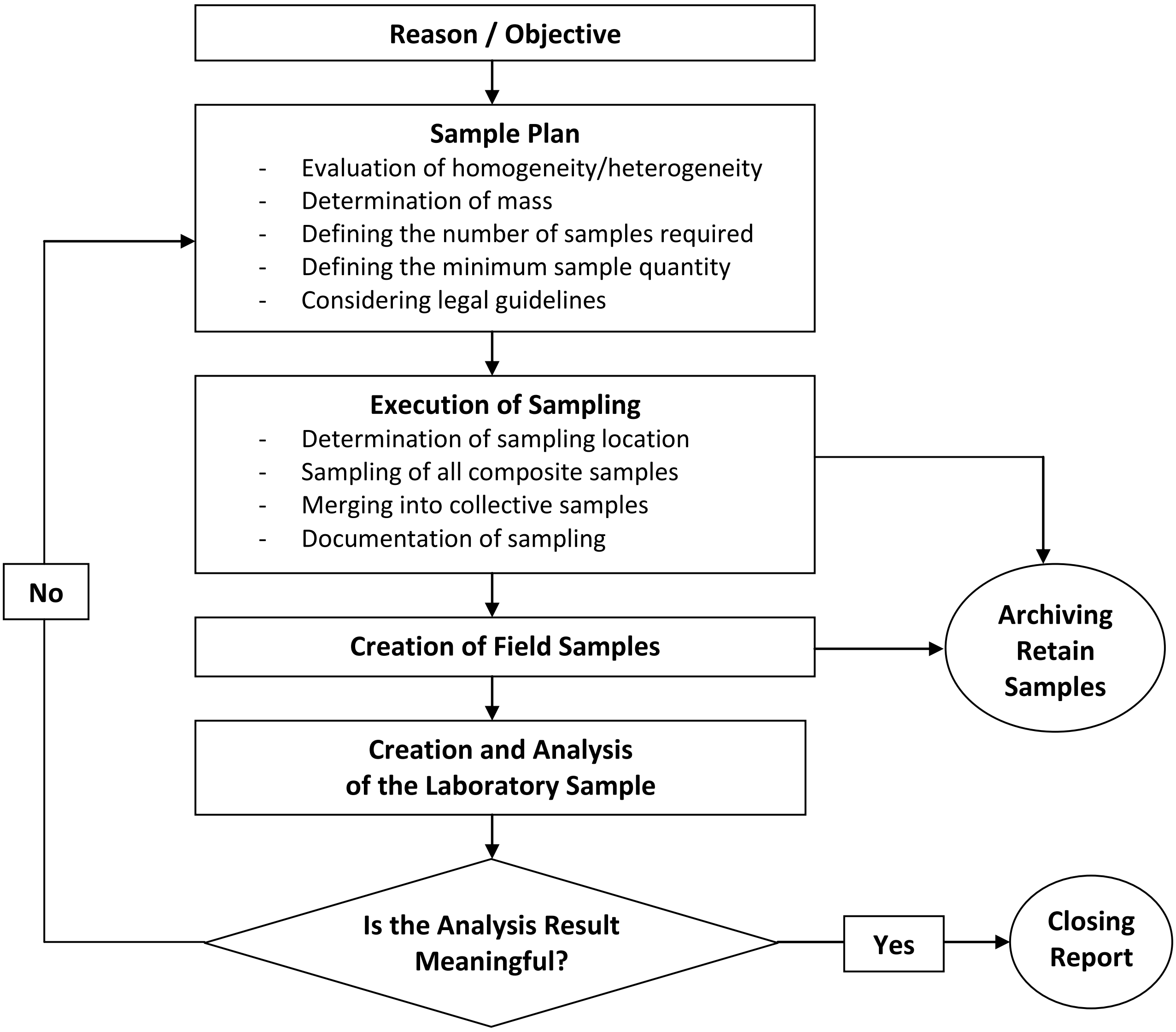


Figure 15: Flowchart for Carrying Out a Waste Analysis(30)

A general sampling procedure works as follows:

Normally, increments are taken which are later merged into composite samples. The number of composite samples to be taken depends on the total amount of waste to be tested. The composite samples may later be merged into collective samples. An aliquot of the composite samples is to be stored separately (=retain sample). In principle, the collective samples are to be used as field samples (number and composition of field samples depends on the total amount of waste), out of which the laboratory sample will be prepared. Each laboratory sample is to be analyzed separately.

3.3.1.2 Sampling Procedure for Wiper tripping the 12 ¼ in Hole Section

The planned samples were defined as **secondary waste** according to Appendix 2 of AWG 2008 as they would accumulate in the course of a waste treatment procedure (= solids control system on a rig: separation via shale shakers, hydrocyclones and centrifuges).

Furthermore, the planned samples were defined as **one-time occurring waste** according to Appendix 2 of the Landfill Regulation 2008. (The reason why it was not defined as a **waste stream** was that the wiper tripping runs were looked at separately and this approach also made sure that enough samples were taken during the wiper tripping runs. Note: For a waste stream fewer samples would need to be taken.)

It was planned to have one wiper tripping run in the 12 ¼ in hole section which would take approximately 2 days. The waste was expected to be very fine cuttings which were grounded from pipe rotation and the circulation of the mud. Furthermore, the waste would be partly contaminated by the mud itself and partly by the flocculating agent that was used.

As the waste would be contaminated by organic components (e.g. polymers from the mud) it could not be defined as **excavation material**, instead it was defined as **OTHER one-time occurring waste** (definitions according to the Landfill Regulation 2008). Thus, the sample plans and the execution and documentation of sampling had to be done according to the Austrian standard ÖNORM S2123:

1. **Homogeneity/Heterogeneity**

   Mud as well as cuttings and flocculated material would be **homogenous** during the wiper tripping runs as the material comes from one geologic formation named *Haller Series* which consists primarily of clay marl. The cuttings and flocculated material would be contaminated by K_2CO_3 mud. The mud system would stay the same during the wiper tripping run (no additives added).

2. **Determination of Mass**

   Amount of waste according to advance information for the 2-3 days lasting wiper tripping runs (assumed density ~ 1,5 t/m³ after ÖNORM S 2123-2):

   a. *Cuttings (unflocculated):* 17 m³ * 1.5 t/m³ = 25.5 t
   b. *Flocculated material:* 35 m³ * 1.4 t/m³ = 49 t
   c. *Mud:* mud is recovered, no waste would occur

   As both cuttings as well as flocculated material were below the **maximum criterion** for OTHER one-time occurring waste it was not necessary to divide them into subsets. Note: The maximum criterion for OTHER one-time occurring waste is **100 tons** for secondary waste (according to Landfill Regulation 2008).

3. **Minimum Sample Quantity**

   a. Per Increment

      Min. Quantity per Increment (kg) = 0.06 * Max. Grain Size (95 % Percentile, mm)

      Minimum Quantity per Increment = 0.06 * 2 mm = **0,12 kg**

   b. Per Composite Sample

      Min. Quantity per Composite Sample = 10 increments * 0.12 kg = 1.2 kg

      But: The minimum quantity for a composite sample is at least **2 kg**.

   c. Retain Sample

      From each composite sample a retain sample has to be kept.

4. **Minimum Number of Samples Required’**

    a. Composite Sample

    Each composite sample must consist of at least **10 increments**. Determination of the number of composite samples after Appendix 4, Table 4, Chapter 1.5 of the Landfill Regulation 2008:

    i. *Cuttings:* up to 50 t → **2 composite samples**

    ii. *Flocculated material:* up to 50 t → **2 composite samples**

    iii. *Mud:* also **2 composite** samples were planned

    b. Field Samples

    For minimum quantities the following is valid: The composite samples have to be merged into **2 field samples**. For the first field sample a full analysis is necessary. For the second field sample only the parameters need to be analyzed which were *relevant for the limiting value*. Depending on the analysis results the parameters need to be grouped into *uncritical*, *relevant* or *relevant for the limiting value*.

The increments should be taken in 1-2 hour intervals at the different solids control outlets (cuttings at shale shakers, flocculated material at centrifuge discharge, and mud at screen underflow of shale shakers).

3.3.1.3 Sampling Procedure for Drilling the 8 ½ in Reservoir Section

As the estimated amount of waste that would accumulate during drilling the 8 ½ in reservoir section did not differ significantly from before, the waste plan and the numbers of samples to be taken stayed the same as for the wiper tripping run before. However, this time it was planned to take samples of cuttings and flocculated material directly out of the mud tanks with the help of a certain sampling device called *Multisampler,* manufactured by the company *Eijkelkamp*. Figure 16 shows a picture of the *Multisampler*.

"The *Multisampler* is a rod operated sampling set that is suitable for sampling up to a depth of 5 meter. Using the *Multisampler* it is possible to take anaerobe samples in a wide variety of wet materials, solid as well as fluid. Using the piston rod (usually extended by means of a wire-line) it is possible to move the piston in the sampling tube while this tube is held stationary. In this way the original stratification of the sampled material is maintained."(32)

When sampling waste from containers it is important to take samples from randomly chosen locations evenly distributed and from the whole container. The samples always need to be taken over the whole depth of the container (each increment must be taken from top to bottom of the container). The increments need to be homogenized and merged into a composite sample at the end so that there is one composite sample existing for each container. This composite sample is the field sample from which the laboratory sample can be obtained.

Figure 16: Sampling Device called 'Multisampler' (Saugbohrer) from the Company Eijkelkamp(32)

3.3.1.4 Sampling Procedure for Drilling the 17 ½ in Top Hole Section

The actual sampling of the 8 ½ in reservoir section had shown that the use of the *Multisampler* was probably not the best way to sample drilled cuttings and flocculated material. The sampling with the *Multisampler* was quite difficult as the material (especially the flocculated material) was very pasty and sticky and thus the movement of the piston in the sampling tube which was achieved by pulling the wire-line required great force and strength and sometimes it was not possible to get a continuous sample from top to bottom of the container.

Thus, the decision was not to sample with the *Multisampler* in the top hole section but to sample the same way as it was done during the wiper tripping run. However, as drilling the top hole section means drilling with a larger diameter bit the maximum grain size (95 % Percentile) changed to about 10 mm which changed the **Minimum Quantity per Increment** to **0.6 kg** and the **Minimum Quantity per Composite Sample** to **6 kg**. Other than that everything stayed the same as in the sample plan for the wiper tripping section.

3.3.2 Actual Sampling Procedures

3.3.2.1 Sampling During Wiper tripping the 12 ¼ in Hole Section

Mud samples, cutting samples and samples of flocculated material were taken during a wiper tripping run in the 12 ¼ in hole section of well X between May 16, 2010 (12:45 pm) and May 17, 2010 (11:30 am).

Geologically, this well section was in the Haller Series which primarily consists of marly clay but may show some minor limestone and sandstone layers. For the wiper tripping run a PDC bit was used. The last casing shoe was set at 380 m (13 3/8 in csg).

The sampling interval was approximately 1-2 hours. A detailed sampling protocol is shown in Table 14. From this table you can see that reaming was done from 450 m down to 1950 m; then a high viscous pill was pumped and three hole volumes were circulated in order to make sure that all cuttings were lifted and the borehole was clean for the subsequent casing run; then backreaming continued and the drill pipes were racked. Please note that the crossed lines in Table 14 mean that a certain sample could not be taken because either the flocculation was out of action or no cuttings were coming over the sieves.

The cuttings lifting time during sampling constantly increased with depth from ~10 minutes at 450 m to ~50 minutes at 1950 m (the lifting time is calculated regularly with a template at the rig site). Please note: The total circulation time (including mud retention time in surface lines and tanks) is of course longer and depends on the active mud volume. A short summary of the total number of samples taken is shown here:

- **18 mud increments (S1 – S18)**
  → 1 composite made out of S1 – S10
  → 1 composite sample made out of S11 – S18
  → the two composite samples were joined into 1 field sample
  → from each increment a subset was kept as retain sample = 18 retain samples

- **11 cutting increments (C1 – C9, C15, C16)**
  → the 11 increments were joined into 1 composite = 1 field sample
  → from each increment a subset was kept as retain sample = 11 retain samples

- **14 increments of flocculated material (G1 – G3, G5 – G15)**
  → the 14 increments were merged into 1 composite sample = 1 field sample
  → from each increment a subset was kept as retain sample = 14 retain samples

Please note: The field samples were at the same time lab samples and were sent to laboratory for analysis. The density of the different types of samples was measured once at the very beginning (in original condition) with a mud balance bar. The water contents given in brackets are approximate figures gained from experience.

- **Density of cuttings:** 1.86 kg/l (~ 25 – 40 % water content)
- **Density of flocculated material:** 1.67 kg/l (~ 50 % water content)
- **Density of mud:** 1.30 kg/l (>90 % water content)

At the shale shakers 50/50/50 and 70/70/70 API sieves were installed. The mud system used during the wiper tripping run was a water based K_2CO_3-Polymer mud (see Chapter 3.1.2.3). Additional information about the mud system and its rheology was provided from regular measurements done by rig personnel (see Table 15).

Table 14: Sampling Documentation from Wiper tripping the 12 ¼ in Hole Section

Sample No.	Date	Time	Fraction	Bit Position	Pump Rate	Remarks
S1	May 16, 2010	12:45 pm	mud	450 m	2650 l/min	
C1	May 16, 2010	12:45 pm	cuttings	450 m	2650 l/min	
G1	May 16, 2010	12:45 pm	flocculated	450 m	2650 l/min	
S2	May 16, 2010	02:15 pm	mud	590 m	2600 l/min	
C2	May 16, 2010	02:15 pm	cuttings	590 m	2600 l/min	
G2	May 16, 2010	02:15 pm	flocculated	590 m	2600 l/min	
S3	May 16, 2010	03:45 pm	mud	810 m	2620 l/min	
C3	May 16, 2010	03:45 pm	cuttings	810 m	2620 l/min	
G3	May 16, 2010	03:45 pm	flocculated	810 m	2620 l/min	
S4	May 16, 2010	04:45 pm	mud	980 m	2600 l/min	
C4	May 16, 2010	04:45 pm	cuttings	980 m	2600 l/min	
~~G4~~	~~May 16, 2010~~	~~04:45 pm~~	~~flocculated~~	~~980 m~~	~~2600 l/min~~	no flocculation
S5	May 16, 2010	05:45 pm	mud	1140 m	2590 l/min	
C5	May 16, 2010	05:45 pm	cuttings	1140 m	2590 l/min	
G5	May 16, 2010	05:45 pm	flocculated	1140 m	2590 l/min	
S6	May 16, 2010	06:45 pm	mud	1270 m	2600 l/min	
C6	May 16, 2010	06:45 pm	cuttings	1270 m	2600 l/min	
G6	May 16, 2010	06:45 pm	flocculated	1270 m	2600 l/min	
S7	May 16, 2010	07:45 pm	mud	1400 m	2600 l/min	
C7	May 16, 2010	07:45 pm	cuttings	1400 m	2600 l/min	
G7	May 16, 2010	07:45 pm	flocculated	1400 m	2600 l/min	
S8	May 16, 2010	09:15 pm	mud	1550 m	2620 l/min	
C8	May 16, 2010	09:15 pm	cuttings	1550 m	2620 l/min	
G8	May 16, 2010	09:15 pm	flocculated	1550 m	2620 l/min	
S9	May 16, 2010	10:30 pm	mud	1680 m	2620 l/min	
C9	May 16, 2010	10:30 pm	cuttings	1680 m	2620 l/min	
G9	May 16, 2010	10:30 pm	flocculated	1680 m	2620 l/min	
S10	May 16, 2010	11:30 pm	mud	1840 m	2640 l/min	
~~C10~~	~~May 16, 2010~~	~~11:30 pm~~	~~cuttings~~	~~1840 m~~	~~2640 l/min~~	no cuttings
G10	May 16, 2010	11:30 pm	flocculated	1840 m	2640 l/min	
	May 16, 2010	01:00 am	bit on bottom 1950 m: Pill pumped, 3 hole volumes circulated			
S11	May 17, 2010	01:30 am	mud	1950 m	2600 l/min	
~~C11~~	~~May 17, 2010~~	~~01:30 am~~	~~cuttings~~	~~1950 m~~	~~2600 l/min~~	no cuttings
G11	May 17, 2010	01:30 am	flocculated	1950 m	2600 l/min	
S12	May 17, 2010	03:15 am	mud	1950 m	2600 l/min	
~~C12~~	~~May 17, 2010~~	~~03:15 am~~	~~cuttings~~	~~1950 m~~	~~2600 l/min~~	no cuttings
G12	May 17, 2010	03:15 am	flocculated	1950 m	2600 l/min	
S13	May 17, 2010	06:00 am	mud	1680 m	2600 l/min	
~~C13~~	~~May 17, 2010~~	~~06:00 am~~	~~cuttings~~	~~1680 m~~	~~2600 l/min~~	no cuttings
G13	May 17, 2010	06:00 am	flocculated	1680 m	2600 l/min	
S14	May 17, 2010	07:15 am	mud	1550 m	2600 l/min	
~~C14~~	~~May 17, 2010~~	~~07:15 am~~	~~cuttings~~	~~1550 m~~	~~2600 l/min~~	no cuttings
G14	May 17, 2010	07:15 am	flocculated	1550 m	2600 l/min	

S15	May 17, 2010	08:15 am	mud	1420 m	2600 l/min	
C15	May 17, 2010	08:15 am	cuttings	1420 m	2600 l/min	
G15	May 17, 2010	08:15 am	flocculated	1420 m	2600 l/min	
S16	May 17, 2010	09:45 am	mud	1290 m	2600 l/min	
C16	May 17, 2010	09:45 am	cuttings	1290 m	2600 l/min	
~~G16~~	~~May 17, 2010~~	~~09:45 am~~	~~flocculated~~	~~1290 m~~	~~2600 l/min~~	no flocculation
S17	May 17, 2010	10:30 am	mud	1170 m	2600 l/min	
~~C17~~	~~May 17, 2010~~	~~10:30 am~~	~~cuttings~~	~~1170 m~~	~~2600 l/min~~	no cuttings
~~G17~~	~~May 17, 2010~~	~~10:30 am~~	~~flocculated~~	~~1170 m~~	~~2600 l/min~~	no flocculation
S18	May 17, 2010	11:30 am	mud	1080 m	2600 l/min	
~~C18~~	~~May 17, 2010~~	~~11:30 am~~	~~cuttings~~	~~1080 m~~	~~2600 l/min~~	no cuttings
~~G18~~	~~May 17, 2010~~	~~11:30 am~~	~~flocculated~~	~~1080 m~~	~~2600 l/min~~	no flocculation

Table 15: Mud Measurements During Sampling the 14 ½ in Section (Mud System in Use: K_2CO_3-Polymer Mud)

								Gel Strength						FAN Values						
Date	Time	SG	Viscosity [sec]	Filtrate [cm³]	Filter Cake [mm]	Plastic Viscosity	Yield Point	10''	10'	pH	Sand Content [%]	Temperature [°C]	Conductivity [mS/cm]	600	300	200	100	6	3	Potassium Content [mg/l]
16-May	12:00 PM	1.30	71	2.1	0.4	42	18	3	8	10.6	0.1		141.7	102	60	45	26	5	3	
16-May	3:00 PM	1.30	60	2.5	0.3	36	13	3	6	10.6	0.1		141.8	85	49	35	20	3	2	120,000
16-May	6:00 PM	1.30	72	2.2	0.4	41	23	4	9	10.6	0.1		142.4	105	64	49	29	5	3	
16-May	9:00 PM	1.29	70	2.4	0.4	37	19	3	7	10.6	0.1	43	140.0	93	56	41	25	4	3	
16-May	12:00 AM	1.29	67	2.5	0.4	36	17	3	5	10.6	0.1		143.3	89	53	39	23	3	2	
16-May	3:00 AM	1.29	60	2.5	0.4	32	15	3	5	10.7	0.1		146.9	79	47	35	20	3	2	
17-May	7:00 AM	1.29	61	2.6	0.4	38	11	3	5	10.7	0.1		149.7	87	49	36	21	3	2	
17-May	1:00 PM	1.29	59	2.4	0.3	38	12	3	5	10.7	0.1		152.2	78	40	31	20	3	2	120,000
17-May	2:00 AM	1.29	67	2.4	0.3	38	19	3	6	10.7	0.1		154.4	95	57	42	25	4	3	
17-May	5:00 AM	1.29	55	2.6	0.3	31	8	3	5	10.7	0.1	45	151.5	70	39	28	17	3	2	

Figure 17: Left Picture - Cuttings Flowing Over the Shale Shakers; Right Picture - Very Fine Cuttings at the Shale Shaker Discharge

**Figure 18: Left Picture - Mud at Screen Underflow of Shale Shakers (Mud Passing the Sieves and Flowing into the Tank);
Right Picture – Flocculation Unit Discharge**

Figure 19: Increments from 12 ¼ in Hole Section: Cutting Sample (Upper Left), Mud Sample (Upper Right) and Sample of Flocculated Material (Bottom)

Figure 20: Left Picture – Laboratory Samples from the Wiper tripping Run;
Right Picture - Retain Samples from the Wiper tripping Run

3.3.2.2 Sampling during Drilling the 8 ½ in Reservoir Section

Mud samples, cutting samples and samples of flocculated material were taken during three days of drilling the 8 ½ in reservoir section of well X between May 25, 2010 (09:00 am) and May 27, 2010 (02:30 pm).

The geology drilled was sandstone with interlayers of sandy and marly clay. A PDC bit was used. The last casing shoe was set at 1950 m (9 5/8 in csg). Total depth was planned to be 3404 m MD. The cuttings lifting time during sampling was approximately 30 min.

During sampling the 8 ½ in reservoir section only the mud samples were taken in a 1-2 hours intervals.

For the detailed mud sampling protocol please refer to Table 16. From this table you can also see that a reaming phase started at ~2,415 m which took about 10 hours until the bit was on bottom again.

The cutting samples and samples of flocculated material were taken directly out of the cutting boxes with the help of the *Multisampler* from *Eijkelkamp* right before the boxes were emptied.

A short summary of the total number of samples taken is shown here:

- **24 mud increments (S1 – S24)**
  → 1 composite made out of S1 – S12
  → 1 composite sample made out of S13 – S24
  → the two composite samples were joined into 1 field sample
  → from each increment a subset was kept as retain sample = 24 retain samples

- **12 cutting increments**
  → with the *Multisampler* 12 increments were drawn at different locations in the cuttings box and joined into 1 composite sample = 1 field sample
  → from the composite sample a subset was kept as retain sample = 1 retain samples

- **12 increments of flocculated material**
  → with the *Multisampler* 12 increments were drawn at different locations in the cuttings box and joined into 1 composite sample = 1 field sample
  → from the composite sample a subset was kept as retain sample = 1 retain samples

Please note: The field samples were at the same time lab samples and were sent to laboratory for analysis. The density of the different types of samples was measured once at the beginning (in original condition) with a mud balance bar. The water contents given in brackets are approximate figures gained from experience.

Density of cuttings:	1.83 kg/l (~ 25 – 40 % water content)
Density of flocculated material:	1.62 kg/l (~ 50 % water content)
Density of mud:	1.20 kg/l (>90 % water content)

At the shale shakers 50/50/50 and 70/70/70 API sieves were installed. The mud system used during drilling the 8 ½ in reservoir section was water based K_2CO_3-Polymer mud with additive MIX II (see Chapter 3.1.2.4). Additional information about the mud system and its rheology was provided from regular measurements done by rig personnel (see Table 17).

Table 16: Sampling Documentation (Mud Samples Only) from Drilling the 8 ½ in Reservoir Section

Sample No.	Date	Time	Fraction	Bit Position	Pump Rate	Remarks
S1	May 25, 2010	09:00 am	mud	2193 m	1900 l/min	
S2	May 25, 2010	10:30 am	mud	2200 m	1900 l/min	
S3	May 25, 2010	12:00 pm	mud	2215 m	1900 l/min	
S4	May 25, 2010	01:30 pm	mud	2230 m	1900 l/min	
S5	May 25, 2010	02:30 pm	mud	2239 m	1900 l/min	
S6	May 25, 2010	03:45 pm	mud	2248 m	1900 l/min	
S7	May 25, 2010	05:00 pm	mud	2262 m	1900 l/min	
S8	May 25, 2010	06:00 pm	mud	2272 m	1900 l/min	
S9	May 26, 2010	07:00 am	mud	2415 m	1900 l/min	
S10	May 26, 2010	08:00 am	mud	2407 m	1900 l/min	tripping, reaming
S11	May 26, 2010	09:45 am	mud	2383 m	1900 l/min	
S12	May 26, 2010	11:15 am	mud	2322 m	1900 l/min	
S13	May 26, 2010	01:00 pm	mud	2270 m	1900 l/min	
S14	May 26, 2010	02:45 pm	mud	2200 m	1900 l/min	
S15	May 26, 2010	04:30 pm	mud	2100 m	1900 l/min	
S16	May 26, 2010	06:00 pm	mud	1959 m	2000 l/min	
S17	May 27, 2010	07:00 am	mud	2442 m	1900 l/min	
S18	May 27, 2010	08:30 am	mud	2444 m	1900 l/min	
S19	May 27, 2010	09:30 am	mud	2463 m	1900 l/min	
S20	May 27, 2010	10:30 am	mud	2471 m	1900 l/min	
S21	May 27, 2010	11:30 am	mud	2479 m	1900 l/min	
S22	May 27, 2010	12:15 pm	mud	2486 m	1900 l/min	
S23	May 27, 2010	01:30 pm	mud	2489 m	1900 l/min	
S24	May 27, 2010	02:30 pm	mud	2499 m	1900 l/min	

Table 17: Mud Measurements During Sampling the 8 ½ in Reservoir Section (Mud System in Use: K_2CO_3-Polymer Mud + Additive MIX II)

								Gel Strength						FAN Values						
Date	Time	SG	Viscosity [sec]	Filtrate [cm^3]	Filter Cake [mm]	Plastic Viscosity	Yield Point	10"	10'	pH	Sand Content [%]	Temperature [°C]	Conductivity [mS/cm]	600	300	200	100	6	3	Potassium Content [mg/l]
25-May	7:00 AM	1.20	63	2.7	0.4	41	6	2	3	10.8	0.3		152.4	88	47	35	19	3	2	
25-May	10:00 AM	1.21	63	2.3	0.3	41	9	2	3	10.8	0.2		152.4	91	50	35	19	2	1	
25-May	1:00 PM	1.21	63	2.4	0.3	39	7	2	2	10.7	0.2	61.2	151.7	85	46	33	18	2	1	
25-May	3:00 PM	1.21	62	2.3	0.3	41	9	2	3	10.7	0.2		149.1	91	50	35	19	2	1	101,000
25-May	6:00 PM	1.22	59	2.3	0.3	36	6	2	2	10.7	0.2		149.9	78	42	30	16	2	1	
25-May	9:00 PM	1.23	54	2.4	0.3	33	6	2	2	10.7	0.1	61.6	146.5	72	39	27	15	2	1	
25-May	11:00 PM	1.22	56	2.2	0.3	35	9	2	3	10.7	0.2		144.9	79	44	31	17	2	1	
25-May	2:00 AM	1.21	59	2.1	0.3	37	11	3	4	10.7	0.2		139.7	85	48	34	19	3	2	
25-May	5:00 AM	1.21	53	2.0	0.3	32	8	2	3	10.7	0.2	60.8	131.8	72	40	29	16	2	1	110,000
26-May	7:00 AM	1.21	55	2.2	0.3	32	7	1	3	10.6	0.2		140.2	71	39	28	16	2	1	
26-May	10:00 AM	1.21	56	2.5	0.3	32	7	2	3	10.6	0.2		138.4	71	39	28	16	2	1	
26-May	1:00 PM	1.21	56	2.5	0.3	31	9	2	3	10.7	0.1	58.0	136.1	71	40	29	16	2	1	
26-May	3:00 PM	1.21	59	2.5	0.3	33	9	2	3	10.6	0.1		138.1	75	42	30	17	2	1	
26-May	6:00 PM	1.21	56	2.5	0.3	31	9	2	3	10.6	0.1		137.5	71	40	29	16	2	1	
26-May	11:00 PM	1.22	62	2.0	0.3	41	10	3	4	10.6	0.3		136.8	92	51	37	21	3	2	
26-May	2:00 AM	1.22	56	2.2	0.3	32	10	2	3	10.6	0.2		135.3	74	42	30	17	2	1	
26-May	5:00 AM	1.21	54	2.2	0.3	31	7	2	3	10.6	0.2	55.3	131.0	69	38	25	15	2	1	105,000
27-May	7:00 AM	1.20	55	2.5	0.3	30	8	2	3	10.6	0.2		130.2	68	38	28	16	3	2	
27-May	10:00 AM	1.20	54	2.4	0.2	28	7	2	3	10.6	0.2		129.4	63	35	25	14	2	1	
27-May	1:00 PM	1.20	55	2.5	0.2	28	10	2	3	10.6	0.2	56.6	127.0	66	38	27	15	2	1	
27-May	3:00 PM	1.20	53	2.6	0.2	27	8	2	3	10.5	0.2		125.2	62	35	25	14	2	1	
27-May	6:00 PM	1.21	57	2.3	0.2	30	11	3	3	10.5	0.3		125.0	71	41	30	17	3	2	
27-May	9:00 PM	1.21	65	2.2	0.3	37	13	2	4	10.5	0.3	62.2	123.8	87	50	36	20	3	2	
27-May	11:00 PM	1.22	60	2.2	0.3	32	17	2	3	10.6	0.3		124.5	81	49	35	19	2	1	

Figure 21: Very Fine Cuttings (from the 8 ½ in Reservoir Section) Flowing Over the Shale Shakers. Due to the Additive MIX II the Mud Appears to Be Foamy.

Figure 22: Sampling of Flocculated Material from the 8 ½ in Reservoir Section. The Samples Were Taken Out of the Container with the Help of the Multisampler from Eijkelkamp.

Figure 23: Increment Sample of Flocculated Material from the 8 ½ in Reservoir Section. The Picture Shows the Sticky and Pasty Consistency of the Samples Taken with the Eijkelkamp Multisampler.

3.3.2.3 Sampling During Drilling the 17 ½ in Top Hole Section

Mud samples, cutting samples and samples of flocculated material were taken during drilling the 17 ½ in top hole section of well Y between July 13, 2010 (07:00 am) and July 15, 2010 (06:00 am).

The geology drilled was the Quaternary which consisted of lacustrine clay from 0 m down to 208 m. Afterwards, from 208 m down to 220 m the ground moraine (=gravel, sand and silt) followed. From 220 m onwards marly clay was drilled. For this top hole section a roller cone bit was used.

The sampling interval was approximately 1-2 hours. A detailed sampling protocol is shown in Table 18. Please note that the crossed lines in Table 18 mean that a certain sample could not be taken because the flocculation was out of action.

The cuttings lifting time during sampling constantly increased with depth from ~5 minutes at 73 m to ~20 min at 375 m.

A short summary of the total number of samples taken is shown here:

- **13 mud increments (S1 – S13)**
  → the 13 increments were joined into 1 composite sample = 1 field sample
  → from the composite sample a subset was kept as retain sample = 1 retain sample
- **13 cutting increments (C1 – C13)**
  → the 13 increments were joined into 1 composite sample = 1 field sample
  → from the composite sample a subset was kept as retain sample = 1 retain samples
- **11 increments of flocculated material (G2 – G10, G12, G13)**
  → the 14 increments were joined into 1 composite sample = 1 field sample
  → from the composite sample a subset was kept as retain sample = 1 retain samples

Please note: The field samples were at the same time lab samples and were sent to laboratory for analysis. The density of the different types of samples was measured once at the beginning (in original condition) with a mud balance bar. The water contents given in brackets are approximate figures gained from experience.

- **Density of cuttings:**	1.60 SG (~ 25 – 40 % water content)
- **Density of flocculated material:**	1.38 SG (~ 50 % water content)
- **Density of mud:**	1.15 SG (>90 % water content)

On both shale shakers 50/50/50 API sieves were installed. The mud system used during drilling the top hole section was a freshwater bentonite mud (see Chapter 3.1.2.2). Table 19 shows the results of regular measurements for bentonite mud. Please note that this table is not incomplete, but for bentonite mud only S.G., Viscosity, Sand Content, and sometimes Temperature are measured by the rig personnel.

Table 18: Sampling Documentation from Drilling the 17 ½ in Top Hole Section

Sample No.	Date	Time	Fraction	Bit Position	Pump Rate	Remarks
S1	July 13, 2010	07:00 am	mud	73 m	2000 l/min	
C1	July 13, 2010	07:00 am	cuttings	73 m	2000 l/min	
~~G1~~	~~July 13, 2010~~	~~07:00 am~~	~~flocculated~~	~~73 m~~	~~2000 l/min~~	no flocculation
S2	July 13, 2010	08:00 am	mud	87 m	2200 l/min	
C2	July 13, 2010	08:00 am	cuttings	87 m	2200 l/min	
G2	July 13, 2010	08:00 am	flocculated	87 m	2200 l/min	
S3	July 13, 2010	10:30 am	mud	95 m	2150 l/min	
C3	July 13, 2010	10:30 am	cuttings	95 m	2150 l/min	
G3	July 13, 2010	10:30 am	flocculated	95 m	2150 l/min	
S4	July 13, 2010	11:30 am	mud	110 m	2550 l/min	
C4	July 13, 2010	11:30 am	cuttings	110 m	2550 l/min	
G4	July 13, 2010	11:30 am	flocculated	110 m	2550 l/min	
S5	July 13, 2010	12:30 pm	mud	119 m	2700 l/min	
C5	July 13, 2010	12:30 pm	cuttings	119 m	2700 l/min	
G5	July 13, 2010	12:30 pm	flocculated	119 m	2700 l/min	
S6	July 13, 2010	01:30 pm	mud	128 m	2700 l/min	
C6	July 13, 2010	01:30 pm	cuttings	128 m	2700 l/min	
G6	July 13, 2010	01:30 pm	flocculated	128 m	2700 l/min	
S7	July 14, 2010	06:00 am	mud	234 m	2800 l/min	
C7	July 14, 2010	06:00 am	cuttings	234 m	2800 l/min	
G7	July 14, 2010	06:00 am	flocculated	234 m	2800 l/min	
S8	July 14, 2010	08:00 am	mud	238 m	2600 l/min	
C8	July 14, 2010	08:00 am	cuttings	238 m	2600 l/min	
G8	July 14, 2010	08:00 am	flocculated	238 m	2600 l/min	
S9	July 14, 2010	09:30 am	mud	249 m	2900 l/min	
C9	July 14, 2010	09:30 am	cuttings	249 m	2900 l/min	
G9	July 14, 2010	09:30 am	flocculated	249 m	2900 l/min	
S10	July 14, 2010	11:00 am	mud	255 m	2800 l/min	
C10	July 14, 2010	11:00 am	cuttings	255 m	2800 l/min	
G10	July 14, 2010	11:00 am	flocculated	255 m	2800 l/min	
S11	July 14, 2010	12:00 pm	mud	265 m	2800 l/min	
C11	July 14, 2010	12:00 pm	cuttings	265 m	2800 l/min	
~~G11~~	~~July 14, 2010~~	~~12:00 pm~~	~~flocculated~~	~~265 m~~	~~2800 l/min~~	no flocculation
S12	July 14, 2010	01:00 pm	mud	278 m	2800 l/min	
C12	July 14, 2010	01:00 pm	cuttings	278 m	2800 l/min	
G12	July 14, 2010	01:00 pm	flocculated	278 m	2800 l/min	
S13	July 15, 2010	06:00 am	mud	375 m	3000 l/min	
C13	July 15, 2010	06:00 am	cuttings	375 m	3000 l/min	
G13	July 15, 2010	06:00 am	flocculated	375 m	3000 l/min	

Table 19: Mud Measurements During Sampling the 17 ½ in Top Hole Section
(Mud System in Use: Pure Bentonite Mud)

								Gel Strength						FAN Values						
Date	Time	SG	Viscosity [sec]	Filtrate [cm^3]	Filter Cake [mm]	Plastic Viscosity	Yield Point	10"	10'	pH	Sand Content [%]	Temperature [°C]	Conductivity [mS/cm]	600	300	200	100	6	3	Potassium Content [mg/l]
13-Jul	7:00 AM	1.33	104								0.2									
13-Jul	10:00 AM	1.32	82								0.2									
13-Jul	12:00 PM	1.21	103								0.2									
13-Jul	2:00 PM	1.21	130								0.2									
13-Jul	6:00 PM	1.21	104								0.2									
13-Jul	9:00 PM	1.18	120								0.2									
13-Jul	11:00 PM	1.23	∞								0.4									
13-Jul	2:00 AM	1.24	∞								0.5									
13-Jul	5:00 AM	1.18	86								0.2									
14-Jul	7:00 AM	1.18	160								0.2									
14-Jul	10:00 AM	1.15	85								0.2									
14-Jul	1:00 PM	1.17	143								0.2									
14-Jul	3:00 PM	1.16	102								0.2									
14-Jul	5:00 PM	1.15	∞								0.2									
14-Jul	9:00 PM	1.14	135								0.2									
14-Jul	11:00 PM	1.12	105								0.2									
14-Jul	2:00 AM	1.13	120								0.2									
14-Jul	5:00 AM	1.13	118								0.2									
15-Jul	7:00 AM	1.12	125								0.2									
15-Jul	5:00 AM	1.17	80								0.2	62.6								

Figure 24: Bentonite Mud Sample – Note the Viscous and Thixotropic Nature of the Mud

Figure 25: Cutting Sample (Left) and Flocculated Material (Right) from the Top Hole Section Where Bentonite Mud Was Used

3.3.3 Recommended Sampling Procedure for the Future

The *Multisampler from Eijkelkamp* was not the perfect tool to sample cuttings and flocculated material on the RAG rig.

One reason for that is the consistency of the material (especially the sticky flocculated material) which posed some problems during sampling and the other reason is the accessibility of the cuttings boxes which is not given everywhere.

My recommendation for sampling cuttings and flocculated material for future investigations is to do it in certain time intervals as it has been done during the wiper tripping run and during drilling the top hole section.

If more regular samples are necessary, the time interval can be shortened or small boxes / other suitable collecting trays can be used to catch the cuttings during a specified time (e.g. 30 minutes or all 5m drilled) and then take a representative sample out of this tray. This way, it is guaranteed that nothing is missed.

3.4. Sample Preparation

3.4.1 Homogenization

When the increment samples of the different fractions were merged into composite samples they were homogenized with a self-made blender wand that could be attached to an electric drill. The homogenized samples were then sent to laboratory for analysis.

Figure 26: Self-Made Blender Wand Attached to an Electric Drill

3.4.2 Sample Preparation for LECO Measurement

In order to find out which fraction of the TOC content of solids comes from the rock itself (coal or hydrocarbons) a LECO measurement was conducted on mud-free and cutting samples.

Hence, subsets of the composite cutting samples from the wiper tripping run as well as from the reservoir section were washed through a sieve so that they were not contaminated by mud anymore. Therefore, a strong water jet and an ordinary tea strainer were used. Then the samples were air-dried over night at room temperature. Afterwards, the dried cutting samples needed to be ground into rock powder so that they could be measured with the LECO measuring device at the Petroleum Geology Department at the Montanuniversität Leoben. For a LECO measurement only 0.1 g rock powder per crucible is needed.

The LECO measuring technique is explained in Chapter 3.5.2.

Figure 27: Washed and Sieved Cutting Samples from the Wiper tripping Run (Left Picture) and from the Reservoir Section (Right Picture)

Figure 28: Ground Cutting Samples (=Rock Powder) from the Wiper tripping Run (Left Picture) and from the Reservoir Section (Right Picture) that were used for the LECO Measurement

3.4.3 Experiments with Retain Samples

3.4.3.1 Dehydration

As dehydration would be an easy and cheap treatment for cuttings and flocculated material, an experiment was conducted which should show whether the TOC content can be reduced when the material is subject to dehydration. Thus, subsets of the composite cutting samples from the wiper tripping run as well as from the reservoir section and subsets from the composite samples of flocculated material from the wiper tripping run as well as from the reservoir section were taken and filled into four 26x20 cm aluminum trays. They height of the material in the aluminum trays was only ~1cm so that a large surface area was obtained for the drying action. Then the four aluminum trays were placed into a drying chamber. The samples were dried under full air supply at 80°C for 115.5 hours. Start of dehydration was Wednesday, 13 July 2010 at 03:30 pm and it stopped on Monday, 19 July 2010 at 11:00 am.

After the first 24 hours (Thursday, 14 July at 03:30 pm) in the drying chamber the samples were taken out from the aluminum plates and put into glass bowls as there were minor indications that the cuttings and flocculated material could react with the aluminum at high temperatures. The dry material was then sent to the laboratory for a TOC analysis (solid and eluate content) and for a LOI (loss on ignition) analysis. It should be noted that the samples had been stored at room temperature for ~ 2 months before the dehydration experiment started.

Figure 29: Drying Chamber

Figure 30: Dried Cuttings (Left) and Dried Flocculated Material (Right) from the Wiper tripping Run

Figure 31: Dried Cuttings (Left) and Dried Flocculated Material (Right) from the Reservoir Section

3.4.3.2 Sunlight & Acidification/Neutralization

One observation that was made in reality was the reduction of TOC content over time at near surface zones of a cuttings heap. The question was now whether this is explained by rainwater washing out the TOC of the surface near zones of a heap or if there was a solar induced degradation of organic matter taking place as well. In order to investigate this, additional experiments with retained samples from the reservoir section were conducted. Please note that the cellulose polymer MIX II was in the mud system during sampling the reservoir section.

The cutting retain samples were divided into four subsets; two of which were exposed to natural sunlight and the other two to artificial sunlight for about ~3 weeks. From the two samples that were exposed to natural sunlight (or to artificial sunlight, respectively) one sample was additionally acidized with citric acid in order to reduce the pH to about 5.5 – 7.0 to allow for bacterial activity and see if this would cause even more reduction in TOC. The same was done with the retain samples of flocculated material. All samples were filled into aluminum plates. Filling height was about 1 cm. Table 20 gives an overview of all the prepared retain samples.

It should be noted that the retain samples had been stored for ~2.5 months at room temperature before those experiments started. When citric acid was added to the retain samples a chemical reaction started, and the cuttings started to swell and an ammonia smell was observed. After some minutes of reaction the mass became set (it solidified). However, when the same was tried with fresh cuttings and flocculated material at the rig site this phenomenon could not be verified. There was no swelling and setting of the material. However, this fresh material was not drilled with MIX II in the system. It is recommended to repeat this experiment with MIX II in the system.

The samples that should be exposed to natural sunlight were placed at the balcony. Those samples were subject to day / night effects, direct sunlight / shade effects, and bad weather. The samples that were exposed to artificial sunlight had no day and night effects as the lamps were not turned off during those ~3 weeks of exposition. However, due to the set-up of the lamps there have been some lateral irradiation effects which were tried to be compensated by a reflector mat. The lamps used were ordinary desk lights but with energy-saving daylight bulbs. Trademark: *Philips Tornado CDL 865, 220-240 V, E 27 ES 8000 h, 1450 Lumen, 23 Watt (=130 Watt), 6500 Kelvin.*

Definitions: Lumen, Lux and Kelvin

The **Lumen** is the SI derived unit of luminous flux, a measure of the power of light perceived by the human eye.(43) The **Lux** is the SI unit of illuminance, a measure of how much luminous flux is spread over a given area.(42) One can think of luminous flux as a measure of the total "amount" of visible light present, and the illuminance is a measure of the intensity of illumination on a surface.(42)

One Lux is equal to one Lumen per square metre: **1 Lux = 1 Lumen/m^2**.(42) On a sunny cloudless day in Austria between 50,000 and 100,000 Lux are striking the ground.(44) On a dull winters day in Austria only 3,000 – 4,000 Lux are hitting the earth's surface.(44)

"The **Kelvin** is often used as the measure of the color temperature of light sources. Color temperature is based upon the principle that a black body radiator emits light whose color depends on the temperature of the radiator. Black bodies with temperatures below about 4000 K appear reddish whereas those above about 7500 K appear bluish."(41) The sun is equal to a black body radiator of about 6500 K.(44)

In the experiment about 21,000 Lux were achieved as the following calculation shows:

Total exposition area = (26 cm + 26 cm) x (20 cm + 20 cm) = 2,080 cm^2 = **$\underline{0.208\ m^2}$**

Lux = Lumen / m^2 = 3 x 1450 Lumen / 0.208 m^2 = **$\underline{20{,}913\ \text{Lux}}$**

The material was then sent to the laboratory for a TOC analysis (solid and eluate).

Table 20: Overview of Retain Samples Exposed to either Natural or Artificial Sunlight

Retain Sample		Details of Exposure	Neutralization	Total Amount	Exposed Area
Cuttings Reservoir Section	Subset 1	Artificial Sunlight from electric daylight bulbs, big open room (no doors), continuous air circulation, 3 lamps that were turned on 24 hours a day, each 1450 lumen, ~30 cm distance between lamp and sample	Without citric acid (pH~10,5)	~ 600 g	All samples were filled into aluminum plates (26x20 cm). Filling height: ~1 cm
	Subset 2		3 heaped tablespoons of citric acid were added (pH~7)	~ 600 g	
	Subset 3	Natural sunlight, outdoor, roofed balcony, day/night effects, direct sunlight/shade effects	Without citric acid (pH~10,5)	~ 600 g	
	Subset 4		3 heaped tablespoons of citric acid were added (pH~7)	~ 600 g	
Flocculated Material Reservoir Section	Subset 1	Artificial Sunlight from electric daylight bulbs, big open room (no doors), continuous air circulation, 3 lamps that were turned on 24 hours a day, each 1450 lumen, ~30 cm distance between lamp and sample	Without citric acid (pH~10,5)	~ 600 g	
	Subset 2		3 heaped tablespoons of citric acid were added (pH~7)	~ 600 g	
	Subset 3	Natural sunlight, outdoor, roofed balcony, day/night effects, direct sunlight/shade effects	Without citric acid (pH~10,5)	~ 600 g	
	Subset 4		3 heaped tablespoons of citric acid were added (pH~7)	~ 600 g	

Figure 32: Picture from 2010/08/03 – Retain Samples from the Reservoir Section When Exposition to Natural Sunlight Started (Flocculated Material at Front Left, Acidified Cuttings at Front Right, Cuttings at Rear Left, Acidified Flocculated Material at Rear Right)

Figure 33: Picture from 2010/08/15 – Retain Samples from the Reservoir Section after Being Exposed to Natural Sunlight for ~ 2 Weeks (from Left to Right: Acidified Cuttings, Flocculated Material, Cuttings, Acidified Flocculated Material)

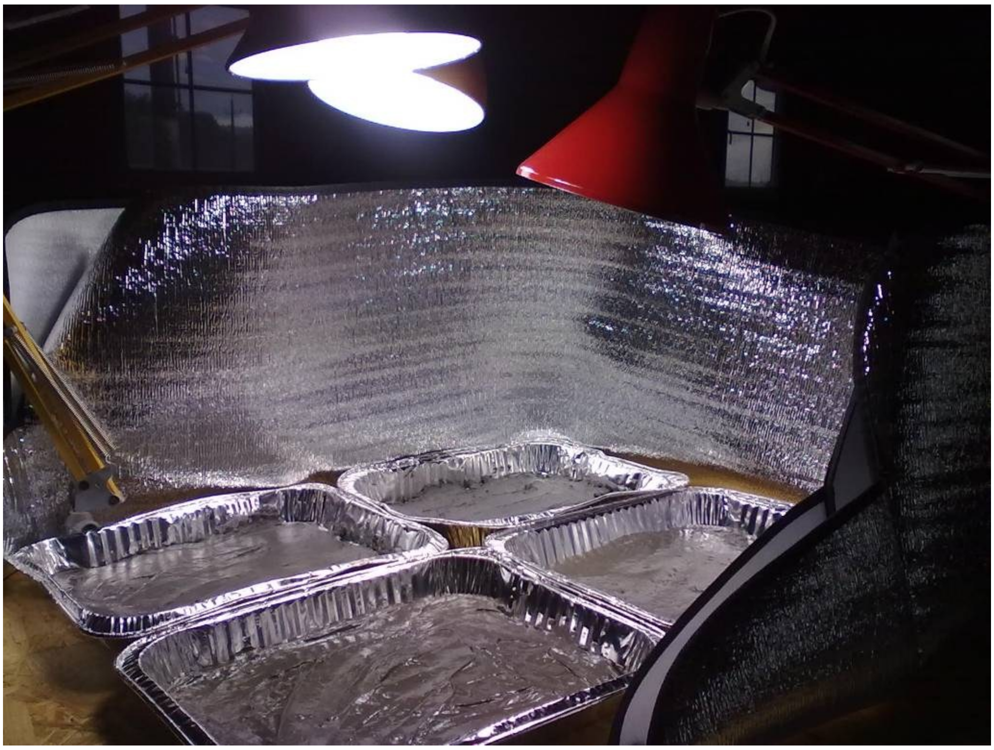


Figure 34: Picture from 2010/08/03 – Retain Samples from the Reservoir Section When Exposition to Artificial Sunlight Started: Flocculated Material at Front Left, Cuttings at Front Right, Acidified Flocculated Material at Rear Left, Acidified Cuttings at Rear Right

Figure 35: Picture from 2010/08/15 - Retain Samples from the Reservoir Section After Being Exposed to Artificial Sunlight for ~ 2 Weeks: Flocculated Material at Front Left, Cuttings at Front Right, Acidified Flocculated Material at Rear Left, Acidified Cuttings at Rear Right

3.5. Lab Analysis

3.5.1 Analysis Techniques for Characterization According to the Landfill Regulation 2008

3.5.1.1 Analysis Techniques for the Solids Content

Table 21 and Table 22 were provided by the accredited laboratory Görtler Analytical Services who carried out the lab analysis of the cutting and mud samples. Table 21 shows which standards are used for measuring certain parameters of the solids content. For example, the standard that is used for determining the TOC content of solids is: *"ÖNORM EN 13137 Characterization of Waste – Determination of Total Organic Carbon (TOC) in Waste, Sludges and Sediments".*

Measuring the TOC Content of Solids According to ÖNORM EN 13137

For this standard the following definitions are valid (these definitions may differ from other scientific definitions)

> **"Total Carbon TC**: Amount of carbon contained in waste; it can be organically and inorganically bound or may be present as elemental carbon."(50)
>
> **"Total Inorganic Carbon TIC:** Amount of carbon that is released as carbon dioxide CO_2 if the waste sample is treated with acid."(50)
>
> **"Total Organic Carbon TOC:** Amount of carbon which is transformed into carbon dioxide CO_2 during combustion and which is not released as CO_2 during treatment with acid."(50)

Field of Application:

"Organic carbon occurs in different forms in waste as well as in sludges and sediments. Because of the high variety of possible organic carbon compounds a quantitative determination of all single organic components is not doable. Thus, only sum parameters can be measured. The TOC is such a sum parameter which is usually used for determining the disposability of waste. This standard describes two methods for determining the TOC in undried waste samples with more than 1 g carbon per kg dry matter which means a TOC > 0.1 %.

Elemental carbon, carbides, cyanides, cyanates, isocyanates, isothycyanates and thiocyanate are also measured as TOC. Currently, there is no standardized measuring technique available for determining the elemental carbon."(50)

Principle of Direct and Indirect TOC Measurements

The TOC can be measured either with direct or indirect methods.

"Indirect Method: Here, the TOC is determined from the difference of the results of TC and TIC measurement. The TC of the undried sample is transformed into CO_2 during combustion in an oxygen containing gas stream which is free of CO_2. In order to ensure complete combustion catalysts or other additives can be used. The released CO_2 is determined with a suitable measuring technique (e.g. gravimetry, infrared spectrometry, coulometry, etc.). The TIC is determined separately from another aliquot of the original sample via acidizing, blowing out of the released CO_2 and measuring the CO_2 with a suitable measuring technique."(50)

"Direct Method: First, the carbonate is removed from the undried sample by acid treatment. Afterwards, the sample is combusted and the released CO_2 is detected with a suitable measuring technique. The measured CO_2 is a direct measure for the TOC."(50)

Application and Potential Problems to Consider

"Generally, the direct and indirect methods can be used for the same TOC contents and TIC/TOC ratios and deliver comparable results. However, the direct method can lead to erroneous results if the sample contains volatile substances which are vaporized during the acid treatment or if side reactions between the sample and the used acid are taking place. In case of doubt the indirect method should be preferred. The quality of the results of the direct method is more dependent on the experience and practice of the laboratory technician. This is especially true for the procedural steps prior to combustion. Biologically active samples need to be analyzed immediately or need to be stored at a minimum of -18°C. For biologically inactive samples no special conservation is necessary. The samples provided for analysis should be as homogeneous as possible and undried. If the samples contain negligible amounts of volatile compounds (except water) they can be dried at 105°C prior to homogenization.

In case of liquid sludges also freeze-drying can be undertaken. The water content is determined on a separate aliquot of the original sample. For samples with no or negligible volatile organic compounds the water content is calculated out of the dry residue.

This standard does not recommend applicable apparatuses concerning the construction type and operational mode. The amount of sample taken should be as large as possible and it is important that the released amount of CO$_2$ lies in the working area of the used device and the calibration, respectively. The measurements are executed at least twice. The difference between the individual results should be ≤10% of the mean value.

For calculating the final analysis results the calibration function, the weight of sample taken, the detection methods, process related constants, water content, and dilution factors.”(50)

Table 21: Analysis Techniques for the Solids Content

Parameter	Analyseverfahren	Bestimmungsgrenze	Einheit
Trockenrückstand	ÖNORM EN 14346	—	—
Glühverlust	DIN EN 12879 (S3a)	—	—
KW-Index	ÖNORM EN 14039	20	mg/kgTR
TOC	ÖNORM EN 13137	1.000	mg/kgTR
Phenolindex	in Anlehnung an DIN 38409-H16-3	0,1	mg/kgTR
POX	in Anlehnung an DIN 38414-S17	0,2	mg/kgTR
EOX	DIN 38414-S17	0,5	mg/kgTR
Summe AKW (BTX)	ISO/DIS 22155, GC/FID, Headspace-Technik	0,1	mg/kgTR
Summe PCB	DIN ISO 10382, GC/ECD	0,01	mg/kgTR
Summe PAK (16 Parameter n. US EPA)	ÖNORM L 1200, HPLC-UV/F	0,5	mg/kgTR
Säureneutralisierungs-kapazität		0,1	mmol/kg
Königswasseraufschluss	ÖNORM EN 13657	—	mg/kgTR
Metalle:	DIN EN ISO 11885 (E22), ICP-OES		mg/kgTR
Aluminium (Al)		5,0	mg/kgTR
Antimon (Sb)		5,0	mg/kgTR
Arsen (As)		3,0	mg/kgTR
Barium (Ba)		3,0	mg/kgTR
Beryllium (Be)		2,0	mg/kgTR
Blei (Pb)		3,0	mg/kgTR
Bor (B)		3,0	mg/kgTR
Cadmium (Cd)		0,3	mg/kgTR
Calcium (Ca)		1,0	mg/kgTR
Chrom$_{gesamt}$ (Cr$_{ges}$)		2,0	mg/kgTR
Eisen (Fe)		0,1	mg/kgTR
Kobalt (Co)		2,0	mg/kgTR
Kupfer (Cu)		2,0	mg/kgTR
Magnesium (Mg)		1,0	mg/kgTR
Mangan (Mn)		5,0	mg/kgTR
Molybdän (Mo)		5,0	mg/kgTR
Nickel (Ni)		2,0	mg/kgTR
Selen (Se)		5,0	mg/kgTR
Silber (Ag)		2,0	mg/kgTR
Thallium (Tl)		0,5	mg/kgTR
Vanadium (V)		2,0	mg/kgTR
Zink (Zn)		2,0	mg/kgTR
Zinn (Sn)		5,0	mg/kgTR
Quecksilber (Hg)	DIN EN 1483 (E12), AAS-Kaltdampftechnik	0,1	mg/kgTR
Chrom VI	DIN 19734	1,0	mg/kgTR

3.5.1.2 *Analysis Techniques for the Eluate Content*

Table 22 shows which standards are used for measuring certain parameters of the eluate content. For example, the standard that is used for determining the TOC content in the eluate is: *“ÖNORM EN 13370 Characterization of Waste – Analysis of Eluates – Determination of Ammonium, AOX, Conductivity, Hg, Phenol Index, TOC, Easily Liberatable* CN^- *,* F^-*”.* This standard only contains some general information and refers to the standard *“ÖNORM EN 1484 – Water Analysis – Guidelines for the Determination of Total Organic Carbon (TOC) and Dissolved Organic Carbon (DOC)”.*

“In ÖNORM EN 13370 it is also mentioned that the ÖNORM EN 1484 was primarily developed for analyzing water samples. The validation was carried out by means of a round robin test for a limited number of other waste eluates which were: contaminated soil, sewage sludge, sandblasting waste, and fly ash filter cake of a municipal waste incineration. The suitability of the standard ÖNORM EN 1484 for waste eluates other than mentioned before needs to be checked and decided by the laboratory that conducts the analysis.”(51)

Measuring the TOC Content of Eluates According to ÖNORM EN 1484:

For this standard the following definitions are valid (these definitions may differ from scientific definitions):

“Eluate: A solution that is obtained from a leaching process.”(52)

“Eluent: An aqueous solution which is used for the leaching process.”(52)

“Total Carbon TC: The sum of organically bound and inorganically bound carbon present in water, including elemental carbon.”(52)

“Total Inorganic Carbon TIC: The sum of carbon present in water, consisting of elemental carbon, total carbon dioxide, carbon monoxide, cyanate, and thiocyanate. TOC instruments mostly register as TIC only the CO_2 originating from hydrogen carbonates and carbonates.”(52)

“Total Organic Carbon TOC: Total organic carbon (TOC) is a measure of the carbon content of dissolved and undissolved organic matter present in the

> water. It does not give information on the nature of the organic substance. The TOC is the sum of organically bound carbon present in water, bonded to dissolved or suspended matter. Cyanate, elemental carbon and thiocyanate will also be measured."(52)
>
> **"Dissolved Organic Carbon DOC:** The sum of organically bound carbon present in water originating from compounds which will pass a membrane filter of pore size of 0.45 µm. Cyanate and thiocyanate are also measured."(52)
>
> **"Volatile Organic Carbon VOC (or POC):** Under the conditions of this method purgeable organic matter (POC)."(52)
>
> **"Non-Volatile Organic Carbon NVOC (or NPOC):** Under the conditions of this method non-purgeable organic carbon (NPOC)."(52)

Field of Application:

"The standard ÖNORM EN 1484 gives guidance for the determination of organic carbon in drinking water, ground water, surface water, sea water and waste water. It deals with water samples having a content of organic carbon ranging from 0.3 mg/l to 1,000 mg/l (whereby the lower value is only applicable in special cases, e.g. drinking water). Higher concentrations may be determined after appropriate dilution. The standard does not deal with instrument-dependent aspects.

In addition to organic carbon the water sample may contain carbon dioxide or ions of carbonic acid. Prior to the TOC determination, it is essential that this inorganic carbon is removed by purging the acidified sample with a gas which is free of CO_2 and organic compounds. Alternatively, both total carbon (TC) and total inorganic carbon (TIC) may be determined and the organic carbon content (TOC) may be calculated by subtracting the total inorganic carbon from the TC. This method is particularly suitable for samples in which the total inorganic carbon is less than the TOC.

Purgeable organic substances, such as benzene, toluene, cyclohexane, and chloroform may partly escape upon stripping. In presence of these substances the TOC concentration is determined separately, or the differential method (TC - TIC = TOC) may be applied."(52)

Principle of the Measurement

“Oxidation of organic carbon in water to carbon dioxide by combustion, by the addition of an appropriate oxidant, by UV radiation or any other high-energy radiation.

The application of the ultraviolet method with only oxygen gas as an oxidant is restricted to low polluted waters containing low concentrations of TOC.

Inorganic carbon is removed by acidification and purging or is determined separately.

The carbon dioxide formed by oxidation is determined either directly or after reduction, for example, to methane (CH_4).

The final determination of CO_2 is carried out by a number of different procedures, for example: Infrared spectrometry, titration (preferably in non-aqueous solution), thermal conductivity, conductometry, coulometry, CO_2-sensitive sensors and flame ionization detection - used after reduction of the CO_2, among others, to methane.”(52)

Determination Procedure to Follow

“Determine the TOC concentrations of the samples in accordance with the instrument manufacturer’s instructions. In the case of direct determination of the TOC, remove the total inorganic carbon (ensure that the pH is below 2) prior to analysis. Carefully minimize the loss of volatile organic substances. The TOC concentration should be within the working range of the calibration. This can be achieved by diluting the sample. Prior to each batch of TOC determinations (for example 10 determinations) carry out appropriate control experiments at the intervals recommended by the manufacturer or specified by the laboratory. After acidification, blow a stream of pure inert gas free of CO_2 and organic impurities through the system (for approximately 5 min) in order to remove CO_2.

Depending on the type of TOC instrument used, different kinds of readings may be obtained from which the TOC or DOC concentration of the analyzed sample is calculated. Calculate the mass concentration using the calibration curve. The mass concentration of TOC or DOC is calculated in mg/l. It can be converted into mg/kg dry matter.”(52)

Table 22: Analysis Techniques for the Eluate Content

Parameter		Analyseverfahren	Bestimmungsgrenze	Einheit
Eluierbarkeit mit Wasser		ÖNORM S 2115 und ÖNORM EN 12457-4	—	—
pH-Wert		ÖNORM EN 12506	—	—
El. Leitfähigkeit		ÖNORM EN 13370	—	—
KW-Index		ÖNORM EN ISO 9377-2, GC/FID	0,5	mg/kgTR
Abdampfrückstand		DIN 38409-H1-2 (Filtrattrockenrückstand)	200	mg/kgTR
Ammonium		ÖNORM EN 13370	0,1	mg/kgTR
Orthophosphat (als P)		DIN EN ISO 15681-2 (D46)	0,05	mg/kgTR
Cyanide $_{\text{gesamt}}$		DIN EN ISO 14403 (D6)	0,1	mg/kgTR
Cyanide $_{\text{leicht freisetzbar}}$		ÖNORM EN 13370	0,05	mg/kgTR
Phenolindex		ÖNORM EN 13370	0,1	mg/kgTR
Fluorid, Chlorid, Nitrit,(als N) Sulfat		ÖNORM EN 12506 bzw. ÖNORM EN 13370	1,0 20 0,05 20	mg/kgTR mg/kgTR mg/kgTR mg/kgTR
Nitrat (als N)		DIN EN ISO 13395 (D28)	0,1	mg/kg TR
POX		DIN 38409-H25	0,1	mg/kgTR
EOX		DIN 38409-H8	0,2	mg/kgTR
AOX		DIN EN ISO 9562	0,05	mg/kgTR
TOC		ÖNORM EN 13370	5,0	mg/kgTR
AKW		DIN 38407-F9, GC/MS, Headspace- Technik	0,1	mg/kgTR
PCB		DIN 38407-F2, GC/ECD	0,0001	mg/kgTR
Summe PAK (16 Parameter n. US EPA)		DIN EN ISO 17993 (F18)		mg/kgTR
Sulfid (als S)		DEV-07	0,2	mg/kgTR
Tenside (als MBAS)		DIN EN 903	0,5	mg/kgTR
Metalle:		ÖNORM EN 12506 bzw. DIN EN ISO 11885 (E22) bzw. DIN EN ISO 17294-2 (E29)		
Aluminium	(Al)		0,1	mg/kgTR
Arsen	(As)		0,1	mg/kgTR
Barium	(Ba)		0,03	mg/kgTR
Berylium	(Be)		0,02	mg/kgTR
Blei	(Pb)		0,1	mg/kgTR
Bor	(B)		0,1	mg/kgTR
Cadmium	(Cd)		0,002	mg/kgTR
Calcium	(Ca)		1,0	mg/kgTR
Chrom$_{\text{gesamt}}$	(Cr$_{\text{ges}}$)		0,01	mg/kgTR
Eisen	(Fe)		0,1	mg/kgTR
Kobalt	(Co)		0,03	mg/kgTR
Kupfer	(Cu)		0,01	mg/kgTR
Magnesium	(Mg)		0,1	mg/kgTR
Mangan	(Mn)		0,03	mg/kgTR
Molybdän	(Mo)		0,03	mg/kgTR
Nickel	(Ni)		0,01	mg/kgTR
Selen	(Se)		0,1	mg/kgTR
Silber	(Ag)		0,01	mg/kgTR
Thallium	(Tl)		0,01	mg/kgTR
Vanadium	(V)		0,03	mg/kgTR
Zink	(Zn)		0,01	mg/kgTR
Zinn	(Sn)		0,1	mg/kgTR
Antimon	(Sb)	ÖNORM EN 12506 bzw. DIN EN ISO 11885 (E22) bzw. DIN EN ISO 17294-2 (E29)	0,1	mg/kgTR
Chrom VI	(Cr VI)	ÖNORM EN 12506	0,05	mg/kgTR
Quecksilber	(Hg)	ÖORM EN 13370	0,002	mg/kgTR

3.5.2 Explanation of LECO Measurement

“The LECO measuring device normally is used for source rock evaluation and measures the TOC of the rock itself by combustion of the organic matter under air or oxygen atmosphere, at a temperature of 1500 °C (LECO induction oven). For the LECO, carbonates should be removed by acid treatment prior to the measurement to avoid interference by CO_2 due to carbonate decomposition at high temperature.

Analytical procedure of the LECO:

a) The sample is dried and grinded (<200 µ)

b) 40 to 400 mg of ground sample is used for LECO analysis.

c) 10 ml hydrochloric acid (2N) is added to the rock sample.

d) Acid treatment is performed for 8 hours at 80°C.

e) The hydrochloric acid remaining after the attack of the carbonate is determined automatically and an approximate mineral carbon content of the rock is given. The sample is then introduced into the induction oven together with copper oxide CuO which will transform CO into CO_2; then CO_2 is measured with an infrared detector.

Advantages and Disadvantages of the LECO measurement:

The LECO gives good results for already mature organic matter, including graphite, because at high temperatures (> 1,000 °C), the carbon combustion is complete. If the rock sample is rich in free hydrocarbons, they are volatized when drying the samples after decarbonatation. In the LECO procedure, the elimination of remaining HCl by filtration may lead to a partial loss of the hydrolysable organic matter, which is particularly important in recent sediments, i.e. before diagenesis. The results given by the LECO apparatus may be disturbed by interferences of sulfated minerals such as gypsum and anhydrite, because of the high temperature utilized. The LECO also provides an estimate of the mineral carbon.

Good source rocks have high TOC values. However, not all high TOC rocks have a good potential. Other methods are necessary to appraise the source rock maturity, the type of organic matter, the present hydrocarbon potential, the estimate of hydrocarbons generated, etc. The TOC is also a witness of past potentials for already mature source rocks. Some residual carbon remains even when the graphite stage is reached. This means that a source rock even at a overmature stage can be recognized by geochemical analysis. Organically lean rocks, i.e. having TOC lower than 0.5 – 1 % are considered in almost all cases as having no source rock potential.”(40)

3.5.3 Problems during Lab Analysis

One observation that was made during the analysis work was the high variability in the results of TOC measurements. "This observation was also confirmed by DI Hildegard Möhrmann from OMV who had done a variety of sample investigations in the past. When she was placing her lab orders she used three different accredited laboratories and sent each of them a subset of the same homogenized cuttings and mud sample. The measured values for TOC content of the identical samples were varying enormously depending on which laboratory had done the analysis."(39)

Therefore possible sources of error were identified. Failures may occur in any and all of the steps that are necessary for a sample analysis, e.g. during sampling, storage, homogenization, sample preparation, calibration, eluting, centrifugation, acidification, and so on. Other variables that either depend on the laboratory technician or the measuring apparatus and method itself are: different mineral acids, different combustion temperatures, drying temperature and time, carrier gas stream, different additives and catalysts to achieve complete combustion, turbulences in the combustion tube, etc.

Clay minerals may also have a great influence on the outcome of the measurement. There is also no standard TOC measuring device specified by law and there are different direct and indirect TOC measuring techniques existing.

Furthermore, the question should be raised whether the existing measuring techniques itself (which were mainly established for measuring the TOC content in drinking water in which the TOC is by far not that high as in our mud) are suitable for our material or if another method needs to be developed.

Due to those observations the decision was to make a sort of experimental quality check for the TOC measurements itself (see Chapter 3.5.3.1).

3.5.3.1 Experimental Quality Check for TOC Measurements

In this experiment the TOC of the individual mud components (dry and in powder form) was measured and the TOC of an already mixed mud was measured.

The individual components were:

1. Potassium carbonate (K_2CO_3)
2. Antisol (anionic cellulose polymer)
3. Citric acid
4. Water (TOC not measured; it is negligible compared to the other components)

The mixing ration of the freshly mixed mud was 17.6 % K_2CO_3, 2.2 % Antisol, 0.9 % Citric acid, and 79.3 % water.

Afterwards, the TOC of the mud mixture was calculated out of the individual measurements (see measurements 1 to 4 from Table 23) considering the mixing ratio. It turned out that the measured TOC of the mixed mud was way higher than the calculated TOC for the same. This meant that the accuracy of the TOC measurement could not be verified, and something must be wrong with the measurement and maybe a different method for measuring the TOC of drilled material is needed.

Author’s note: Initially, the plan was to calculate the TOC content in a stoichiometric way as well and compare it to the TOC value of the measurement. However, this turned out not to be that easy as one would need to consider all of the following and more:

- Purity levels of the individual substances (those are not known)
- Solubility of the single components
- Calcium content of the fresh water and its counter-reaction with HCO_3^- ions
- Amount of soluble CO_2 from the air

Table 23: Measured TOC Values for Individual Mud Components and Mud Mixture

	Dry Components			Liquid Comp.	TOC of mud measured (mud = mixture of dry components + water)	TOC of mud calculated out of measurements 1)-4) considering mixing ratio
	1) K2CO3	2) polymer	3) citron acid	4) water		
mixing ratio	17.60%	2.20%	0.90%	79.30%		
TOC solids [mg/kg dry matter]	2,200	260,000	270,000	negligible	36,000 >>	8,537
TOC eluate [mg/kg dry matter]	130	48,000	340,000		31,000 >>	4,139

Figure 36: Freshly Mixed K_2CO_3-Polymer Mud (Left) and Powdered Polyanionic Cellulose Polymer Called Antisol (Right)

Figure 37: Crystalline Citric Acid (Left) and Powdered Potassium Carbonate Salt (Right)

3.6. Results & Interpretation of Analysis Reports

Because of confidentiality reasons no specific numbers can be shown from the analysis reports of the investigated samples taken on RAG rigs. However, the results will be discussed qualitatively in this chapter. The templates (for solid and eluate parameters) that were used to determine the landfill category based on the analysis results are shown in Appendix A. As this categorization was done for an Austrian company the templates are in German. Furthermore, the safety data sheets (in German language) of the used mud components can be found on the CD in the book cover.

Discussion of TOC Limits in Austria

The TOC is a very important parameter when it comes to deposition of cuttings and mud. Table 24 shows the TOC limits in mg/kg dry matter for the lowest and the highest landfill category in Austria. It is important to know that there are TOC limits for the solids content and the eluate content and in case of deposition one has to comply with both. For the highest landfill category 50,000 mg/kg dry matter is the limit for the solids content and 2500 mg/kg dry matter is the limit for the eluate content. For drilling waste, mostly the eluate is the problem. However, for shale gas the TOC can range from 1.5 % (=15,000 mg/kg dry matter) to over 20 % (=200,000 mg/kg dry matter).(53)

The problem with a high TOC is that there may be gas development in landfills and rainwater may dissolve organic compounds which may then end up in the groundwater. However, landfills normally must be sealed-off so that seepage water should not be a problem. Dung also has a high TOC but it is needed for plant growth and distributed on fields. Often times there are lobbies responsible for certain limits to be set so high or so low and sometimes one should question their sense.

Table 24: TOC Limits for the Highest and Lowest Landfill Category in Austria

	Lowest landfill category in AUT (Bodenaushubdeponie)		Highest landfill category in AUT (Massenabfalldeponie)	
Limits for	Solids content	Eluate content	Solids content	Eluate content
TOC	30,000	200	50,000	2,500
Unit	mg/kg dry matter			

Results for Cuttings, Mud and Flocculated Material from the K_2CO_3 Mud Systems

In this case a complete analysis according to the Landfill Regulation 2008 was conducted. In summarizing it can be stated that a deposition of cuttings, mud and flocculated material from a K_2CO_3 mud system is not possible in surface dumpsites in Austria as the eluate limits for TOC and evaporation residue of the highest landfill category in Austria were exceeded in all samples. Other eluate parameters that were mostly elevated were: electrical conductivity, aluminum, iron, chromium, barium, arsenic, and phosphate. The measured TOC values were highest in the mud samples, followed by the flocculated material and the less contaminated cuttings. The cuttings are least contaminated because only a small percentage of mud adheres to them. However, the finer the cuttings the more mud will adhere and thus the higher the TOC will be. It also means that the more effective the separation of cuttings and mud at the shale shakers is the less the organic contamination will be present in the cuttings.

Another observation made was that the mud system which had the additive MIX II (=cellulose polymer) in it showed consistently higher TOC values than the mud system without MIX II. Furthermore, for those samples with MIX II also the TOC content of solids exceeded the limit of the highest dump category. For the other samples without MIX II only the TOC content of the eluate was exceeded.

Moreover, it could be seen that the used flocculant also increases the TOC as the flocculated material always showed higher TOC values than the not flocculated cuttings. Additionally, it is assumed that the additive Antisol (= cellulose polymer) and the citric acid, which is added in minor amounts, are causing TOC.

The electrical conductivity is directly proportional to the potassium content and hence obviously elevated when a potassium mud is used. The evaporation residue is obtained by drying up the sample and includes all non-volatile organic and inorganic substances (e.g. includes the inorganic hydrogen carbonate which comes from the K_2CO_3 mud) and consequently is also very high. The aluminum value of the samples is this high as clay consists of aluminum-silicate-layers and the formation drilled is mostly clay and marl.

The iron value is also noticeable high as well as other metals (such as barium, chromate, nickel, arsenic). This can have geogenic reasons or can be caused by the drilling process itself, as the mud is continually in contact with different steels (e.g. drill pipes, casing, bit, etc.). Further, elevated parameters were phosphate, fluoride, and ammonium. The parameters sulfate and chlorides were sometimes also elevated but those limiting parameters are only relevant for Inert Waste Landfills.

"The analysis results were confirmed by another laboratory called *'Umweltlabor Dr. Axel BEGERT'* which had investigated cuttings from a different RAG well and made a waste classification which brought the same result: Because of too high TOC values in the eluate no surface deposition in landfills in Austria is possible. The material can either be combusted in a hazardous waste incinerator or used as mining backfill (=subsurface deposition)."(54)

Another possibility for making drilling waste disposable would be a mechanical-biological waste treatment. Then the TOC limits would not apply but other waste stability parameters would need to be met. A mechanical-biological waste treatment aims at reducing gas formation and elution. This approach would need further investigation and most probably would be very costly and not an economic solution.

Results for Cuttings and Flocculated Material from the Bentonite Mud System

The samples that were taken during drilling with a bentonite mud system were investigated only for TOC and LOI (Loss on Ignition). The result was that the TOC of the solids as well as of the eluate stayed below the limits of the lowest landfill category in Austria. This means that cuttings, mud and flocculated material from bentonite mud systems can be disposed of in Excavation Soil Landfills in Austria (=Bodenaushubdeponie) provided that the other limits (e.g. metals, ammonium, phosphate etc.) are not exceeded. This still needs to be found out. The parameter LOI was only measured for the case the TOC would be too high because then an exemption could have applied which says that the TOC is judged to have been kept if the LOI is below a certain value.

Results for LECO Measurement

As already mentioned before it was found out that the reasons for a high TOC primarily come from mud additives like polymers, citric acid, and flocculants. However, TOC may also come from hydrocarbons or the lithology itself. Thus, with doing a LECO measurement of the washed (mud-free), dried and ground cuttings the rock immanent TOC content was determined. The LECO measurement showed that the cuttings of the wiper tripping run had a TOC content of 0.84 % (= 8,400 mg/kg) and the cuttings of the reservoir section had a TOC content of 0.78 % (= 7,800 mg/kg). One should keep in mind that both values are the TOC of the solids content not the eluate content.

Results for Dehydrated Retain Samples

After dehydrating the retain samples at 80°C for ~4.8 days in a drying chamber under full air supply the samples were analyzed for TOC and LOI. This way, it should be investigated whether drying (e.g. by using waste heat) would cause a reduction of TOC and could make cuttings disposable in landfills in Austria. Unfortunately, the results did not show a clear downward trend. Sometimes the TOC value has decreased compared to the original measurement, sometimes it has increased. However, even in case of a TOC decrease it was way too little to make the material disposable in surface landfills. The TOC of the eluate was still far beyond the limits of the highest landfill category in Austria. One thing that should be mentioned here is that the retain samples were already 2.5 months old before this experiment had started and as it turned out later it also happened that the laboratory got a new measuring device between the first analysis and the analysis of the retain samples which may question the comparability of the results. The LOI was measured because of the same reason as mentioned before for the bentonite mud system.

Results for Retain Samples Exposed to Natural / Artificial Sunlight

In this experiment the samples were exposed either to sunlight or to artificial sunlight for about 3 weeks. The result was a decrease in TOC of 40-50% in solids and 10-20% in eluate content for both light sources. However, the initial TOC values were so high that there was no change in dump category. When looking at the reduction of TOC one should also keep in mind that the retain samples were more than 3 months old and were stored at room temperature. It also happened that the lab got a new TOC measuring device between the first analysis and the analysis of the retain samples which may question comparability and even if the results would be valid, the TOC reduction would take very long and large surface areas would be needed.

Experimental Quality Check

One observation that was made during the analysis work was the high variability in results of TOC measurements. As already mentioned in 3.5.3 there are many sources of error that may occur in all the different stages (from sampling until the measuring process itself). One disadvantage of the whole TOC measuring process is also that there is neither a standard TOC measuring device nor a standard measuring method defined.

Furthermore, as shown with the experimental quality check in Chapter 3.5.3.1 the question should be raised whether the current measuring technique itself is suitable for drilling waste or if some other method needs to be developed.

An additional idea to find out more about the quality of TOC measurements would be the execution of a round robin test. This way, one could find out more about the variance of TOC measurements. However, this is a question of cost and benefit.

Outlook

As presented here the TOC of drilling waste poses a big problem regarding its deposition in surface landfills in Austria. Thus, the next chapter deals with alternative possibilities to handle and avoid drilling waste.

4. How to Handle & Avoid Drilling Waste

4.1. Overview Plot

Figure 38 shows four different branches for handling and avoiding drilling waste with high TOC contents. The first branch (in green) shows what could be done to avoid and minimize the accumulation of hazardous drilling waste. The second branch (in blue) shows the recycling possibilities of cuttings in different industries. The third branch (in orange) gives an overview of surface and subsurface deposition; and the fourth branch mentions the possibility of combustion of hazardous waste. These different possibilities are discussed in more detail in the following sections.

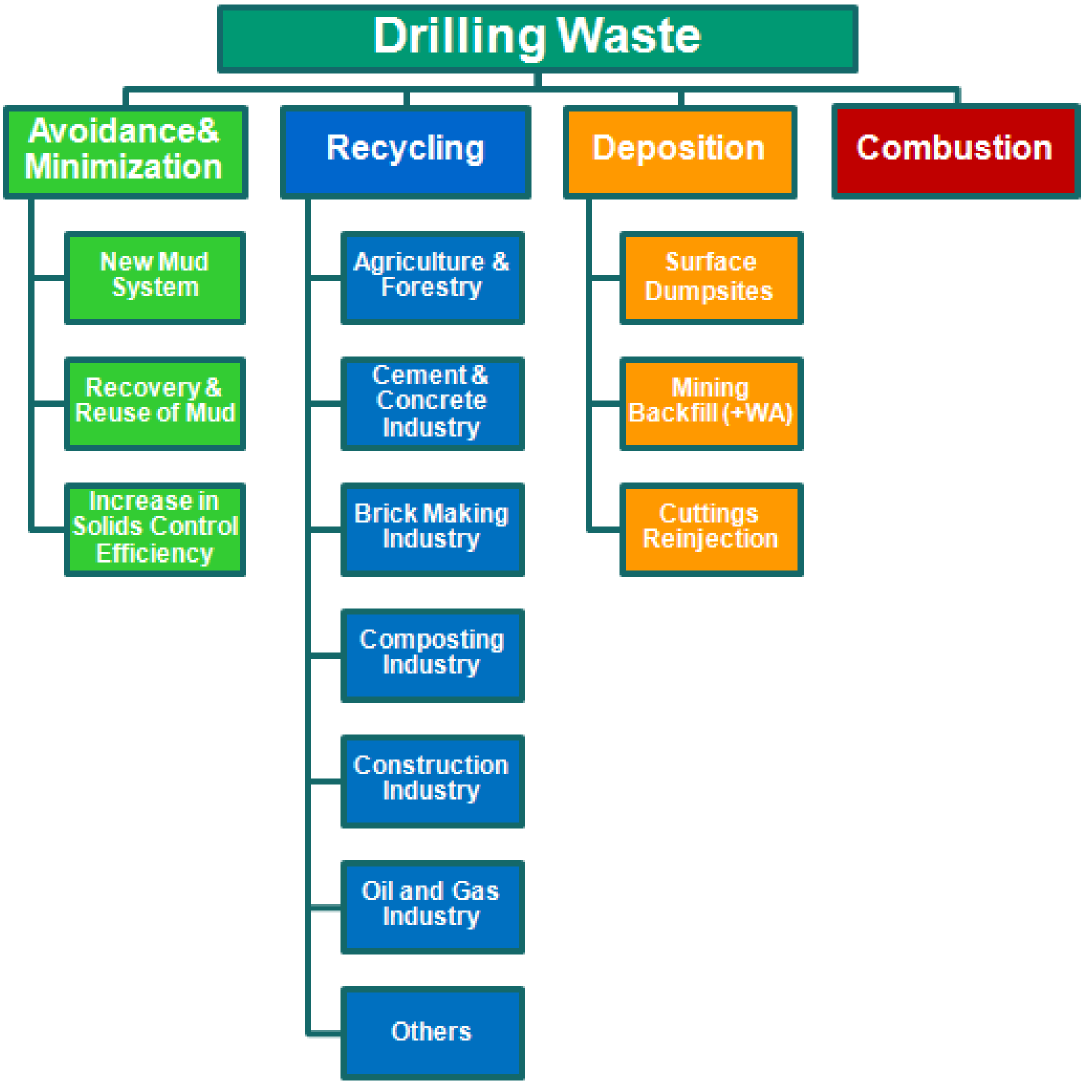


Figure 38: Overview Plot – How to Handle & Avoid Drilling Waste

4.2. Drilling Waste Avoidance and Minimization

4.2.1 New Mud System

One possibility to avoid hazardous drilling waste would be the development and application of a new mud system that does not cause such a high TOC content. But this would mean that no polymers could be used anymore. So far, the industry does not know how to achieve the desired properties of drilling fluids without using polymers. Finding a replacement for polymers that does not cause a high TOC poses difficulties and challenges to the Oil and Gas Industry and especially to mud services companies. Further research is required and it is not sure whether a viable solution can be found at all.

Nevertheless, it is important to question the use of each additive in a proposed mud system because the fewer additives are used the less contamination of cuttings and mud is caused. Not all additives are necessary every time and it may be right that service companies earn more money if they sell more additives.

Another very important point is the quality control of the individual mud additives that are bought. It has already happened in the past that some additives were contaminated by heavy metals, Hg, Cr, Cr^{6+}, Cl, etc.(2) Thus, it is very important to check the purities of the individual mud components.

4.2.2 Recovery and Reuse of Mud

The recovery and reuse of mud is very important as it is not only a sustainable and environmentally friendly approach it also saves drilling cost. Hence, the goal should be to recover and reuse 100 % of the mud. Even if we know that this is not possible in reality as there will always be some losses (e.g. due to mud leaking into the formation, due to mud adhering to discarded cuttings, or due to mud contaminated during cementing) our task as engineers is to get as close as possible. The only requirement for that is enough storage capacity so that the mud can be kept somewhere during rig move.

4.2.3 Increase in Solids Control Efficiency

"An increase in solids control efficiency (a high degree of separation of cuttings and mud) means less mud loss, less waste and less cost. Additionally, with a high degree of separation the waste contains less water and thus can be handled more easily. In order to be able to achieve high solids control efficiency, it is important to identify the waste minimization potential. This is only possible if a measuring system is installed which identifies when, where and how much waste accumulates on the rig. Generally, it is very important and helpful to use multiple pits and tanks so that problematic waste can be separated from unproblematic waste. Furthermore, it is important to prevent dilution as this would cause greater waste volumes. Some ideas to get a more efficient separation are e.g. the use of high g shale shakers, belt filter presses, centrifugal cuttings dryers, decanters, hydrocyclones."(3) In order to find out more about the dewatering behavior and the effectiveness of separation experiments would be necessary as material properties like grain size distribution, density, filtration behavior, sedimentation (especially of bentonite), pH value, … all influence the outcome.(55)

4.3. Recycling Possibilities of Cuttings

4.3.1 General Remarks & Overview

For the cuttings recycling branch it is important to have a mud system that allows recycling. Cuttings drilled with a chloride mud system could not be recycled but recycling of cuttings drilled with the K_2CO_3 mud system of RAG has proven to be possible. Moreover, for certain applications the potassium ion and the high pH of the K_2CO_3 mud system are beneficial, as may be the high TOC which represents energy-rich properties. Another advantage is the drilled rock itself which is a clay/marl/lime mixture in the RAG wells and which is beneficial for certain industries.

Some of the recycling possibilities are: using cuttings for soil improvement (Bodenhilfsstoff) which is called Landfarming, adding cuttings to cement and concrete or bricks, adding cuttings to flower soil, using them in the construction industry (e.g. for asphalt, as filling material in pipeline traces), and there may be other applications as well.

However, for recycling it is very important to recognize that sensitive and responsible behavior is required which also means that each recycling possibilities needs to be investigated individually. It is essential to speak to the company that is willing to make use of the cuttings.

Probably the most important thing, when recycling cuttings, is to emphasize the ‘end of waste character’. In case of recycling cuttings are – by law – not defined as waste any longer. Hence, it is vital to step away from the term ‘waste’ and instead name it ‘secondary raw material’ because no industry/no company wants to hear that waste is put into their products and no customer wants to buy a product when there is waste in it. So, it is absolutely necessary to communicate the right way. E.g. a brick manufacturer may be very concerned about his reputation when he gets the offer to add drilling ‘waste’ to his bricks.

It also needs to be strengthened that the recycling idea alone is not enough. Many other things need to be considered as well:

All the applicable laws and the current legal situation in the country, necessary evidence to get notifications in different provinces (although in case of recycling an additional legal approval is often not necessary but it is usually “good to have”), consideration of seasonal applications (varies worldwide), not only technical but also environmental and social requirements, a continuous quality control so that each party knows what it delivers or gets, responsible contact persons, necessary pretreatment/conditioning/stabilization steps and how to implement the addition of cuttings in a certain process, possible risks and problems and how to avoid them, and of course, economics.

Although the implementation of a recycling branch, as well as its operation, is time consuming and sensitive (it should be a continuous improvement process) it is a very sustainable and environmentally friendly solution.

4.3.2 Agriculture & Forestry (Landfarming)(2,57)

4.3.2.1 Idea

The idea is to use cuttings as a soil improvement material because the high pH value and carbonates (as in a liming procedure) are beneficial for acid soils, the K^+ ion is a fertilizer (potash fertilizer) which is needed for the growth of many plants, the high water retention capability of the shale cuttings is beneficial for dry land.

4.3.2.2 Applicable Laws

Fertilizer Law (=Düngemittelgesetz), Fertilizer Regulation (=Düngemittelverordnung), also provincial laws like the Soil Conservation Law (=Bodenschutzgesetz) and the Sewage Sludge Regulation (=Klärschlammverordnung) need to be considered.

4.3.2.3 Technical, Environmental & Social Requirements

Only cuttings are used for Landfarming. For precautionary reasons the flocculated material is not used for Landfarming in order to avoid possible long-term effects caused by the flocculating agent.

The high TOC content of cuttings should not be a problem as dung and liquid manure also have a high organic content. As with liquid manure the application of cuttings to the land is not allowed year-round because of groundwater protection. Thus intermediate storage for cuttings is needed.

Varieties in grain size distribution and consistency are not a problem for the soil itself but may pose challenges depending on the type of application (device used).

4.3.2.4 Quality Control

A continuous quality control starting at the rig site is very important. First of all, the different fractions (cuttings, flocculated material, cuttings contaminated by cement, rubber etc.) should not be mixed and no other garbage is allowed to ‘fall’ into the cutting boxes. Only the cutting fraction should be used for Landfarming. Furthermore, a continuous sample analysis needs to be done to avoid that cuttings with undesired impurities reach the farmers’ lands.

4.3.2.5 Pretreatment & Implementation

As Landfarming is not possible all year round, suitable intermediate storage facilities are necessary (considering odor formation). Depending on the type of application to the land (device used) and the consistency of the cuttings also pretreatment steps and mixing equipment will be required. There were several ideas how to apply the cuttings to the land:

a) By liquefaction of cuttings (e.g. mixing it with liquid manure) and then using some sort of a manure trailer with pressurizing capability and constant mixing equipment in order to effectively spread the material and prevent settling in the manure trailer.

b) Dehydration of cuttings and making a rock powder out of it (application to the land as in a liming procedure).

c) After quite some trials RAG figured out that a compost spreader is a well-working means of applying wet cuttings to the land.

4.3.2.6 Risks / Problems

The Oil and Gas Operator cannot deal with every single farmer that is willing to use cuttings as a soil improvement material. Thus, one responsible person or cooperative is needed that coordinates the delivery of the material.

If the cuttings need to be stored for a longer time period before they can be applied to the land by farmers measures to avoid odor nuisances of third parties should be taken.

Concerns about reputation in case of something happening and general public acceptance should be worked out and measures undertaken to prevent problems.

4.3.2.7 Costs (€/t)

No cost estimates available.

4.3.2.8 Current Legal Situation / Status Quo in Austria

No legal approval would be necessary but RAG holds a notification that allows the company to use cuttings as soil improvement material.

4.3.3 Cement and Concrete Industry(2, 58)

4.3.3.1 Idea

The idea is to use cuttings as well as flocculated material as an aggregate for cement and concrete. The base material for cement is marl and limestone which is very similar to the material drilled by RAG. One major advantage compared to Landfarming is that the drilled material can be recycled all year-round.

4.3.3.2 Applicable Laws

Only technical requirements of a cement plant need to be fulfilled.

4.3.3.3 Technical, Environmental & Social Requirements

The cement plant requires a certain consistency of the material that is added in the production process. This means that a pretreatment and intermediate storage is necessary. The advantages for this recycling path are that grain size distribution, TOC content, pH value, and minor impurities are not a problem.

4.3.3.4 Quality Control

At the rig site it needs to be decided which material is used for the cement industry. The required consistency of the material needs to be monitored before and after the treatment step. The cement plant itself regularly takes samples and makes a chemical analysis of the material.

4.3.3.5 Pretreatment & Implementation

The pretreatment steps look as follows: The cuttings and flocculated material are brought to an open storage hall where they are shuffled in lines. Then about 10 weight percent of cement is put onto the drilled material which is then intermingled with a turn-over machine usually used for composting (=Wendemaschine). This way the cement is binding the water and the consistency of the material is enhanced.

However, this also means the greater the water content of the drilled material the more cement is needed and the greater the increase in original volume. After this stabilization process the material is left undone for 3 to 4 days before it is brought to the quarry owned by the cement plant. There it is stored for further use.

Currently, about 300 t of drilled material can be stabilized per day. However, at the moment it is a discontinuous process and the frequency of stabilization depends on how much material is delivered from the rig sites. Figure 39 and Figure 40 give an idea about how the stabilization process looks like.

Figure 39: Stabilization Process of Drilled Material with a Turn-Over Machine 1

Figure 40: Stabilization Process of Drilled Material with a Turn-Over Machine 2

4.3.3.6 Risks / Problems

As the storage hall is open and the cuttings are not stabilized every day some odor nuisance may be present. Thus, it is important the stabilization process does not take place in densely populated areas.

4.3.3.7 Costs (€/t)

The stabilization costs about 25-35 €/t depending on how much cement needs to be added and the cement plant itself charges about 20-30 €/t for taking the material. Furthermore, the cost of transport from the rig site to the stabilization hall and from there to the quarry needs to be taken into account. In general it should be mentioned that this recycling path would not cause too high transport costs as there are many cement plants in Austria.

4.3.3.8 Current Legal Situation / Status Quo in Austria

RAG is successfully stabilizing and recycling cuttings in a cement plant in Austria.

4.3.4 Brick Making Industry(2, 56)

4.3.4.1 Idea

The idea is to use cuttings as an aggregate for bricks (red bricks as well as concrete bricks). However, only red bricks are discussed here. The receipe for red bricks is as follows:

- 5% residue of paper industry (pure cellulose) to increase the porosity
- 3% saw dust also to increase the porosity
- The remaining 92 % consist of equal parts of clay and marl
    - As the cuttings from RAG wells are also a clay and marl mixture the idea is now to replace between 1 and 5% (of those 92%) with cuttings.

One advantage may be that the high TOC of bricks creates additional pores when the brick is burnt as the carbon may form CO_2.

4.3.4.2 Applicable Laws

Only technical requirements of brick manufacturer need to be fulfilled.

4.3.4.3 Technical, Environmental & Social Requirements

It is important that the thermal conductivity, compressive strength and color are not influenced negatively when cuttings are added. Thus, samples of the material were sent to a brick research institute in Essen, Germany which conducted different experiments and came to the conclusion that the material is suitable for bricks (it does not affect brick strength) and could be added at the suggested percentages.

The color of the red bricks was a concern because salt, sulphur and lime may cause efflorescence (=Ausblühungen) in the bricks which is unwanted and would be a reason not to add cuttings in brick production.

Another important requirement of the brick manufacturer is that no impurities are in the material that is used (bricks are a natural product).

4.3.4.4 Quality Control

A continuous quality control is very important and needs to be implemented at the rig site and at the brick manufacturer because chemical impurities and other impurities like plastic parts, cement, wooden parts etc. would cause a decrease in brick quality.

4.3.4.5 Pretreatment & Implementation

According to the brick manufacturer it is not possible to add cuttings directly into the production process. One reason for that is that the cuttings should not be larger than 0.9 mm as this is the size of the roller clearance (=Walzenspalt). Thus a premixing of cuttings with the ordinary clay-marl mix from the company owned quarry would be necessary. For this step a feeder, a rolling mill and a blender would be needed. In this pretreatment the cuttings would need to be crushed into smaller particles, then clay and marl could be added and the single components mixed in a blender before they could be stored in a roofed warehouse for further use.

This intermediate storage capacity is important because if a certain brick product is made the production process and the material used should stay the same during the total batch (one certain brick series). Therefore, a certain (large) amount of cuttings is necessary to avoid a short-term switch to a different product or a change in quality and visual appearance within one batch.

The used material should be as dry as possible. Hence, the flocculated material with its high water content may not be suitable or would need an additional pretreatment step. E.g. the waste heat of the brick factory could be used for dehydrating the flocculated material. One benefit of flocculated material is that fines mean an increase in brick hardness. (Please note that the brick experiments in Essen were only conducted with cuttings, not flocculated material.)

For grey bricks (concrete bricks) the high water content would not be a problem.

4.3.4.6 Risks / Problems

There are concerns about the reputation of the brick manufacturer as its bricks are a natural product. So, public acceptance is very important. Furthermore, impurities may cause a lot of problems (brick quality, efflorescence) and may lead to whole brick series to be discarded. Thus quality control is very important.

4.3.4.7 Costs (€/t)

No costs available. Cost of transport may be high if brick manufacturer is far away.

4.3.4.8 Current Legal Situation / Status Quo in Austria

So far, this recycling path has not yet been realized in Austria. An approval procedure was meant to be started.

4.3.5 Composting Industry (Flower Soil)(2)

4.3.5.1 Idea

The problem of compost is that it is lean in potassium and has a very low pH value. Therefore the idea is to add cuttings to the compost to increase the pH and provide K^+ ions. Moreover, the high TOC and the dark color of cuttings are also beneficial for the compost.

4.3.5.2 Applicable Laws

Federal Composting Regulation, Regulation for State-of-The-Art Composting, …

4.3.5.3 Technical, Environmental & Social Requirements

The material used for composting should be as fine grained as possible. Thus probably a pre-crushing of cuttings would be necessary. High water content is beneficial as it allows better and easier intermixing. The consistency of the material is not a big issue as it will be intermixed with other compost (bushes, shrubs, grass …) anyhow.

4.3.5.4 Quality Control

Quality control is very important and starts at the rig site. Contamination by steel and rubber components must be avoided. A regular quality control (e.g. chemical analysis) also needs to be done during the composting process.

4.3.5.5 Pretreatment & Implementation

Intermixing could be done with the same turn-over machine as mentioned and shown before in Chapter 4.3.3.5.

4.3.5.6 Risks / Problems

Emissions and malodor during intermixing and composting may be a problem. Densely populated areas should be avoided. Impurities like geogenic metals may cause problems. Other impurities like rubber, steel residue, cement etc. must be avoided. A very high pH value is not good as it reduces bacterial activity during composting.

4.3.5.7 Costs (€/t)

No costs available. Less trucking cost expected as there are many composting plants in Austria.

4.3.5.8 Current Legal Situation / Status Quo in Austria

So far, this recycling path has not yet been realized in Austria. A legal approval would be required prior to realization of this recycling path as composting products (flower soil) is something every user has direct (skin) contact to.

4.3.6 Construction Industry(2)

Thinking of cuttings recycling in the construction industry there is a wide range of applications, e.g. cuttings and flocculated material may be used when roads, asphalt, pipeline traces, buildings, sites, etc. are constructed.

For these applications no legal approval would be necessary. Depending on the type of application impurities, grain size distribution, and consistency of the material may be a problem. Pretreatment and intermediate storage also may be required which would increase cost. However, because of the wide range of possible applications cost of transport would be low.

4.3.7 Oil and Gas Industry(2)

Also within the Oil and Gas Industry there is a wide range of application when it comes to cuttings recycling. Some possibilities are mentioned here:

- Cement: for plug and abandonment of wells
- Landfarming: recultivation and reconstruction of well sites
- Construction work / Bricks: drill sites, pipeline traces, facilities, roads, …
    - When using cuttings as filling material in pipeline traces the high pH may be very beneficial as it acts as a corrosion inhibitor. Moreover, the low permeability and high water retention capability of shale would be beneficial as it would mean no water circulation behind the pipeline.
- Recycling of waste sites: many existing facilities are currently used as an intermediate storage and need to be cleared/reconditioned.

4.3.8 Others

There may be a variety of other recycling possibilities of cuttings, e.g. using cuttings as a sealing layer in dumpsites, using cuttings in the fertilizer industry, using cuttings in biogas plants, etc.

4.4. Deposition of Drilling Waste

4.4.1 Surface Deposition on Dumpsites

Scenario 1: If the investigated cuttings (that were drilled with the K_2CO_3-Polymer mud system) are defined as 'mining waste' according to the BBA-G then a surface deposition in Austria would be possible on a landfill that belongs to the mining business itself. (Reminder: A landfill granted under BBA-G does not have to comply with the Landfill Regulation 2008 and thus the TOC limits are not of interest). But the problem in Austria is that many existing landfills of the mining companies are almost full and it would be too expensive to build new ones.

Scenario 2: On the other hand, a surface deposition of the investigated cuttings (that were drilled with the K_2CO_3-Polymer mud system) on a general landfill in Austria which is granted under AWG would only then be possible if prior treatment, stabilization or conditioning could reduce the TOC and make the cutting disposable. Examples for possible treatments would be:

- Bio-mechanical treatment
- Bacteria degradation
- Natural degradation with sunlight
    - This approach would require further investigations as simple preliminary experiments were without great success.
- Ohters (e.g. cracking of polymer chains, …)

The problem with all those treatment steps is that they are very time and cost consuming and it is not said that they can reduce the TOC content effectively enough to allow surface deposition on a general landfill in Austria.

No cost estimates are available for Scenarios 1 and 2.

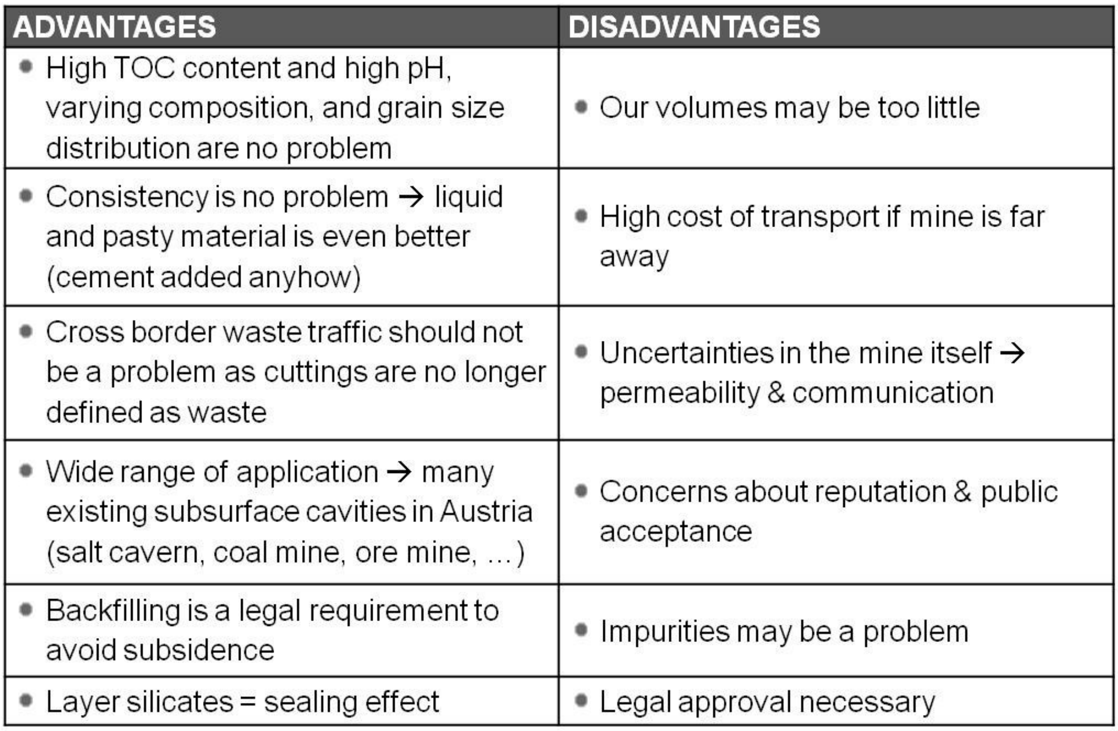
Author's comment: Cost estimates for the deposition of cuttings from the top hole bentonite section in an Excavation Soil Landfill (=Bodenaushubdeponie) are about 40€/t including 50 km transport cost.(24) Additionally, 8 €/t ALSAG fee must be paid in Austria.

4.4.2 Subsurface Deposition: Mining Backfill (incl. Well Abandonment)

General Considerations:

In case of using drilled cuttings for mining backfill or well abandonment the following advantages and disadvantages need to be mentioned:

Table 25: Advantages and Disadvantages of Using Drilling Waste for Mining Backfill (incl. WA) (2)



ADVANTAGES	DISADVANTAGES
• High TOC content and high pH, varying composition, and grain size distribution are no problem	• Our volumes may be too little
• Consistency is no problem → liquid and pasty material is even better (cement added anyhow)	• High cost of transport if mine is far away
• Cross border waste traffic should not be a problem as cuttings are no longer defined as waste	• Uncertainties in the mine itself → permeability & communication
• Wide range of application → many existing subsurface cavities in Austria (salt cavern, coal mine, ore mine, ...)	• Concerns about reputation & public acceptance
• Backfilling is a legal requirement to avoid subsidence	• Impurities may be a problem
• Layer silicates = sealing effect	• Legal approval necessary

Salt Cavern in Stassfurt: One current possibility of underground deposition is the injection of cuttings into a salt cavern in Stassfurt, Germany. The KGS Stassfurt injects drilling cuttings and mud together with their other sludges from salt production into depleted parts of the salt cavern. Some problems and risks with this approach are:

- Cross-border-waste traffic (cross-border notification procedure)
  - However, it could be argued if cuttings reinjection for salt production falls under the category recycling and then cuttings are not defined as waste any longer. Then, cross-border waste traffic should not be a problem.
- What if problems during salt production arise and they stop injecting cuttings?
- High costs of transport
  - From Vienna or Salzburg to Stassfurt (Saxony-Anhalt): ~650 – 700 km

If drilled cuttings from Austria were brought to Stassfurt for injection, the following costs would need to be considered: At the KGS Stassfurt between 30 to 90 €/t must be paid, the transport cost from Austria (Vienna or Salzburg) to Stassfurt would be about 50 – 60 €/t depending on the possibilities of combined traffic (road & rail). For such a distance it would not be possible to pick-up the drilling waste just-in-time from the rig. Hence, intermediate storage facilities would be required which would also increase cost. Moreover, the ALSAG fee must be paid if this procedure is not seen as recycling.

4.4.3 Subsurface Deposition: Cuttings Reinjection

This possibility is not discussed in this thesis as it is currently not a topic in Austria.

4.5. Combustion of Hazardous Waste

"Combustion of cuttings sounds like an easy solution but it is not. There are several problems that need to be overcome before cuttings can be incinerated. First of all, most hazardous waste incinerators often use grates for the combustion of waste which means that the material must not be liquid as it would leak through the grates; instead, the material needs to be solid and compact (lumpy). This means if cuttings should be burnt in such an incinerator they need to be conditioned before.

Furthermore, the calorific value of an average material to be burnt in incinerators is about 8,000 to 9,000 kJ/kg. From that material approximately 5 % remains as ash which needs to be disposed of. The costs for burning in this case would be ~130 €/t without considering transport cost. If we look at cuttings and their high mineral content it is assumed that about 60 % of the material remains as ash. Furthermore, as the calorific value of cuttings is so low, one would need to add higher energy materials to the cuttings, e.g. saw dust or something similar.

Ottmar Polczer, authorized signatory of the waste management company *J. Ehgartner GmbH* in Bavaria (Germany) said that because of all those necessary steps and considerations he would assume that the cost for burning cuttings would be several times higher than 130 €/t. Furthermore, the ALSAG fee needs to be paid as well in Austria."(24) OMV's tentative cost estimates for cuttings combustion were at ~400 €/t without considering transport.(14)

4.6. Economic Comparison

Table 26 shows an economic comparison for three different scenarios for drilling waste with a TOC content that is too high for general landfill AWG.

Cost estimates of other recycling possibilities (except cement industry) were not available but they are expected to lie in more or less the same range.

From the table, it can be clearly seen that combustion is not an economic solution.

However, it is very interesting that due to the low cost for combined traffic from Austria to Stassfurt (Germany) the mining backfill is also a viable solution.

But still, for most cases the recycling possibility of cuttings in the cement industry would be the most economic decision and shows the highest cost savings potential.

Table 26: Economic Comparison of Mining Backfill, Combustion and Recycling in Cement Industry

Mining Backfill Salt Cavern in Stassfurt, Germany	**Combustion of Hazardous Waste**	**Recycling in Cement Industry**
Injection: 30-90 €/t	Combustion: > 400 €/t	Cement Plant: 20-30 €/t
Storage: n.a.	ALSAG fee: 7 €/t	Pretreatment: 25-35 €/t
Transport: 600 – 700 km (=50-60 €/t for combined traffic)	Transport: 30 – 300 km	Transport: 50 – 200 km

5. Conclusion

5.1. Discussion

As mentioned in this thesis the TOC content of solids and eluates is an important parameter in terms of waste deposition in Austria. However, it is not quite clear why the TOC limits were set this way by law as landfills must be sealed off anyhow and thus the TOC content in the eluate should not be a problem.

The legal situation concerning drilling waste in Austria was not very clear in the past but this situation changed when new laws came into effect in 2010 (BBA-G, BBA-VO, Guideline for Mining Waste). According to the Guideline for Mining Waste drilled cuttings are defined as a ‘side-product’ when they are/will be recycled in the own mining business or in another industry. In this case the BBA-G, BBA-VO and AWG do not apply. If drilling waste should be disposed in a landfill that belongs to the mining business itself then it is defined as ‘mining waste’ and the BBA-G and the BBA-VO apply but the AWG does not apply. If the drilled material can only be disposed externally then the material is called ‘waste’ and the AWG (together with the Landfill Regulation 2008 and its TOC limits) applies.

Although it sounds quite convenient to be able to dispose ‘mining waste’ in the mining company’s own landfill and not having to comply with the TOC limits of the AWG this is not a popular solution in Austria, at least for RAG. The reason is that RAG’s company owned landfill is almost full and it would be very expensive to build a new one. Moreover, RAG believes that it would be unlikely to get the legal permit to establish a new waste site in the environmentally sensitive area (groundwater protection area, tourism) where they operate.

So, for RAG the only possibilities to handle drilling waste are either deposition of cuttings as ‘waste’ in surface dumpsites in Austria (but this is only possible if the TOC limits are kept), or a subsurface deposition of cuttings outside Austria, or cuttings reinjection, combustion or recycling.

In order to find out whether a surface deposition in one of Austria’s categories of landfill would be possible for cuttings from RAG wells a sample analysis was undertaken. It showed that cuttings drilled with a K_2CO_3-Polymer mud system cannot be disposed in AWG landfills in Austria because the TOC limits were above the highest landfill category in Austria (=Mass Waste Landfill). However, cuttings drilled with a bentonite mud system showed a TOC that was below the limit of the lowest landfill category (=Excavation Soil Landfill) and thus those cuttings could be deposited provided that the other limits are kept. From the sample investigation it was inferred that the high TOC contents are primarily caused by mud additives (like cellulose polymers, citric acid) and the flocculating agent. With the LECO measurement it could be shown that the rock immanent TOC of solids was only minor (~8,000 mg/kg). So, the following question was whether a different mud system would not cause such a high TOC. But currently, the industry does not know how to replace the polymers without losing the necessary mud properties. It could also be seen that fine cuttings with lots of mud adhering to them had the highest TOC content. This showed how important it is to have high solids control efficiency. Furthermore, sunlight and dehydration experiments with retain samples were conducted in order to find out whether such a simple treatment could reduce the TOC of cuttings and make them disposable. Although the sunlight experiment showed some reduction in TOC it was too little for a change in landfill category. An additional observation made during the analysis was that the current TOC measuring devices and methods may probably not be suitable for drilling waste. For a detailed discussion of the results of the sample analysis please refer to Chapter 3.6.

This meant that the other alternative solutions for handling K_2CO_3-polymer cuttings needed to be looked at:

<u>Author's comment:</u> Cuttings reinjection was not discussed in this thesis as it is currently not considered to be a viable and economic possibility in Austria. Up to now cuttings reinjection is mostly done offshore for oil contaminated cuttings because on platforms this is a cost efficient and time saving alternative to skipping & shipping cuttings to shore including expensive subsequent disposal onshore. Often times, with the skip & ship procedure the problem is logistics: A lot of space is needed on the platform for intermediate storage of cuttings and to ensure that drilling continues and/or ROP is not slowed down as e.g. at bad weather/waves off-loading of cuttings

onto ships would not be possible immediately. Cuttings reinjection is often convenient offshore if more wells are drilled from one platform with multiple slots and e.g. one slot is dedicated for cuttings reinjection only. A suitable formation for cuttings reinjection is important. Usually, cuttings are injected into permeable “thief” zones (fractures, vugs, …). Sometimes formations may also be fractured and cuttings injected then. For cuttings reinjection it is also important to have a cuttings slurrying system installed which ensures a consistent rheology of the injected material. In Austria, suitable formations for cuttings reinjection are not readily available and furthermore liquefaction of cuttings and subsequent injection would probably be more expensive for not oil-contaminated cuttings than disposal or recycling.

Combustion would be very expensive and poses some problems as the drilling waste often has a liquid consistency, is low in calorific value and has a high mineral content (lot of ash remaining).

It turned out that subsurface deposition abroad (=injecting the cuttings into a salt cavern in Stassfurt, Germany) and recycling were the two most economically viable solutions. However, the recycling of cuttings seems to have more savings potential and is a more sustainable solution for Austria.

The advantages of recycling are that in many applications the properties of the cuttings (+adhering mud) are beneficial, e.g. the high pH, the K^+ ion, the clay/marl/lime mixture of the drilled material itself. In case of recycling it is most important to act in a sensitive way and to emphasize the ‘end of waste’ character of the drilled material. Often times, the requirement for recycling is that the material is as dry as possible. This means that high solids control efficiency is not only important because it helps to reduce the waste volume (and thus the cost) but it also facilitates the recycling of cuttings.

Due to the cost savings potential and the many different possible applications (e.g. in the brick making, cement, composting, or construction industry, or in agriculture) cuttings recycling seems to be THE alternative for Austria.

5.2. Recommendations

Considering recent events which brought more emphasis on environmental issues and maybe will bring even stricter regulations in the future, and thinking of new developments like shale gas in Europe which could cause great amounts of drilling waste, the author believes, it is important to act in a provident way. Thus, the recommendations for the near future are:

- Minimize the waste volume and increase the solids control efficiency.
- Minimize the use of mud additives and start thinking of benefits vs. consequences of certain additives.
- Realize recycling possibilities (but consider acting sensitive) as this seems to be a working alternative to deposition in Austria and is also an economically viable solution.

Seen long-term, it may probably be good to invest in research for new mud systems and TOC reduction possibilities.

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List of Abbreviations

EFD	Environmentally Friendly Drilling
CEO	Corporate Executive Officer
RAG	Rohöl-Aufsuchungs Aktiengesellschaft; an oil and gas company with headquarters in Vienna, Austria. The company operates many underground gas storage facilities in Austria.
OMV	Austria's largest oil-producing, refining and gas station operating company with important activities in other Central European countries (originally ÖMV for "Österreichische Mineralölverwaltung", meaning Austrian mineral oil authority).
TOC	Total Organic Carbon
K_2CO_3	Potassium Carbonate (Potash)
BBA-G	Bergbauabfallgesetz (Mining Waste Law)
MinroG	Mineralrohstoffgesetz (Mineral Resources Law)
AWG	Abfallwirtschaftsgesetz (General Waste Management Law)
BBA-VO	Bergbauabfall-Verordnung (Mining Waste Regulation)
RL	Richtlinie (Directive)
RRL	Rahmenrichtlinie (Framework Directive)
VO	Verordnung (Regulation)
MM	Million
M	Thousand
BAWP	Bundes-Abfallwirtschaftsplan (Federal Waste Management Plan)
EU	European Union (Europäische Union)
BMLFUW	Bundesministerium für Land- und Forstwirtschaft, Umwelt und Wasserwirtschaft (Federal Ministry of Agriculture, Forestry, Environment and Water Management)
LCA	Life Cycle Assessment (Ökobilanz)
TD	Total Depth
MD	Measured Depth
OH	Open Hole
m	meter
in	inch
t	tons
incl.	including
WA	Well Abandonment
km	kilometer
LOI	Loss on Ignition (Glühverlust)

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Appendix A

Auswertungstabelle für Gehalte im Feststoff

Parameter	Einheit	Bodenaushubdeponie				Inertabfalldeponie		Baurestmassendeponie		Reststoffdeponie		Massenabfalldeponie	
		I		II 1)									
		Messwert	Grenzwert	Messwert	Grenzwert	Messwert	Grenzwert	Messwert	Grenzwert	Messwert	Grenzwert	Messwert	Grenzwert
Arsen (als As)	mg/kg TM		50		200		200		200		5 000		500
Barium (als Ba)	mg/kg TM												10 000
Blei (als Pb)	mg/kg TM		150		500		500		500				5 000
Cadmium (als Cd)	mg/kg TM		2		4		4		10		5 000		30
Chrom ges (als Cr)	mg/kg TM		300		500		500		500				8 000
Cobalt (als Co)	mg/kg TM		50				50		100				500
Kupfer (als Cu)	mg/kg TM		100		500		500		500				5 000
Nickel (als Ni)	mg/kg TM		100		500		500		500				2 000
Quecksilber (als Hg)	mg/kg TM		1		2		2		3		20 6)		20
Silber (als Ag)	mg/kg TM												100
Zink (als Zn)	mg/kg TM		500		1 000		1 000		1 500				5 000
TOC (als C)	mg/kg TM		30 000 2)		30 000 2)		30 000 4)		30 000 4) 5)		50 000 7) 8)		50 000 7) 10)
Kohlenwasserstoff Index	mg/kg TM		200 3)		200 3)		500		1 000		5 000		20 000
PAK (16 Verbindungen)	mg/kg TM		4		4		20		30		300 9)		300
Benzo(a)pyren	mg/kg TM		0.4		0.4		2						
BTEX	mg/kg TM		6		6		6		6		6		6
PCB (7 Verbindungen)	mg/kg TM						1						
POX (als Cl)	mg/kg TM												1 000

Fußnoten für Feststoff-Tabelle:

1) Ist bei Bodenaushubmaterial der Gehalt eines Schadstoffes geogen bedingt, so ist eine Überschreitung bis zu dem in Spalte II angeführten Grenzwert zulässig.

2) Bei nicht verunreinigtem Bodenaushubmaterial und nicht verunreinigten Bodenbestandteilen mit aufgrund ihrer Humusgehalte erhöhten TOC-Werten: 90 000 mg/kg

3) 50 mg/kg TM gilt für Bodenaushubmaterial mit TOC ≤ 5000 mg/kg TM
100 mg/kg TM gilt für Bodenaushubmaterial mit TOC > 5000 ≤ 20000 mg/kg TM
200 mg/kg TM gilt für Bodenaushubmaterial mit TOC > 20 000 mg/kg TM

4) Bei einem Glühverlust von nicht größer als 5 Massenprozent gilt der TOC-Grenzwert als eingehalten.

5) Nicht maßgeblich für Abfälle gemäß §7 Z 7 lit. b, c und h.

6) Wenn Quecksilber in Form schwerlöslicher sulfidischer Verbindungen vorliegt, ist ein Quecksilbergehalt bis maximal 100 mg/kg TM zulässig. Liegt Quecksilber in Form schwerlöslicher sulfidischer Verbindungen vor und wurde der Abfall stabilisiert oder immobilisiert, ist ein Quecksilbergehalt bis maximal 3000 mg/kg TM zulässig.

7) Bei einem Glühverlust von nicht größer als 8 Massenprozent gilt der TOC-Grenzwert als eingehalten.

8) Dieser Grenzwert gilt nicht für Abfälle gemäß §7 Z 7 lit. a bis c.

9) Für Abfälle, deren Eluatwert (zentrifugiert, nicht gefiltert) weniger als 1,5 mg/kg TM beträgt, ist ein Grenzwert von 500 mg/kg TM zulässig.

10) Dieser Grenzwert gilt nicht für Abfälle gemäß § 7 Z 7 lit. a bis d, f und h bis j.

Abkürzungen:	n.n.	nicht nachweisbar
Farblegende:	🟥	Grenzwert überschritten
	🟧	grenzwertrelevanter Wert (80-100% des Grenzwertes)
	🟨	relevanter Wert (20-80% des Grenzwertes)
	🟪	könnte als Überschreitung gewertet werden

Auswertungstabelle für Gehalte im Eluat

Parameter	Einheit	Bodenaushubdeponie		Inertabfalldeponie		Baurestmassendeponie		Reststoffdeponie		Massenabfalldeponie	
		Messwert	Grenzwert	Messwert	Grenzwert	Messwert	Grenzwert	Messwert	Grenzwert	Messwert	Grenzwert
pH-Wert			6,5 - 11 1) 5)		6,5 - 12 1)		6 - 13 1)		6 - 12 13)		6 -13
elektr. Leitfähigkeit	mS/m		150 2)		150 6)		300 9) 10)		(*) 3)		
Abdampfrückstand	mg/kg TM						25 000		60 000		100 000
Aluminium (als Al)	mg/kg TM		(*) 3)		(*) 3)				100 14)		
Antimon (als Sb)	mg/kg TM				0.06				0.7		5
Arsen (als As)	mg/kg TM		0.5		0.5		0.75		2		25
Barium (als Ba)	mg/kg TM		10		20		20		100		300
Blei (als Pb)	mg/kg TM		1		0.5		2		10		50
Bor (als B)	mg/kg TM						30				
Cadmium (als Cd)	mg/kg TM		0.05		0.04		0.5		1		5
Chrom gesamt (als Cr)	mg/kg TM		1		0.5		2		10		70
Chrom 6wertig (als Cr)	mg/kg TM						0.5				20
Cobalt (als Co)	mg/kg TM		1		1		2		5		50
Eisen (als Fe)	mg/kg TM		(*) 3)		(*) 3)				20 14)		
Kupfer (als Cu)	mg/kg TM		2		2		10		50		100
Molybdän (als Mo)	mg/kg TM				0.5				10		30
Nickel (als Ni)	mg/kg TM		1		0.4		2		10		40
Quecksilber (als Hg)	mg/kg TM		0.01		0.01		0.05		0.1		0.5
Selen (als Se)	mg/kg TM				0.1				0.5		7
Silber (als Ag)	mg/kg TM		0.2		0.2		1		1		10
Zink (als Zn)	mg/kg TM		20		4		20		50		200
Zinn (als Sn)	mg/kg TM		2		2		10		20		200
Ammonium (als N)	mg/kg TM		8		8		40		300		10 000
Chlorid (als Cl)	mg/kg TM				800 7)		5 000				
Cyanide, leicht freisetzbar (als CN)	mg/kg TM		0.2		0.2		1		1		20
Fluorid (als F)	mg/kg TM		20		10		50		150		500
Nitrat (als N)	mg/kg TM		100		100		500				
Nitrit (als N)	mg/kg TM		2		2		10		15		1 000
Phosphat (als P)	mg/kg TM		5		5		50		50		
Sulfat (als SO_4)	mg/kg TM				1 000 7) 8)		6 000 11)				25 000 16)
TOC (als C)	mg/kg TM		200		500		500		500		2 500 17)
Kohlenwasserstoff Index	mg/kg TM		5		5		50		100		200 18)
EOX (als Cl)	mg/kg TM		0,3 4)		0,3 4)		3 12)		30 15)		30 15)
anionenaktive Tenside (als MBAS)	mg/kg TM		1		1		5		20		
Phenolindex	mg/kg TM				1						1 000

Fußnoten für Eluat-Tabelle:

[1] Für aufgrund natürlicher Entwicklung versauertes Bodenaushubmaterial gilt der pH-Wertebereich ab 3,5.

[2] Für geogen bedingt gipshaltiges Bodenaushubmaterial beträgt der Grenzwert für die elektrische Leitfähigkeit 300 mS/m.

[3] Der Wert ist zu bestimmen und in die Beurteilung des Deponieverhaltens mit einzubeziehen.

[4] Gilt auch als eingehalten, wenn der Parameter AOX nicht mehr als 0,3 mg/kg TM beträgt.

[5] Werden die Gesamtgehalte der Spalte I in Tabelle 1 eingehalten, so ist ein pH-Wert von 6,5 bis 12 zulässig. In diesem Fall beträgt bei einem pH-Wert zwischen 11 und 12 der Grenzwert für die elektrische Leitfähigkeit 250 mS/m.

[6] Bei einem pH-Wert zwischen 11 und 12 beträgt der Grenzwert für die elektrische Leitfähigkeit 250 mS/m. Für geogen bedingt gipshaltiges Bodenaushubmaterial beträgt der Grenzwert für die elektrische Leitfähigkeit 300 mS/m.

[7] Statt der Grenzwerte für Chlorid und Sulfat kann ein Grenzwert für den Abdampfrückstand von 4000 mg/kg TM angewendet werden.

[8] Wird bei einem Abfall der Grenzwert von 1000 mg/kg TM nicht eingehalten, ist eine Annahme dennoch zulässig, wenn die Auslaugung die folgenden Werte nicht überschreitet: 1500 mg/L als Co bei L/S = 0,1 L/kg und 6000 mg/kg bei L/S = 10 L/kg. Zur Ermittlung des Grenzwertes bei L/S = 0,1 L/kg unter anfänglichen Gleichgewichtsbedingungen ist ein Perkolationstest erforderlich. Der Wert bei L/S = 10 L/kg kann entweder durch den Chargen-Auslaugtest oder einen Perkolationstest unter annähernden lokalen Gleichgewichtsbedingungen ermittelt werden.

[9] Für mit hydraulischen Bindemitteln verfestigte Abfälle oder stabilisierte nicht gefährliche Abfälle oder stabilisierte gefährliche Abfälle, sofern sie ausschließlich die gefahrenrelevante Eigenschaft reizend oder ätzend aufweisen, ist der Grenzwert von 300 mS/m nach 28 Tagen Aushärtezeit einzuhalten.

[10] Bei frisch gebrochenem Beton, Betonierungsrückständen und Bentonit-Schlämmen: 800 mS/m.

[11] Für gipshaltigen Bauschutt und andere gipshaltige Abfälle, sofern letztere auf einem Monokompartiment abgelagert werden, ist eine Überschreitung bis zu 14 000 mg/kg Sulfat unter der Bedingung zulässig, dass die Ca-Konzentration im Eluat mindestens die 0,43-fache ermittelte Sulfatkonzentration erreicht; in diesen Fällen ist auch eine Überschreitung des Grenzwertes für die elektrische Leitfähigkeit zulässig.

[12] Gilt auch als eingehalten, wenn der Parameter AOX nicht mehr als 3 mg/kg TM beträgt.

[13] Für mit hydraulischen Bindemitteln verfestigte oder stabilisierte Abfälle ist ein pH-wert bis 13 zulässig.

[14] Nur gültig für mit hydraulischen Bindemitteln stabilisierte Abfälle, ausgenommen stabilisierte Schlacken und Aschen aus (Mit-)Verbrennungsanlagen im Sinne der Abfallverbrennungsverordnung, BGBl. II Nr. 389/2002, in der Fassung der Verordnung BGBl. II Nr. 296/2007, sofern die Anforderungen des Anhangs 5 Kapitel 3.2.3 a) eingehalten werden.

[15] Gilt auch als eingehalten, wenn der Parameter AOX nicht mehr als 30 mg/kg TM beträgt.

[16] Für magnesitgebundene Holzwolledämmbauplatten: 50 000 mg/kg TM.

[17] Gilt nicht für mechanisch-biologisch behandelte Abfälle gemäß § 7 Z 7 lit. f, ist jedoch zu bestimmen und in die Beurteilung des Deponieverhaltens mit einzubeziehen.

[18] Für Bodenaushubmaterial: 50 mg/kg TM

Abkürzungen:	n.n.	nicht nachweisbar
	n.best.	matrixbedingt nicht bestimmbar
Farblegende:	🟥	Grenzwert überschritten
	🟧	grenzwertrelevanter Wert (80-100% des Grenzwertes)
	🟨	relevanter Wert (20-80% des Grenzwertes)
	🟪	könnte als Überschreitung gewertet werden