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Äspö Hard Rock Laboratory

Rock Characterisation System – RoCS

Final report – feasibility study, phase I State-of-the-art in 3D surveying technology

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April 2006

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Keywords: RoCS, Rock characterisation system, Geological mapping, Underground mapping, Digital photogrammetry, Laser scanning, Geodetic surveying, Tunnel layout, Data processing, Data storage, Data analysis

This report concerns a study which was conducted for SKB. The conclusions and viewpoints presented in the report are those of the author(s) and do not necessarily coincide with those of the client.

Abstract

The report presents the results of the first stage of a feasibility study concerning a possible new system for characterization of the rock in a future underground storage for nuclear waste. The project has been named the RoCS (Rock Characterization System) study, and is a joint programme between SKB and Posiva.

Both organizations have so far used conventional mapping methods for rock characterization. In this case it means that all field work (collection of field data and drawing of maps) is manual. Geological data such as fracture orientations, widths, rock characteristics etc. are recorded on special forms and the maps are drawn in a 2D format where the walls and the roof of a tunnel are unfolded to form one plane. In the office, after a field/underground session, the field maps are digitized and the data are fed into a database.

One of the ideas with a new mapping system would be to diminish some of the double handling in the current mapping procedure. If the geological mapping could be digitally recorded and data fed directly into the computer underground a lot of time could probably be saved. Another aim for a new rock characterization system would be to get a higher accuracy in the maps that are drawn.

During the last few years SKB has tested laser scanning surveying methods at the Äspö Hard Rock Laboratory (Äspö HRL) to establish if this technique could be useful in the characterization of the rock in the near future.

Posiva has for the same purpose tested digital photogrammetry at the final repository site at Onkalo. More recently, laser scanning has also been tested at this site and an integrated system of laser scanning and high-resolution digital photography has also been tested. The result is an image that looks like a colour photo. The normal laser scanning image is black and white.

Both laser scanning and photogrammetry, with the help of some geodetic surveying, will have the advantage that geological as well as other features in the future repository will be positioned correctly in the 3D coordinate system in use. Thus, a higher accuracy in the geological mapping is likely to be obtained if any of these methods could be used in a future rock characterization system.

A disadvantage with both laser scanning and photogrammetry is the large amount of data that is produced. Each 10 m tunnel section will produce between 0.5 and 1 Gb of data depending on the resolution that is chosen. With modern computer technology this is, however, not a major problem.

There are a number of software applications that can handle laser scan data and that can deliver the data in a format that can be used in various CAD-systems. To handle digital photogrammetry SiroVision appears to be the most widely used software.

A review of current software that can be used in geological mapping and modelling has been undertaken. With a few exceptions (e.g. SiroVision), it was found that most of the software that is used in geological mapping operated in 2D. On the other hand, the geological modelling tools were quite commonly 3D applications. Thus, to perform geological mapping in 3D that will meet the standards for rock characterization of a deep repository for spent nuclear fuel, new software or adjustments of already existing software will be needed.

In addition to geologists, people from other disciplines of work can use the data from laser scanning and photogrammetry. For example, the design group of a future repository could use these data to obtain the correct tunnel geometries of an excavated tunnel in 3D, to document where rock bolts and other types of reinforcement have been placed, and to calculate excavation volumes etc.

Since the laser scanning technique has developed rapidly in recent years, and photogrammetry less so, the future work should concentrate on the former as a part of RoCS. It appears realistic to assume that a new 3D rock characterization system based on an integrated laser scanning/digital photography system together with mapping applications already in use or with some modifications can be accomplished within a reasonable amount of time.

Sammanfattning

I föreliggande rapport presenteras resultatet från en ”feasibility” studie rörande ett eventuellt nytt karteringssystem för att karakterisera berget i ett kommande slutförvar av kärnavfall. Projektet har kallats RoCS (Rock Characterization System) och är ett samarbete mellan SKB och Posiva.

Båda organisationerna använder för närvarande ett konventionellt sätt att kartera berget vid tunnelarbeten. Systemet är i fält helt manuellt där geologisk data noteras i speciella formulär och själva ritandet sker i 2D med tunnelväggarna uppvikta så att de tillsammans med taket bildar ett plan. På kontoret, efter en karterings omgång digitaliseras sedan fältkartorna och noteringarna skrivs in i en databas.

Ett av de mål som eftersträvas med ett nytt karteringssystem är att minska det dubbelarbete som utförs i det nuvarande systemet. Om digitalisering och datainmatning kunde ske redan under jord skulle en hel del tid kunna sparas. Dessutom eftersträvas en högre noggrannhet i de kartor/ritningar, som produceras.

Under de senaste två åren har SKB testat laserskanning i Äspölaboratoriet för att se om denna teknik kan användas som en del i ett framtida karteringssystem.

Posiva har av samma anledning testat fotogrammetri i det blivande slutförvaret i Onkalo. På senare tid har även laserskanning testats på samma plats. Här har även ett integrerat system av laserskanning och högupplösande digitalkamera testats. Resultatet blir en ”bild” vilken liknar ett färgfoto. Den normala laserskanning-”bilden” är i svart/vitt.

Både laserskanning och fotogrammetri i kombination med geodetiska inmätningar av ett antal referenspunkter har den fördelen att geologiska liksom andra objekt i ett framtida slutförvar positioneras korrekt i 3D och i gällande koordinatsystem. Således bör en större noggrannhet i den geologiska karteringen kunna uppnås om någon av dessa tekniker kan bli en del av det framtida karteringssystemet.

En av nackdelarna med både laserskanningen och fotogrammetrin är den stora datamängd som produceras. För varje 10 m tunnelsektion så produceras det c:a 0.5-1 Gb data beroende på den upplösning man valt för systemet. Med modern datorteknologi anses detta dock inte välla något problem enligt initierat folk.

Det finns ett flertal programvaror som kan hantera laserskanning data och som kan omvandla den till format, som kan hanteras i olika CAD-system. För att hantera information från digital fotogrammetri tycks SiroVision vara den mest spridda programvaran.

Marknaden har genomsökts efter program som kan användas till geologisk kartering. Det visade sig att de flesta karteringsprogrammen arbetade i 2D miljö medan när det gällde modelleringsprogrammen så var även 3D vanligt förekommande.

Förutom geologer är det tänkt att även personal från andra arbetsområden skall kunna utnyttja den data som produceras från laserskanning alternativt fotogrammetri. T.ex. skulle en designgrupp för ett kommande slutförvar kunna utnyttja denna data för att få exakta tunnelgeometrier i 3D för den utsprängda tunneln, för att korrekt dokumentera var bultar och annan förstärknings materiel har placerats etc.

Laserskanningtekniken har de senaste åren utvecklats i ganska snabb takt medan utvecklingen inom fotogrammetrin tycks, om inte stannat av, så i alla fall minskat. Det fortsatta arbetet med RoCS bör därför koncentreras till laserskanningtekniken. Inom en inte alltför avlägsen framtid bör ett nytt 3D karteringssystem, som är baserat på ett integrerat laserskanning/digitalt fotograferingssystem tillsammans med befintliga eller något modifierade karteringsprogram, kunna vara i bruk.

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1 Introduction and background to the study

At present SKB and Posiva perform geological mapping mainly by the conventional method, *i.e.* manually in all steps of field-data collection and documentation. This system has been used during the mapping of the tunnels in Äspö HRL. However, for the future construction of a final repository for spent nuclear fuel, further qualities in a rock characterisation system are desirable. These include: more careful, consistent and objective approach to data collection and documentation; a better preservation and traceability of the data collected; and elimination of some of the present steps for possible errors during the mapping procedure. Compared to the mapping system presently in use, the estimated time for mapping may be reduced by a more automatic method for collection of geological data. It must be emphasised that the new system must reduce the subjectivity and inconsistency that may occur in manual mapping and data recording when many geologists are involved. A system that meets increased requirements is not available at present. The project concerned in this report is a joint-project between SKB and Posiva with the intention to investigate if and how such a system can be created. The project as well as the possible mapping system has been given the name RoCS – Rock Characterisation System.

The RoCS-project has been divided into three main stages (Figure 1):

- Stage 1 is “the feasibility study” and is so far the only part of the project with a project decision. The feasibility study has been separated into two parts, Phase I and Phase II:
 - Phase I covered by the present report, is to establish the state-of-the-art in underground mapping techniques.
 - Phase II will aim to establish requirements for rock characterisation in a future deep repository, both internally (SKB/Posiva) and from external public authorities. The intention is to present a specification of requirements and a brief cost estimate for the whole project in the Phase II report at the end of 2006 or more probable in 2007.
- Stage 2 is “the evaluation stage”.
- Stage 3 “the development stage”.

The completed feasibility study presented in the reports from-Phases I and II-will serve as a platform for a future decision if SKB and Posiva need to update their present rock characterisation systems.

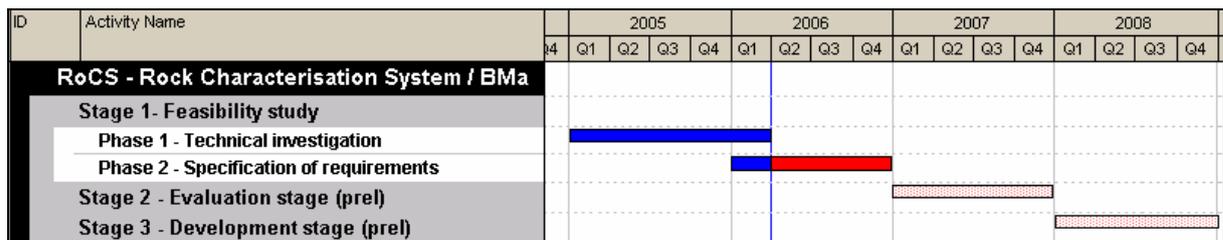


Figure 1. Time schedule for the RoCS-project.

2 Objectives

The objective for the phase I of the feasibility study has been to search the global market for possible systems and techniques to use in a future RoCS. The aim of the search has been to cover all existing systems at present in operation and also techniques from known users of 3D digital data, also outside the field of geology.

To achieve an indication of the desired final result, the major overall goals of the whole project, not only the feasibility study, have been identified.

- As a final result the RoCS project should deliver a portable operative system for rock characterisation. To be operative, the system should have been tested in an underground environment and thus must be durable in this environment. The resulting system shall give higher quality of rock characterisation than the present system with respect to objectivity, traceability, precision and time consumption.
- Any methodology adopted must have potential to be further developed after the project has been completed, in order to take advantages of future improvements and upgrades respect to hardware, software and the links between these. A condition for this is that the project has ensured competence in SKB and Posiva to manage and continuously develop the system also after the project has been terminated.

To reach the above goals, a preliminary plan for continued work after the feasibility study has been established. In *Stage 2, the evaluation stage*, the systems and techniques discovered during the feasibility study will be evaluated. A selection will be made of systems and/or techniques that are either available to purchase ‘off-the-shelf’, or that can be developed into an operative rock characterisation system. This selection defines the milestone between stages 2 and 3. In *Stage 3, the development stage*, selected systems and/or techniques will be developed to a rock characterisation system suitable for SKB and Posiva requirements. To complete the project, cyclic work with development-tests-improvements until the system is considered operational by SKB and Posiva will be needed.

2.1 Present method of rock characterisation in SKB and Posiva

While SKB are in the site investigation and planning stages for a final repository, Posiva has started to build the combined test laboratory and final repository Onkalo in Olkiluoto. Posiva is considering upgrading the present system for rock characterisation during construction of the Onkalo facility.

2.1.1 SKB method

The present method for geological mapping and rock characterisation at SKB is based on a conventional method where tunnel roof and walls are “unfolded” and represented as a projection onto a 2D plane (Figure 2). The same mapping procedure that is used today was used already during the construction of the Äspö HRL. Underground, the

geological map for each unfolded segment of the tunnel is drawn by hand and data collection is performed visually (Figures 2 and 3). Figure 3 shows data for some of the fractures collected during regular mapping of tunnel Q (TASQ) at Äspö HRL. Besides fracture data, data for rock types, lithological boundaries or contacts, deformation zones (formerly termed *fracture zones*) and groundwater inflows are collected. Further, the rock quality is estimated by following SKB's simplified version of RMR (Rock Mass Rating, Bieniawski 1976).

During the construction of the Äspö HRL each excavation cycle (drilling – blasting – unloading) gave a 4-5 m new tunnel segment which was mapped as soon as safety was sufficient. The rate of mapping and data acquisition for general geological rock characterisation was approximately 4-5 m tunnel per hour, utilizing a team of two geologists. It should be noted, however, that it was not possible to achieve and maintain this mapping rate in all parts of the tunnel and that the mapping and data recording rates were necessarily slower in more complex tunnel sections in order to produce a correct geological map. Unfortunately, sometimes the mapping rate had to be kept at the expense of mapping accuracy.

After completion of mapping, photos of the mapped rock surfaces were taken. The photos were named in a way that made it possible to connect them to their correct position in the tunnel. However, the same problem turns up here as in the issue about geological data collection; the accuracy depends on the individual geologist. This should be avoided, as one objective with the present project should be to eliminate the human factor as much as possible.

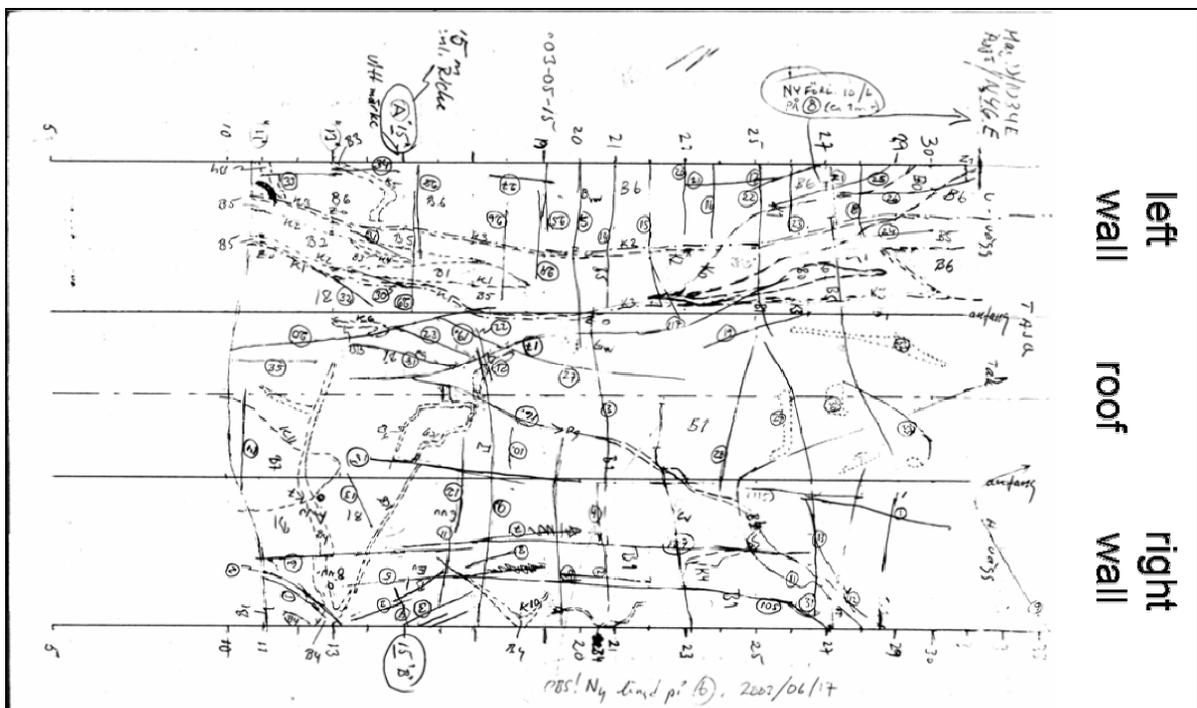


Figure 2. Present SKB method for geological mapping, tunnel roof with walls unfolded (field version).

SKB		FRACTURES															2002-03-22 Version 1.0.1									
Attachment to geological Tunnel Mapping System																	Page 1 of									
Site		Object ID code			Section			Date			Geologist															
Aspe		TASR			35-40			2002/06/26			RMC, C, H															
Part ID	No of frac	Frac Space m	Width mm			Orientation			Rock	Length m	Form	Type	Surf struc	Depth m	Striation			Fracture filling	Sample	Fracture ends			Water	Remarks		
			width	apert	apert	Strike	Dip	vis							trend	plunge	end1			to	end2	to				
P 01	1		-	2	20	0	0	B1	2.8	1	2	104	Z				EP, DX		2		2		Approx. horizontal orient	✓		
02	1		-	3	50	225	20	B2	3.2	1	2	104	Z				EP, DX		2		3	4		✓		
03	4		-	0.5	1	0.20	60	B2	3.7	1	4	107	N				TS, TA		1		2		All tracks not continuous	✓		
04	1		-	1.5	195	75	B3	4.6	1	4	107	N					KL, KH, EP		1		2			✓		
05	1		-	3	10	0.45	20	B1	2.0	1	2	104	Z				EP, DX		2		2			✓		
06	1		-	0.5	30	350	55	B1	1.8	1	2	104	Z				DX		2		2			✓		
07	1		-	50	-	212	50	B2	3.5	2	2	104	Z				Q2, KL		2		2		Q2 - segregation up to 30 x 20 cm	✓		
08	1		-	0.5	-	120	90	B1	1.4	3	2	107	Z				DS		2		2			✓		
09	2		-	0.5	-	72	70	B3	2.1	1	2	104	N				TS		2		2		2 cm + fract.	✓		
10	1		-	1	-	40	80	B3	2.5	1	2	107	N				KL, AT		2		2			✓		
11	1		-	1	-	112	90	B3	5.3	1	2	107	N				KA, KL		1		2			✓		
12	1		-	1	-	95	80	B1	2.3	1	2	104	Z				KA		2		2			✓		
13	1		-	20	-	0.30	80	B1	2.9	2	2	104	Z				PG		2		3	106		✓		
14	1		-	25	-	170	90	B1	1.7	2	2	104	Z				XX		2		3	106		Vein of greenstone	✓	
15	1		-	20	-	170	90	B1	4.6	2	2	104	Z				XX		2		2			✓		
16	1		-	1	300	0	0	B1	3.6	1	2	107	N				EP, KA, KL		2		2			Approx. horizontal	✓	
17	1		-	50	10	0.35	80	B1	4.0	2	2	104	Z				EP, KL, XX		2		2			Could be sheared	✓	
18	1		-	5	-	0.35	80	B3	15.2	2	2	104	Z				EP		2		2			EX-mineral could be quite	✓	
19																										
20	1		-	3	30	0.15	40	B1	6.7	1	2	104	Z				EP, DX		3	121	3	209			✓	

Figure 3. Field form for fracture data.

After-completion of an underground mapping session, maps are digitized in the Tunnel Mapping System (TMS), a MicroStation-based 2D application that was originally created for SKB by the now closed down company Sveriges Geologiska AB (Figure 4 and 5). Geological data are fed into the TMS Access database and links are established between every digitized feature and its collected data attributes (Figure 4). Quality control is conducted on the data transposed from underground to data fed into TMS database.

However, the quality of the original data collected underground can not be monitored and verified easily. This is of course a problem since manual underground mapping involves a lot of subjectivity in what is recorded by the individual geologists. For example, one geologist may emphasize some features or miss things that another geologist would record. This suggests that more objective data collection would be desirable and could be achieved by more automated collection and documentation of data underground. However, it is stressed that geologists in the future should perform all interpretations and judgements associated with the mapping as they do now.

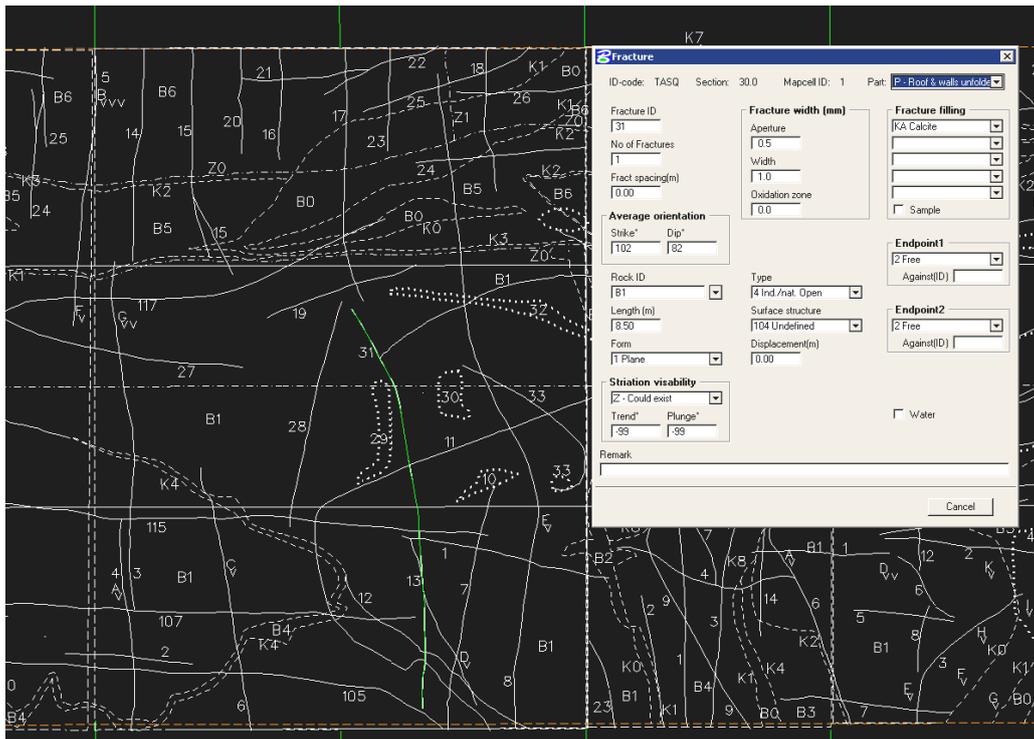


Figure 4. A drawing in the TMS with a digitized part of a geological map and an example of the dialog boxes that are in use to feed data into the data base or to show data already linked to a certain element in the drawing.

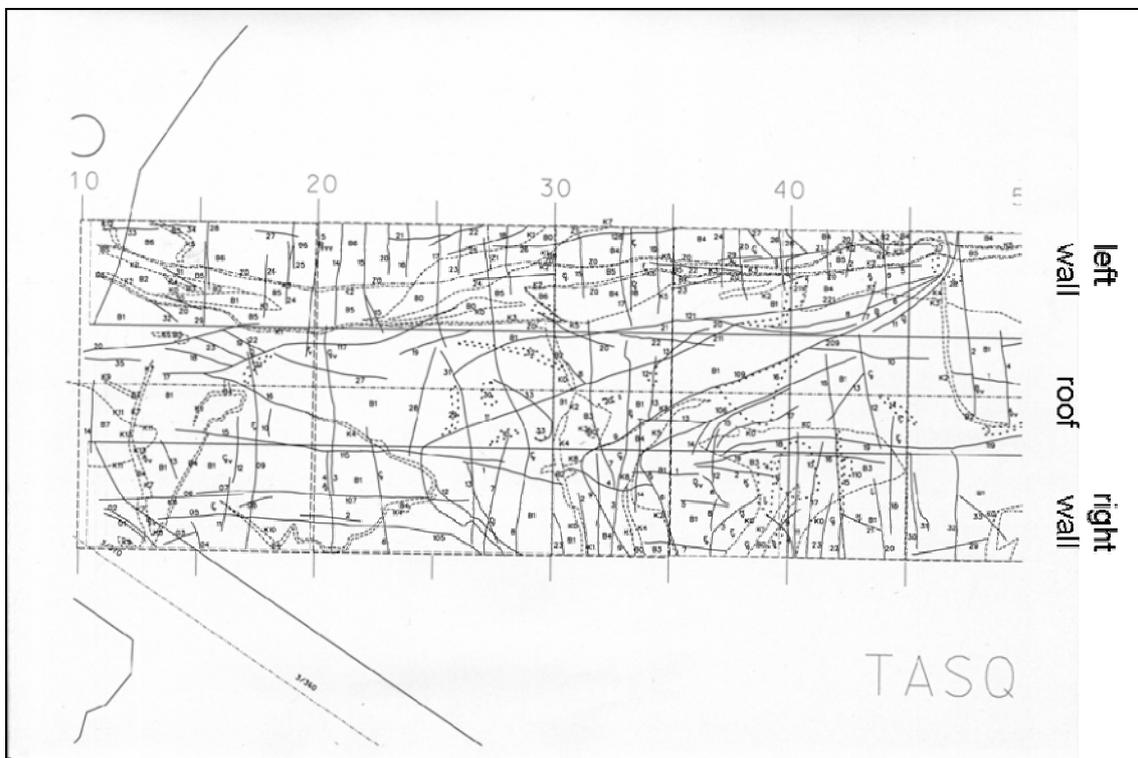


Figure 5. Present SKB method for geological mapping, tunnel roof with walls unfolded (digitised version)

Based on the experience of the time used for mapping during the construction of Äspö HRL, which showed that a team of two geologists can typically map about 4 m of tunnel per hour (see above), it is calculated that it would take the same two geologists more than 6 years to map the estimated 45 km of tunnel in a future final repository if they worked about 220 days/year and 8 hours/day *i.e.* 12 man years of effort are required for undertaking just the mapping alone!.

Note that this time estimation does not include any practical problems or delays of any kind, no failing equipment or “time conflicts” between geologists and contractors, but assumes ideal conditions underground. These “time conflicts” occurred sometimes during the construction of Äspö HRL. They resulted in either too little time for the mapping of certain parts and, naturally, decreased quality of mapping, or needed extra time was causing extra costs for SKB due to stand-by time for the contractors.

The digitizing and data feeding performed in the office after completed underground mapping is not included in the above calculation. A brief estimate is that geologists spend at least the same amount of time by the TMS computer as they do underground to complete the geological mapping. This gives a total time of at least 24 man years for the geologists to complete the mapping of the final repository. It is most likely, however, that the mapping during the construction of the final repository for nuclear waste will require greater accuracy and more parameters to be mapped than was the case at Äspö HRL. For example, if the cut off for mapped fractures in the future will be ½ m instead of the present 1 m this will greatly increase the number of fractures to be mapped and to which data will have to be recorded. It can thus be assumed that even more time will be needed, may be as much as 50% of the present mapping time or 6 extra man years, to fulfil the expected new requirements if the present rock characterization system will still be in use.

2.1.2 Posiva method

Posiva’s present geological mapping method in ONKALO is divided into three stages. All these stages have their own aims, such as producing initial data for tunnel support or specifying the geological model. The different stages are planned in a way that work interrupts excavation as little as possible. The mapping is carried out during drilling, charging or pre-grouting.

The first stage is “round” mapping *i.e.* mapping of each excavated segment of tunnel that is the result of one cycle of drilling – blasting - unloading. This type of mapping concentrates mainly on the needs of the rock reinforcement design and pre-grouting works. Mapping data will be delivered to the designers after a control procedure has been exercised. The mapped area is situated 5-30 m behind the tunnel face. All information is recorded underground *in situ* in an Excel form and a simple sketch is hand-drawn for later reference (Figure 6). The mapping procedure is based on the Q-system in which six rock variables are determined (Barton 2002).

The transcriptions of Excel forms and scanned sketch are stored in Posiva’s server and document management system (POSIDOC).

FIRST STAGE MAPPING STRATEGY IN ONKALO

The first stage of tunnel mapping and carried out during excavation. Mapping results are initial data for the planning of the temporary rock reinforcement. Observations consists:

- Chainage
- Rock type
 - grain size
- RQD (Rock Quality Designation)
- Joint set number (J_n)
- Fracturing
 - 10-20 main fractures
 - length over 1 metre
 - orientation (dip and dip direction)
 - joint roughness number (J_r)
 - joint alteration number (J_a)
 - rock type
- Joint water reduction factor (J_w)
- Stress reduction factor (SRF)
- Short sketch of rock quality
- Data storage in Access database and interpretations are done with Dips and Surpac programs.



The image shows a screenshot of a software application window titled 'ONKALO Mapping'. The window contains a data entry form with various fields for recording geological observations. Below the form is a large grid with multiple columns and rows, likely used for logging data across different chainages or locations. The interface includes standard software elements like a menu bar and buttons.

POSIVA

Kimmo Kemppainen

Figure 6. ONKALO first stage mapping strategy.

The second mapping stage, systematic mapping, is based on the needs of modelling (geological, rock mechanical etc.). All measurements are recorded on a special form (Figure 7) and a simple drawing of the area is made during the mapping (tunnel walls and roof are “unfolded” to a 2D plane). All measurements and observations, such as lithology, natural fractures (both open and sealed, if these can be recognised), foliation and other structural features, are transferred from 2D drawings (digitised) to 3D in a Surpac program (Figure 8). Also, all mapped surfaces are photographed.

The intersections of deformation zones in the tunnel are mapped after the second stage as a separate minor survey stage. The deformation features are classified in four classes, which include both brittle and ductile structures. Mapping includes location (using chainage number and tachymeter), description and kinematical observations, which are visualized using Surpac. A judgement is also made on the continuity of the features between their intersections at different locations of the ONKALO.

Development of geological mapping will be done during the next few years. This will entail changes in mapping procedure and equipment Aims of the development are to:

- Increase the accuracy of coordinates.
- Assess the suitability of, and to use, the laser scanning data in tunnel mapping to provide a base map, that can show the accurate position of geological features such as fractures and lithological units.
- Assess the suitability of laser scanner 3D-images
- Carry out *in situ* “on-line” mapping and recording of geological information. The mapping should be done directly to computer.
- Modelling/model upgrading during excavation. Based on borehole and tunnel mapping data.

2.2 Advantages of an upgraded rock characterisation system

The advantages of the RoCS include increased objectivity and traceability of the collected data. These parameters are to significantly improve by a system that automatically gives true tunnel geometries and positions in 3D with high accuracy and with which 3D images and maps can be created. This in turn will be favourable for the construction of a future final repository for spent nuclear fuel.

Elimination of some of the present opportunities for errors during the mapping procedure would also be a necessary measure to increase the quality on rock characterisation. If the locations of fractures, rock boundaries etc. will be provided more or less automatically by the new rock characterisation system the geological map can be created digitally underground by the use of some type of hand-held computer. The geological information, such as fracture filling, fracture roughness, etc. (c.f. section 2.1) that is recorded for a specific feature can be fed into a database and attached to the feature at the same occasion. Thus, by attaching geological data to a 3D digital map underground, the present transposition of data would be avoided.

Further, more careful data collection and documentation, with a higher accuracy, would also help to significantly improve the documentation associated with rock characterisation. The presently obtained precision and accuracy in geological mapping are based on occasional measurements with a measuring tape from fixed points. In parts of the tunnel inaccessible to the geologists, that is everything above two meters height, no measurements can be made and estimation by the naked eye is the method used.

Estimated time for mapping using the present system will be very long. Hence it would be economically favourable to consider a more automatic method for collection of geological data. The time spent on mapping underground may be shortened by a more automatic system for data collection than the one presently at use. However, the time spent on for example the TMS work, presently performed by SKB in the office after completion of the underground mapping, will be significantly reduced if most of this work has been done at the rock face underground.

2.3 Possible areas of usage beside geology

Besides geologists, other groups in SKB and Posiva are also expected to gain from RoCS (Figure 9). This would be important not only for economic reasons, but also in terms of ease access to data and effectiveness of “information sharing”. If a common database is generated that could be used not only by geologists, but also by the future tunnel layout group, rock mechanics and other groups, many advantages could result from this “common raw database” and sharing of information.

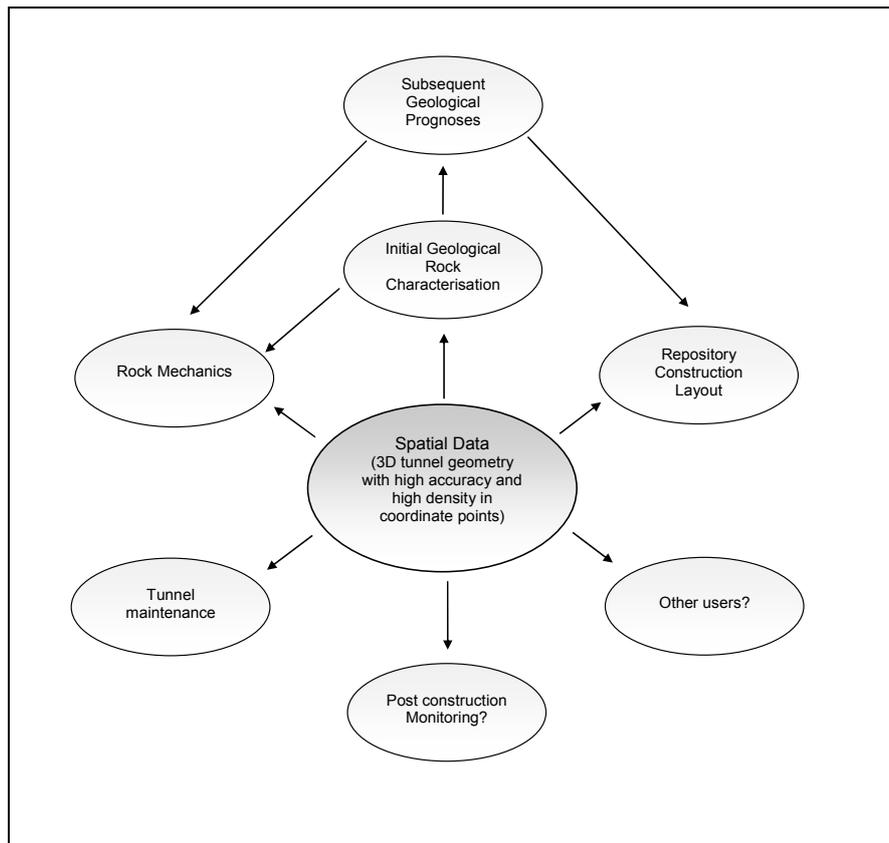


Figure 9. Information sharing - other possible users of RoCS.

As a field of activity closely related to geology, rock mechanical issues are mainly focused on fracturing, rock stresses and rock stability. By getting 3D position data with high accuracy from RoCS, automatic prognoses of rock fallouts could be achieved. For instance, rock bolts and rock reinforcements could be accurately placed and their position well documented. By using high accuracy, there may also be possibilities to investigate the EDZ (Excavation Damage Zone).

The tunnel maintenance group would gain by the precise 3D maps. In the first instance, the maps will serve as a 3D view of the achieved tunnel system, including tunnel cross sections, profiles and volumes. Secondly, the maps could serve as base for a comparison with a second geometry survey (depending on what method for collecting tunnel geometry data that is used) with the purpose to calculate accurate volumes (of used concrete, removed rock, etc) and exact position of air tubes, drainage etc.

The group responsible for tunnel layout may find assistance in true tunnel geometry in 3D (in comparison to the present 2D layout maps). The 3D survey maps will come as benefit from the original rock characterisation. Further, it will contain prognoses of zones of weakness in the rock, to help fitting the tunnel layout to existing rock features.

If RoCS can assist in creating good 3D models of the future repository for spent nuclear fuel this will be of great help for the safety assessment. The 3D models may be used to accept or reject deposition hole locations in the repository.

The accurate 3D image, which will be produced as a base for the geological rock characterisation, can also serve as a base for Virtual Reality (VR) images. These types of images have previously been used in other underground facilities to practice underground activities and handling of machines, with very good results. In one example, Deutsche Montan Technologie (DMT) cut their costs per tunnel metre by 50%.

3 Project organisation and time plan

3.1 Project organisation

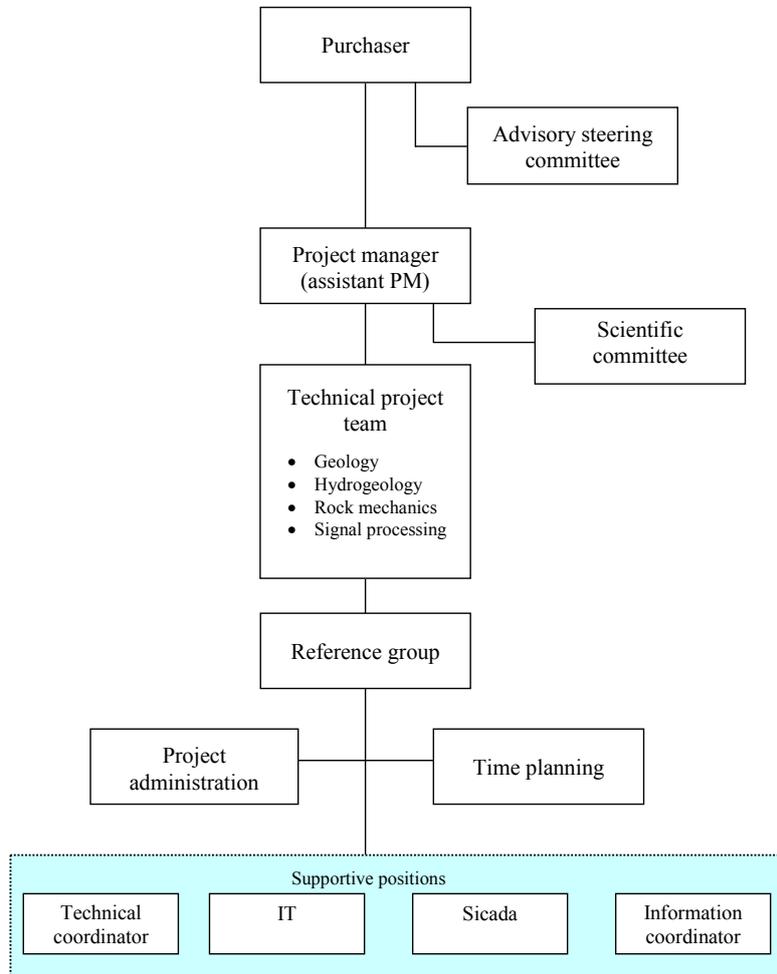


Figure 10. Project organisation.

Purchaser (overall responsibility for the project): Christer Svemar (SKB, TU)

Technical project team (directly involved in the project work and responsible for the actual performance of the project):

Project manager + geology (till February 2006): Björn Magnor (SKB, TD/now at Hifab AB - Envipro miljöteknik)

Assistant project manager (project manager from February 2006) + geology: Carljohan Hardenby (SKB, TD/Vattenfall Power Consultant AB, former SwedPower AB)

Signal processing: Anders Eng (SKB, TD/Acuo Engineering)

Information coordination: Mikael Andersson (SKB, VI)

Project administration: Annelie Engqvist (SKB, TD/Skrivstugan AB)

Time planning: Thomas Palmqvist/Ingela Palmqvist (SKB, TD/Pilgrimer AB)

Technical coordination: Mats Lundqvist (SKB, TD)

Reference group (supportive functions in the project and contribution with competence in each area of interest):

Tunnel maintenance: Fredrik Norman (SKB, TD)

Rock mechanics: Rolf Christiansson (SKB, TU)

Geology: Kimmo Kemppainen (POSIVA)

Geology: Matti Talikka (POSIVA/GTK)

IT: Dan Eriksson (SKB, IT)

SICADA: Ebbe Eriksson (SKB, P Datasystem)

Digital techniques: Pär Kinnbom (SKB, PO/3D-Inovation)

Geology: Raymond Munier (SKB, PA)

Tunnel construction: Rickard Karlzén SKB, TD)

Underground design: Eva Widing (SKB, TU)

Detailed characterisation programme: Göran Bäckblom (Conrox)

Advisory steering committee (support to the purchaser):

Anders Sjöland (SKB, TD)

Stig Pettersson (SKB, TU)

Liisa Wikström (POSIVA). Deputy Kimmo Kemppainen (POSIVA)

Scientific committee (advisory to the project manager and will evaluate the technical content of the project):

Norbert Benecke (Deutsche Montan Technologie GmbH)

Antoni Milodowski (British Geological Survey)

3.2 Project time plan

The length of the preliminary stages 2 and 3 shown in Figure 1 are only brief estimations. Depending on the results of the evaluation in stage 2, the development in stage 3 may result in a time consuming generation of a unique rock characterisation system. On the other hand, it may also result in a purchase of existing components that only require minor adjustments to be used by SKB and Posiva.

4 Results from the investigation

The starting point for the present phase of the feasibility study has been the current system for rock characterisation. Some parts of the existing system are functioning well but some will need to be improved in order to meet the efficient and cost-effective delivery of consistently high-quality objective information that is needed by the end-user community. For example, the present drawing by hand on 2D tunnel layout paper maps and handwritten geological data on paper forms should be replaced by automatically achieved 3D high-accuracy true tunnel geometries on which geological features can be digitally drawn, and the data fed directly into a database at the rock face. The same basic principles of workflow will be used, but the techniques to achieve the results will be improved by a new rock characterisation system.

4.1 Investigated areas

Below an attempt has been made to summarize the type of mapping tools that are in use by various industries or markets.

4.1.1 Mining industry

The mining industry has been investigated for digital mapping techniques, both in Sweden and globally. In Sweden, this market area mainly uses the conventional method of geological mapping in 2D. In some of the mines the hand drawn geological field map is in the office scanned and fitted into the main mine map. Mining companies such as Zinkgruvan, Boliden and LKAB in Sweden use a Prorok software module (Cmap) for core logging (Lars Malmström, Zinkgruvan, pers. com. 2006). Modelling of geological features, however, often uses 3D tools.

In general the situation is the same in a global perspective. However, the Australian research company CSIRO together with Newcrest Mining (who holds Telfer gold mine) developed an operative system for rock characterisation based on digital photogrammetry and using the SiroVision software.

4.1.2 Hydropower industry

The same situation as for the mining industry prevails for the hydropower industry in Sweden. Geological mapping performed on rock surfaces and shafts has been done by the conventional method. Often no particular mapping software is used to visualize the geological mapping. Instead standard CAD-programs such as Auto-CAD and Microstation are used.

4.1.3 Oil industry

The oil industry uses a wide spectrum of exploration methods, such as geological mapping, bore hole surveys and geophysical surveys. The geological mapping may include traditional surface mapping as well as remote sensing methods. The study of rock cuttings and cores from bore holes give important information about the characteristics of the rock below surface. The bore hole surveys include a large variety of more or less automated logging tools. Core imaging and tomography are useful applications to characterize the rock. Depending on the logging tools wireline and LWD loggings are used to register e.g. radioactive, electrical and acoustic properties of the rock, to register fractures, the dip of fractures or rock boundaries, flow and pressure in the well. The main difference between wireline and LWD logging is that with former the measurements are performed from the bottom of a bore hole and upwards whereas with LWD logging (LWD = Logging While Drilling) the measurements are performed from the top of a bore hole and downwards. The geophysical surveys, besides those performed in the bore holes, include gravimetric and magnetic methods (surveyed from the air or/and from the surface) and two dimensional as well as three dimensional seismic methods (onshore or/and offshore).

The techniques from this branch are, however often specialized and customized to meet oil industry needs, as for example in structural and reservoir analysis. Probably several of these techniques could be adapted to meet some of the requirements of automated geological information recording during repository excavation, but a lot of development work would be needed.

Today a lot of the work performed in the oil industry is highly dependent on computer and integrated data systems. A number of 3D modelling tools are used to utilise and visualise geological and geophysical information (cf. section 4.2.3). An interesting issue that may be relevant to the RoCS is how the huge amount of multivariate information and data generated by the oil industry is stored.

4.1.4 Geotechnical and civil engineering industry

The geotechnical and civil engineering industry area has put effort in increasing speed and functionality in underground rock investigations, for example in road and railway tunnels. However, the mapping of geological of geological information and subsequent presentation of data and interpretations is largely based on 2D maps or drawings. In Sweden the Auto-CAD applications Autograph and Stenograph are often used for presentation of surface investigations and underground investigations/mapping respectively. Again, modelling work many times uses 3D software.

In the last few years laser scanning has been introduced as a major method to use in these investigations. As the requirements for detail and for data capture at the tunnel front are much lower than for SKB/Posiva, a technical improvement would be needed for SKB/Posiva purposes.

4.1.5 Utilities industries

Water supply, telephone, electricity companies etc. are concerned with trying to record underground information with regard to accurately mapping, recording and 3D visualising the location and distributions of different types of underground infrastructure. Mapping and recording of information must be done on computer directly in the field. The development of databases, the use and development of GIS applications and the use of 3D visualisation tools and software appear to be applicable to RoCS.

In UK projects such as the VISTA project and the Mapping the underground project are involved in research concerning the matters mentioned above.

4.1.6 3D surveying- and modelling companies

3D surveying and modelling companies are conducting research and development in fields that could be adapted to underground purposes. Until recently they have mainly been focused on 3D surveying of complex interior of industrial buildings and other areas with a high concentration of detail, and the need for accuracy. Several companies have been contacted and information has been collected, concerning both digital photogrammetry and laser scanning.

4.1.7 Meetings

To get a better insight in the status of laser scanning technology Björn Magnor participated in the IAEG Commission 19 meeting concerning “3D terrestrial laser scanning technology in the Geosciences”. The meeting was held in Lyon 2005 by the European Association of Engineering Geology and Environment (EAEG).

4.1.8 Summing up

It appears quite evident that many of the investigated market areas use various tools, some 2D and some 3D, for modelling and presentations of geological and geotechnical features. When it comes to geological mapping of rock faces all of it, with a few exceptions, appears to take place in a 2D environment. However, logging of drill cores is quite often performed in 3D.

4.2 Geological surveying techniques

The two presently investigated methods for digital documentation underground are digital photogrammetry and laser scanning. There is also a third digital method, which is based on measuring individual points by total station. This method has, however, been deselected by the project group, mainly on the basis of a longer sampling time (Feng, 2001).

4.2.1 3D rock characterisation systems presently in operation

As stated in the introduction, a system that suits SKB/Posiva's requirements does not currently exist in the market. There are, however some examples of semi-automatic data collection and development from the conventional type of rock characterisation.

In the Telfer gold mine in Australia, which is owned by Newcrest Mining Ltd, digital photogrammetry is routinely used as a basis for the geological documentation. They are using the same kind of system used by Posiva, which is digital photogrammetry by "off-the-shelf" digital cameras combined with SiroVision software. Apparently, the SiroVision software could be used to handle any kind of 3D data, but no tests have been performed on formats other than digital photos. According to Posiva geologists, however, some disadvantages have been revealed with this system during mapping in Onkalo (see section 4.2.2).

4.2.2 Digital photogrammetry

In digital photogrammetry (Figure 11), 3D images are constructed by combination and triangulation of two ordinary digital photos taken from different angles of the same target area. Each of these "picture pairs" is combined to produce one 3D image. To cover the walls and roof of the tunnel section (about 4-5 metres) that is the result from one round (drilling, blasting and unloading), five to six picture pairs are needed. The number of reference points fixed on the tunnel walls is large when using digital photogrammetry. For instance, during their photo sessions Posiva uses fourteen to sixteen reference points for one round of tunnel.



Figure 11. The use of digital photogrammetry in Onkalo, camera set up.

The major advantages with photogrammetry are fast sampling speed, high image quality and the exact reproduction of the mapped rock faces, which increase quality and traceability of mapping.

One of the major disadvantages of the photogrammetry is that research and development within the method appear to be diminishing. Posiva has experienced disadvantages such as too low coordinate accuracy, a large number of reference points are needed underground, as well as problems in fitting the picture pairs together. This makes the system time consuming, even though the photo session itself may be fast. For example, Posiva spend 30 minutes per round just taking the photos used in photogrammetry. When using coordinates and camera orientation approximately 45 minutes are spent at the rock face and, finally, if the 14-16 reference points on the rock wall are used, 1-1.5 hours are spent for reproducing the tunnel layout. On top of this comes the time for geological mapping using the resulting 3D image as a basis.

Software applications to digital photogrammetry

In the case where digital photogrammetry is used for data collection, the most widespread software used to handle this data is SiroVision from CISRO in Australia. It would probably be possible to use SiroVision for data collected with laser scanning, but this has not been tested. For data collection by digital photogrammetry, SiroVision assumes two tripod mounted cameras (Figure 11). This stereoscopic system gives high quality 3D color images. Although this system cannot provide the same base for a complete 3D model with as accurate coordinates as a laser scan system, it only requires the use of one software package. SiroVision data also can be directly exported to many of the major modelling tools, including Surpac, Vulcan, Datamine and MineSight (Figure 12).

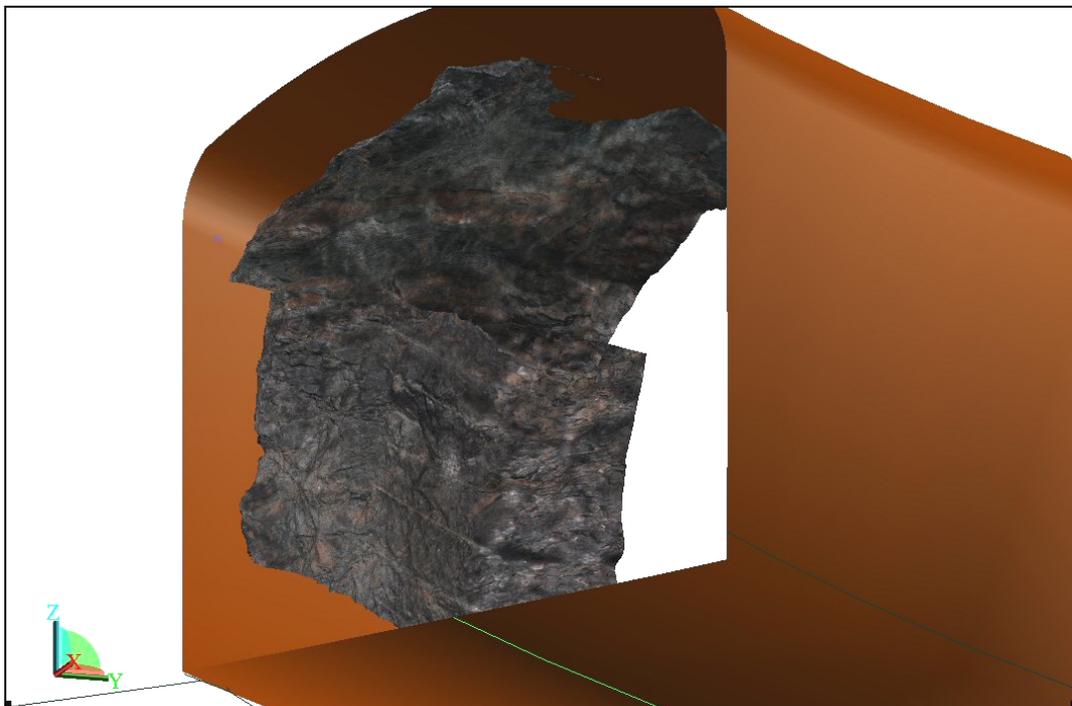


Figure 12. The use of digital photogrammetry in Onkalo. Digital photos fitted to the tunnel model by the use of Surpac Vision software.

4.2.3 Laser scanning

Laser scanning (Figure 13) is based on measuring the distance and angle from scanner to object (for instance rock wall) by a laser beam that rotates 360° horizontally. Due to the scanner tripod only 310-320° is covered vertically. The scanner type used in this study has been of the phase-based type, which means that the laser beam is sent in several pulse-phases, resulting in high-speed measurements. At its best, this method can collect up to 625 000 coordinate points per second (“3D Visual laser scanning & modelling”, BBK leaflet 2003). Two other methods of laser scanning exist, which both have been considered unsuitable in the RoCS study. One is the triangulation method, which gives precision up to the micrometre scale. It is, however, very time consuming and displays only point clouds. No images are corresponding to the collected laser points unless the instrument is equipped with a built-in digital camera.. The other method which has been considered is the pulse-based method. It is mainly used for long-range scanning (> 100 m) and is considered to be unsuitable for RoCS purposes because it is also too time consuming.



Figure 13. Laser scanning. The laser scanner is mounted on the tripod and the computer collecting scanning data is placed on the box on the floor.

The phase-based method of laser scanning has been used by all three companies performing tests in Äspö HRL and Onkalo in the RoCS project. Different brands of scanners have, however, been used. The companies who performed the tests are Berg Bygg Konsult AB (BBK), Sweco and ATS AB. To be able to compare scanning results, all three companies have been scanning the same tunnel areas in Äspö HRL. The open part of TASZ (Zedex tunnel) was used to test laser scanning in a blasted tunnel, showing pronounced, un-pronounced, filled and un-filled fractures, as well as both wet and dry areas (Figures 14 and 15).

A part of the TBM-tunnel was used to test the scanning technique in a drilled tunnel. The chosen section, approximately 30 meters long, contains the same variety of fractures as in the blasted tunnel section, as well as both wet and dry surfaces.

In addition BBK performed a test on laser scanning in a vertical deposition hole, DO0010G01. ATS AB conducted laser scanning for geological purposes in DA1622A01, the 15 m long horizontal deposition hole in the KBS-3H-site.

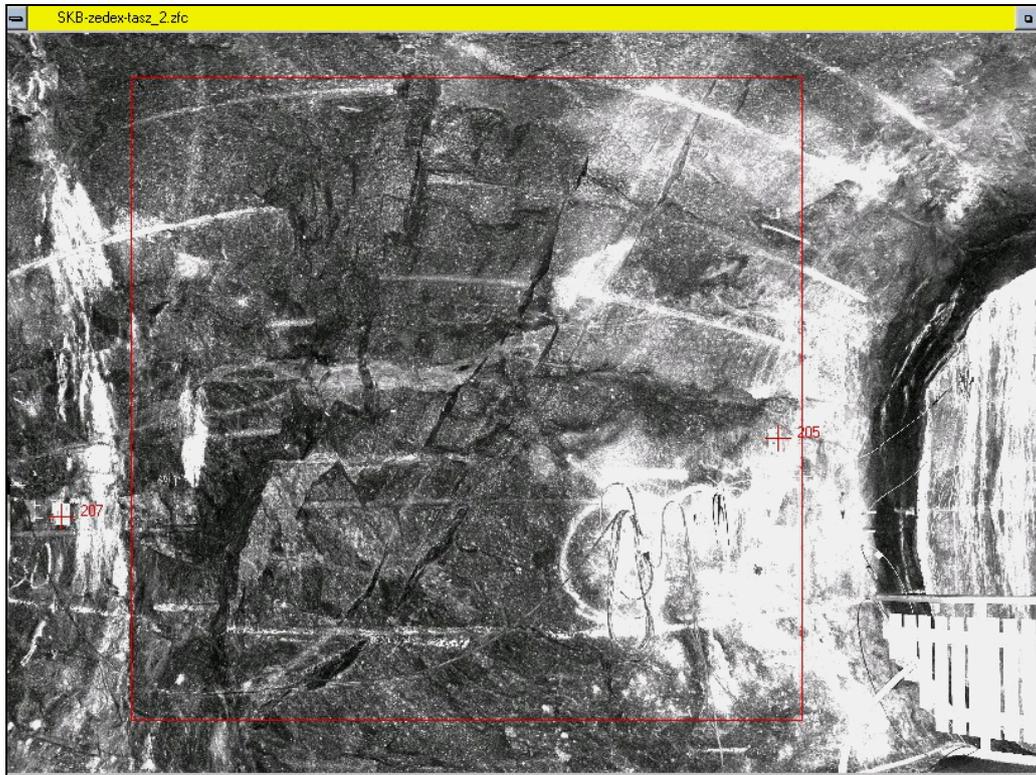


Figure 14. The image is a result of laser scanning of a part of the Z-tunnel (TASZ) in the Äspö HRL. The tunnel was used to show how scanning will perform in a drilled and blasted tunnel.

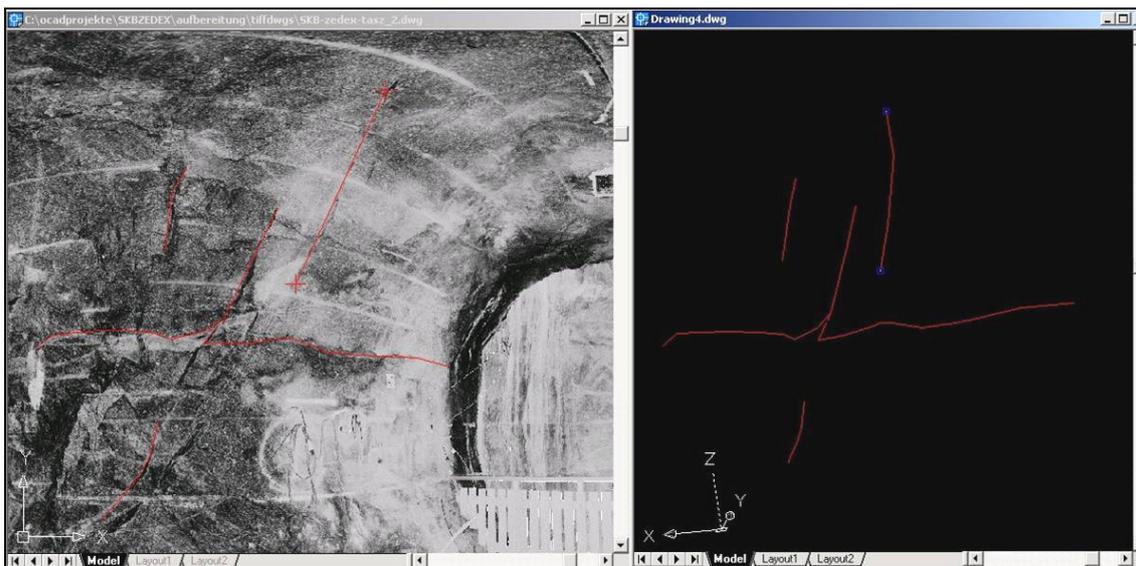


Figure 15. Left, laser scanning image (TASZ) with some fractures (red) drawn interactively between the registered laser image and the AutoCAD drawing on a separate CAD layer than the one showing the image. Right, only the CAD layer with the drawn fractures is displayed.

Furthermore, ATS AB performed a demonstration in Onkalo where laser scanning was combined with a high-resolution (up to 50 MPix) digital camera (from the German company SpheronVR AG), and were able to produce true-colour images with high-accuracy positioning (Figure 16).



Figure 16. A laser scanning image in combination with high resolution digital photo. Scanning and photography took place simultaneously (Onkalo).

Three levels of resolution are commonly used: medium, high and super high. Using super-high resolution, one scan that covers at least 8-12 meters in the tunnel will take around 15 minutes while a medium resolution scan will take about half the time. Specifications claim that scanning distances up to 50 meters or more could be used (for example 54 m for Leica HDS4500 and 79 m for Leica HDS6000). However, as the laser beam widens with distance and shooting angle, higher accuracy can be achieved by erasing coordinate points on distances longer than 8-12 meters.

Advantages with laser scanning are obvious. It is a fast method which gives accurate tunnel geometries and high-quality images with a small number of reference points. Using the combination of laser scanning and high resolution digital camera mounted on the same tripod, coloured images are obtained if the lightning conditions are good. Further, there is an increasing amount of research and development on laser scanning, both in hardware and in software.

Software applications to laser scanning

Provided that laser scanning is the choice for data collection of tunnel geometries in the rock characterization system, the software package needed can be divided into two major parts; raw data handling software and 3D modeling software. The raw data handling software which can create e.g. 3D point clouds and 2D/3D images shows the coordinates collected by the laser scan system as points in a volume. 3D modelling software is used to build and present a virtual model of an object based on the full coverage 3D laser scanning data. Special programs, like Trimble® RealWorks Survey™ (cf. Table 1), have been developed for the needs of the surveyor/scanner contractor. The software incorporates a series of precision tools and empowering features particularly suited to civil engineering survey, and allows surveyors and engineers to produce 2D and 3D deliverables for direct output or export to AutoCAD, MicroStation and Surpac compatible data formats. Comparable programs and the potential for subsequent development of these, give us the means to undertake tunnel mapping (including recording of fractures, lithology, deformation zone intersections etc.) directly and accurately for the RoCS-project

Raw data handling software

The raw data handling software is specially designed for viewing and processing the extensive 3D scan point clouds from high resolution 3D laser scanners. This software allows manipulation and analysis of raw 3D scan points to produce point clouds (Figure 17) as well as 2 or 3D black and white “photos”/images (Figure 14). Scan points can be prepared for export into the user’s 3D CAD-system.

Important features of these software packages are:

- Acquisition of point cloud data
- Data management / administration / manipulation
- Registration of scans
- Elimination of error and measurement noise
- Measuring of distances, areas, surfaces, volumes
- Modelling tools (Planes, Boxes, Spheres, Cylinders etc.)
- Make complex surfaces and 3D meshing
- Collision, deviation and evenness control
- Import/Export of CAD Data
- Free selection of point of view
- Visualisation and Animation tools (Video File formats, VRML)

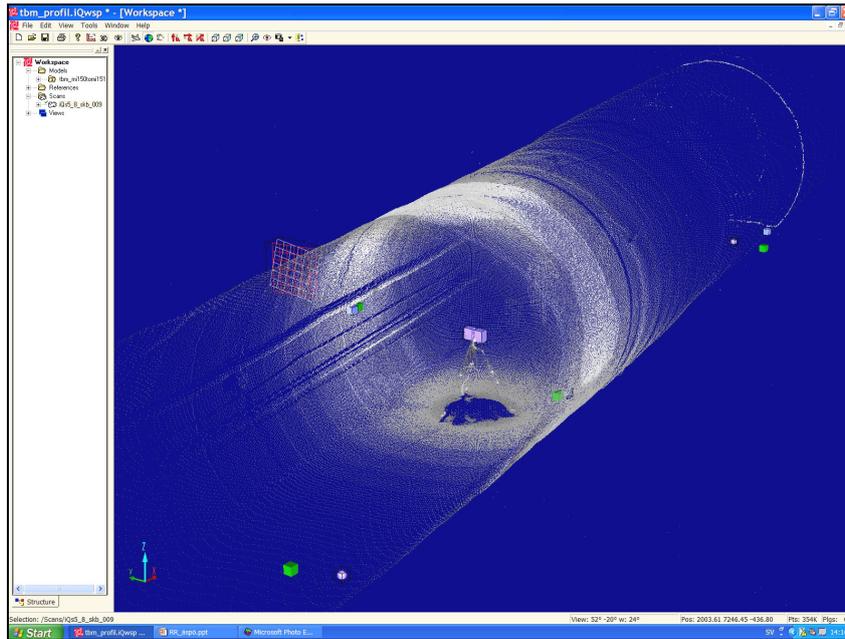


Figure 17. 3D point cloud image from laser scanning. Under the laser scanner there will be an area where data will be missing because the laser beam cannot reach it. The scanner is shown in the picture to indicate where the “blind spot” will appear under the scanner.

Table 1 (from the DMT report, 2006 in the Appendix), below gives an overview on typical Laser scanning software packages:

Table 1. Laser scanning software packages

Company	Software	Web
3G	Joint Metrix	www.3gsm.at
Amberg MT	TMS	www.amberg.ch
Faro	Faro Scene	www.faro.com
Geo-Byte	Tectoni-CAD	www.geo-byte.at
Geodata		www.geodata.at
Mensi/Trimble	Realworks 3Dipsos	www.trimble.com
Riegl	RiScan	www.riegl.co.at ; www.riegl.com
Leica	Cyclone / CloudWorx	hds.leica-geosystems.com www.zf-laser.com

Note that the Amberg TMS system in Table 1 is not the same as the SKB Tunnel Mapping System (TMS). Sales of the Amberg TMS system is done by Leica.

3D modeling software

From the point clouds given by the laser scan a 3D model can be prepared. The model can show characteristics of the rock using layers, intersections etc. In a 3D model specific parts can be hidden to visualise only selected parts of the system. This will increase the ability to study, visualize and understand the characteristics of the rock.

A rapidly increasing number of software products are available on the market, which are tailored to create static geocellular models (or evenly named block models) for geological tasks. Some of the 3D-modeling software is related to a specific scanner system whereas others are common 3D CAD applications. In general, 3D modelling software is widely used in four geoscientific branches: the petroleum industry, the mining industry, geotechnical branches (numerical simulation) and hydro geological surveys (groundwater modelling).

The software screening was limited to products available on the market (2005) and which are recognised as major products in the specific branch. A number of 3D modelling software packages were found to meet the objectives of the search. Table 2, below (modified from the DMT-report, 2006 in the Appendix), gives an overview of available software that was found during the market screening. In addition to these commercial programs it could be worth mentioning RVS (Rock Visualization System) that is a MicroStation based 3D modelling and visualisation application tailor made for SKB.

Table 2. Overview of 3D modelling software

Market Area	Key Geoscientific Discipline	Product
Exploration Geology	Geophysics, Petrophysics, Borehole Geology, GIS Geology, core logging *	Target, Montaj RockWare (various earth science & GIS software) * ESRI ArcGIS * WellCad *
Oil & Gas	Geophysics, Structural Geology, Sedimentology, Reservoir Simulation	EarthVision, IRAP-RMS, Petrel, GOCAD
Mining	Surveying, Mine Planning, Geostatistics Geology, core logging * Rock mechanics *	Datamine, Surpac, Vulcan, Minesight, DUDE RockWare (various earth science & GIS software) * RocScience (various rock mechanical and geostatistical software) * DataPolama (Digikart 2.0) * Prorok *
Geotechnics	Geomechanics	Eram-SIS, UDEC, Flac3D, RocScience (various rock mechanical and geostatistical software) *

* not in the original Table from DMT (2006). For further information about the software see the DMT report (2006) in the Appendix.

4.3 Geodetic surveying

Both photogrammetry and laser scanning needs reference points to establish a 3D tunnel geometry fitted to the same and often local coordinate system. In this way locations of for example, fractures, water inflows and other features found on the rock faces can be obtained with high accuracy. In both photogrammetry and laser scanning the reference points are positioned by using the surveying instrument total station.

Briefly it can be said that once positioned the total station measures angles and distances from the station with its known coordinates to a point to which coordinates are to be established. To position the total station two ways are possible: either the instrument is placed over a fixed point with known coordinates or it is put at a random place from which the angles (vertical and horizontal) and the inclined distance to at least two, preferably more, fixed points with known X, Y, Z-coordinates are measured. When these initial measurements have been performed the instrument will calculate its exact position and orient itself within the coordinate system that has been chosen. From now on the total station can be used to position any point within the coordinate system. The instrument accuracy is about 0.3 mgon for angles and ± 3 mm for distances. Of course, the accuracy will vary with the type of total station that is in use. The instrument measures with infra red light against a reflector or with laser directly on the point in question. All calculations can be performed in the field by the instrument or at the office by the use of a computer.

Digital photogrammetry needs a large number of reference points, as discussed in 4.2.2. Using laser scanning, fewer reference points are needed. Different ways exist to mark the reference points. One method uses 1 dm paper scale sheets that are positioned by total station, while another method uses bulbs that are attached to the rock wall by sockets drilled into the walls (Figure 18). These sockets allow a second surveying event using the same reference points.



Figure 18. A bulb, to be used as one of many reference points during laser scanning, is mounted on the rock wall.

4.4 Data handling

Irrespective of the method that will be chosen for rock characterization one thing is certain, a lot of data will be produced during the construction of the final storage for nuclear waste products. The RoCS-data may be divided into two major groups. One group contains data related to the true geometry of the repository and geological features. It will be composed of data produced by the geodetic surveying and digital photogrammetry or laser scanning. We know today that laser scanning will produce in the order of 1 Gb or 0.5 Gb of data per 10 m tunnel with super high or medium high resolution respectively. Photogrammetry (just the corrected photos) on the other hand will need >860 Mb to cover a 10 m section of the tunnel according to the tests made by Posiva. There is however ways to reduce the great amount of data. Scanner software e.g. Faro scene is able to compress the size of the scan data by a factor of about 10. Via various algorithms permanent point reduction can be accomplished, but then some of the original data will be lost.

The other major group of data is related to the actual characterization of rock performed by the geologist. It may also include data produced by other possible users of the RoCS. Up till now the geological data produced by geological mapping of the tunnels and niches at Äspö HRL and handled by the present rock characterization system TMS amounts to approximately 100 Mb (the Access database amounts to approximately 10 Mb and the Microstation drawings to about 90 Mb). Photos and 3D models of the Äspö HRL are not included in the 100 Mb but amounts to about 17 Gb and 15 Mb respectively.

4.4.1 Data processing

As noted above, the use of the RoCS system will generate a large amount of data. Data from the rock characterization using laser scanning or photogrammetry must be processed (Figure 19). The data processing will ensure that the data is correct and that it is possible to store it in the preferred SKB databasing system (SICADA, TMS etc). Data quality assurance is also an important part of this process. It is essential that in-data checks are performed at an early stage by the geologist and/or the surveyor to assure that correct data are stored.

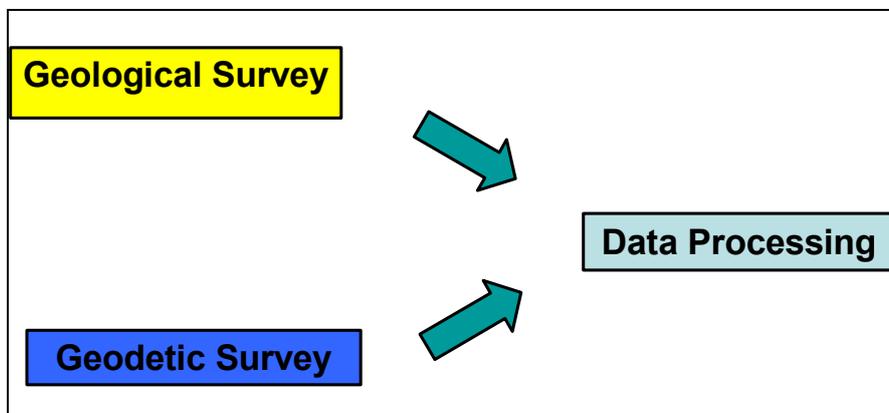


Figure 19. Data processing –the data from the geological and the geodetic survey will both need some processing in order to be able to produce maps and models.

Data format is an important issue. Is it acceptable to store data on a specific third party format or should the data be converted to a standardized file format? Perhaps both formats should be stored? The use of a specific third party file format could render some issues in the future if the software is exchanged or the used file formats are abandoned. If the data is converted into a standard generic file format the possibility of accessing the data will probably be higher in the future. Regardless of the solution, it will probably be necessary in the future to convert the data files to suit upcoming standards, to ensure the security and accessibility of the data.

Data synchronisation, or alignment, is also important. The data collected using different systems (automatic and manual) must be marked to ensure that the metadata give the same information regarding position of the collected information. This could easily be automated to minimize the possibility of storing faulty metadata.

Scripts performing the required data manipulation tasks, quality control and file format conversion, can either be run directly on the computer used for the characterisation or as a batch job in the main computer. Both solutions have their advantages and disadvantages. While the on-line scripts will immediately inform the operator/geologist of a problem, the performance of the system might be affected. A batch job will not affect the performance of the operators system, but a reported problem will take additional time for the geologist to correct since he/she is not at the site when receiving the report.

4.4.2 Data storage

At present SKB uses the Sicada database for most data produced by the activities performed by SKB. The TMS Access database is used by SKB to store data produced by geological mapping of the Äspö HRL. Posiva uses at present a temporary Access database to store tunnel mapping data. All forms and sketches are stored in Posiva's document management system, POSIDOC and working copies in a server.

All RoCS-data may be stored either in one main database together with all other data produced during the construction of the nuclear waste caverns or stored in a separate RoCS-database. None of the present databases used by SKB and Posiva are prepared for managing all of the new data that will be produced during the construction of the caverns for final storage of nuclear waste. Either the old databases, for example the SKB Sicada database will have to be expanded or completely new ones will have to be introduced. The expanded or new databases of SKB and Posiva should contain all produced data. In the near future Posiva's official database (PoTTi), which is currently undergoing testing, will be completed.

Because of the large amount of data that will be provided, particularly by the photogrammetric or laser scanning methods it may, however, be appropriate to store this type of data in a separate database. SKB and Posiva respectively may own this database or it could be owned and handled by some other organisation or company giving SKB/Posiva full access to the data. Not owning the data base has, however, the disadvantage that it may be more difficult for SKB/Posiva to have full control of it. Therefore, it is here suggested that owning the database is the best alternative.

One of the ideas within the RoCS is that data produced underground should be directly fed into a laptop computer and stored immediately in a database. The data could be stored locally underground in the laptop computer to be transferred later into the main or RoCS database once back in the office on the surface. Alternatively, the data could be uploaded directly into the main or RoCS database, whilst operating underground, in one form or another if network connection is available for the laptop.

4.4.3 Data analysis

Whichever way the RoCS-data will be stored it needs to be accessible for analysis and modelling, sometimes at short notice by a variety of users.

Some of the data, particularly that originating from the geodetic surveying and digital photogrammetry or laser scanning, needs to be accessible once it is produced underground. For example digital photos and/or laser images will be used in the characterization of the rock which is supposed to take place more or less directly after photos have been taken and/or laser scanning has been performed.

In many cases not all photogrammetry or laser scanning data will be needed. For example, when less accuracy is required it is essential that, even if permanent point reduction has been performed, image data can be temporarily filtered to reduce resolution in order to speed up the procedures that will handle and analyse the data.

Geologists can use photogrammetry and/or laser scanning data not only for example to locate rock boundaries, fractures and deformation zones during the mapping procedure, but also to analyze the data. For example Feng (2001) has shown how fracture orientations can be calculated from laser scanning and/or total station data. The data can also be used in modelling and/or visualisation work to e.g. show the geometry (orientation, width etc) of major fractures and deformation zones in 3D.

Apart from the geologists, other users (Figure 9) such as for example design teams can use photogrammetry and/or laser scanning data to compare true cavern geometry to the theoretical one, to calculate the excavated volume, create tunnel sections etc. e.g. by the use of Geo that is a common surveying software in Sweden.

The initial use of RoCS is rock characterization. Thus, as mentioned before, RoCS-data is not only composed of data from photogrammetry and/or laser scanning but also from geological observations. Various types of software from e.g. RockWare and Rocscience can be used to analyze the data originating from the geological observations and to show mineral and rock distributions, occurrences and quantity of water, orientations of geological structures etc. Further analyses of the data can be used for example for rock quality predictions as a help to the design and excavation personnel.

There are of course many more analyses than those mentioned above that can be performed from the RoCS-data. The various users of RoCS will need their own specific software suitable for their needs of analyses. This will, however, have to be discussed later within the RoCS project.

4.5 Complementary equipment

4.5.1 Computers

The variety of computers and other hand held hardware suitable for underground surveying has increased within recent years. The Hammerhead series from WalkAbout Computers appears to be one of the more sturdy ones in the market. One of their most powerful versions of Tablet PCs is equipped with 10.4" touch screen, 20-40 GB hard disk, 1GB RAM and a Pentium M1, 1GHz processor running Windows XP operating system.

4.5.2 Instruments

Electronic compasses (or, more correctly, "geological data collectors for stratum measurements") would be very useful for the underground geological mapping. One major gain would be that potential human errors would be eliminated, as this device electronically registers and stores orientation measurements coupled to a specific feature or locality. A maximum of approximately 4000 measurements, subdivided into 99 outcrops/localities, are able to be stored in ASCII-format by this equipment. Data transmission to a PC is conducted by using an interface cable. A possible complement to the primary geological mapping would be a portable mineral analyzer. For example the modern PIMA (portable infrared mineral analyser) SP instrument, which is a short wave infrared reflectance (SWIR) spectrometer, needs less than a minute to record the data needed for identification of a variety of minerals. The SWIR technique is particularly useful to detect minerals with OH, H₂O, CO₃ and/or SO₄ in their structure, for example phyllosilicates. An alternative or compliment to the SWIR-instrument could be a hand held XRF-spectrometer which is often used in mineral exploration. Considering the amount of measurements to be performed during the fracture mapping, the processing of the data may take too long to be executed in the field. The data can, however, be stored electronically in a portable PC underground to be processed later on the surface. Both these mineral analysing instruments can be integrated with existing positioning systems; on the surface with GPS and underground with an external positioning system.

5 Final conclusions and recommendations

In this report, results from a wide screening of underground surveying techniques and geological rock characterisation methods are presented. External experts contributed to the study as members of the scientific committee. It should be noted that not all information gathered is presented in the report, as it may be considered to be more about complementary techniques than part of the RoCS itself. This information is however stored and will be possible to use in future stages of the RoCS project. Many of these techniques are based on geophysical methods, for example the integrated interpretation of borehole electrical and acoustic imaging analysis and analysis of cores, to provide orientated, attributed discontinuity data sets developed by the British Geological Survey (Figure 20). The BIPS (Bore hole Image Processing System)/Boremap/Wellcad system used by SKB combines bore hole video images with the core logging procedure and if so wished the resulting core logs.

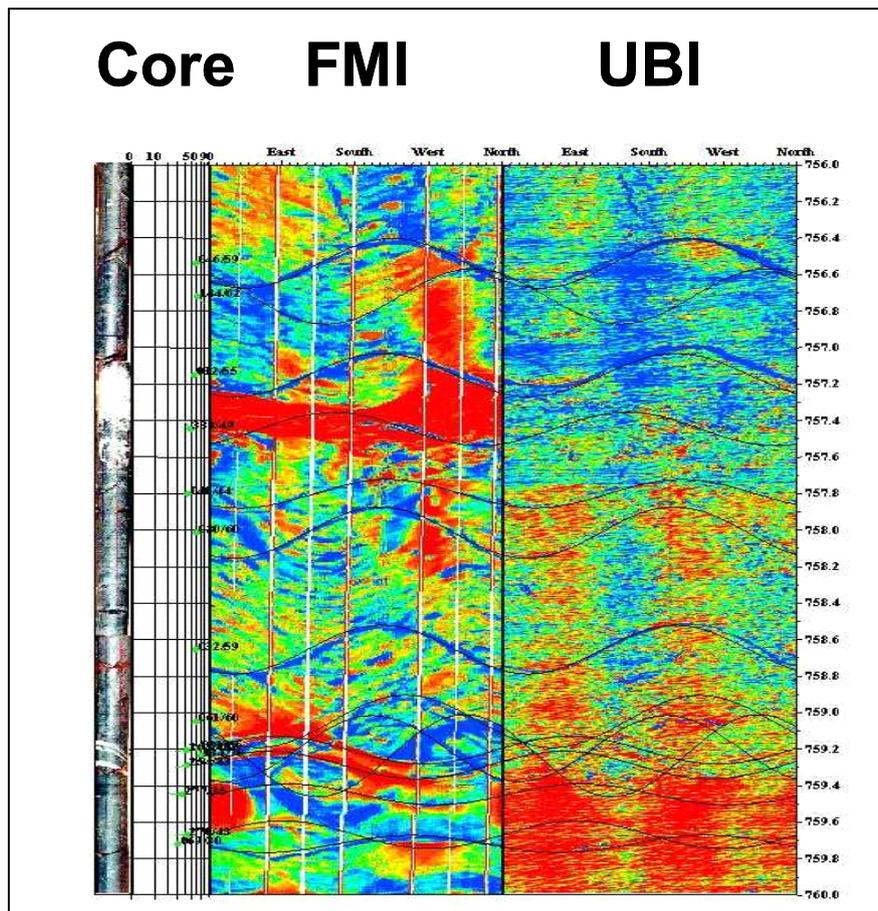


Figure 20. Drill hole analyses by electrical and acoustic measurements as an example of complementary techniques that in the future may be used within RoCS (modified from a Power Point Presentation presented by A. Milodowski, BGS at a RoCS project meeting at Äspö HRL 13-14 June, 2005. The diagram is used by permission of the British Geological Survey, based on Nirex data from Sellafield. © NERC. IPR/84-01C).

It is agreed by the project group that an operational RoCS can be achieved with gains in all areas compared to the presently used mapping system. The majority of the techniques are presently available on the market. The linkage between them to make them suitable for geological purposes and to adapt to SKB/Posiva requirements will however have to be developed. The more detailed features of the RoCS will be an issue post-dating the second phase of the feasibility study, the specification of requirements. During a project meeting it was decided that the planned process chain (feasibility study parts I and II, evaluation stage and development stage) will be the most suitable way to undertake the project.

The two methods, photogrammetry and laser scanning with digital photography, have proved to produce good 3D images in a X, Y, Z coordinate system. Both methods are believed to be suitable to use as a base for a future mapping system. Since both methods operate at a distance from the rock face at least some data always ought to be obtained from an unstable tunnel section or rock face that cannot be approached by for example a geologist.

It appears that the use of digital photogrammetry is going to diminish, while the use of laser scanning will increase. Also, research and development of laser scanners and connected software and techniques will probably increase, while the development of digital photogrammetry for underground use probably will be reduced. Because of these conclusions, as well as the features listed in the report, it is recommended that SKB and Posiva concentrate on laser scanning as the primary method for data collection in a future final repository. However, in the following feasibility phase some effort still should be put to study both the field of digital photogrammetry, and to allow evaluation of other methods that are not yet available.

5.1 Desired properties of a rock characterisation system in operation

A major requirement of a rock characterisation system for the construction of a final repository is the ability to continuously upgrade it. There should never be a risk that a purchased system will become unsuitable to use because of subsequent development of new data formats, software or hardware. It is essential that the eventual RoCS is continuously upgradeable. To make it suitable for secondary usage, both subsequent geological interpretations and other user groups, data format should be compatible with existing SKB/Posiva formats.

An important feature of a rock characterisation system should be the automatic collection of the geodetic survey geometries. This will give the opportunity to perform geological rock characterisation on a true 3D reproduction of the rock walls, improving the quality of the mapping. Also, mapping speed and traceability of the mapping will be enhanced. On a more detailed level, the combination of this high accuracy 3D positioning and true colour images is desired.

6 Continued work in the RoCS-project

During the Phase 2 of the feasibility study in 2006 the project team will establish requirements of a future RoCS. The requirements may come both externally from public authorities and from SKB/Posiva internally. The work will be conducted mainly by cooperation with the project's steering group. The resulting list will be used for establishing a specification of requirements. It is recommended that different levels of requirements are identified, so that essential features are separated from those which are desirable, but not necessary, for the function of the system. It is essential that this work is performed as thoroughly as possible, to ensure that all potential users are represented and have contributed to the final design of the RoCS.

If the final report from the feasibility study, that will include both Phase 1 and 2, shows favourable conditions for a continuation of the project, the work will continue into Stage 2, evaluation of the techniques collected in the feasibility study and possibly into Stage 3, purchasing/developing an operative system for underground rock characterisation.

7 References

The following reports and publications are focused on- or contain tests of automatic methods for underground rock characterisation. Further, numerous documents from manufacturers and surveying companies have been collected and used for information, but are not listed in this reference list.

Barton, N. 1976. Recent experiences with the Q system in tunnel support design. In:

Barton, N. 2002. Some new Q-value correlations to assist in site characterisation and tunnel design. *International Journal of Rock Mechanics and Mining Sciences* 39(2), 185-216.

Bieniawski, Z.T. (ed.) 1976. Proceedings of the Symposium on Exploration for Rock Engineering, Johannesburg, Vol. 1, 107-115

Feng, Q., 2001. Novel methods for 3D semi-automatic mapping of fracture geometry at exposed rock faces. Doctoral thesis at Royal Institute of Technology (KTH).

Kärki, A. & Paulamäki, S. 2006. Petrology of Olkiluoto. Posiva report 2006-02. Posiva Oy, Eurajoki.

Nilsson, A., 1997. Fracture mapping and cross section measurement with laser scanner in the TBM- and ZEDEX tunnels. SKB Progress Report HRL-97-18.

Patel, S., Dahlström, L.-O. & Stenberg, L., 1997. Characterisation of the rock mass in the prototype repository at Äspö HRL, stage 1. SKB Progress Report HRL-97-24.

Stenberg, L. & Gunnarsson, D., 1998. Characterisation of the Zedex drift in advance of the backfill and plug test. SKB Progress Report HRL-98-10.

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We would also like to thank R. Munier of SKB for his comments on the report and Q. Feng of Berg Bygg Konsult AB (BBK) for his comments on the part of the report that concerns laser scanning.

Appendix

Status Report 2 (Final Report), Feasibility Study for your Rock Characterisation System – RoCS – Consulting Services by DMT (2006)



Status Report 2 (Final Report)
Feasibility Study for your Rock Characterisation System
- RoCS -
Consulting Services by DMT

Client: SKB - Swedish Nuclear Fuel and Waste Management
Co

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SKB Project ID: F134
DMT Contract Number: EG-IG-05-060

Number of pages: 15
Attachments:

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Date: 30 January 2006

Version: 2.0 (final version)

(Benecke)

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1. Scope of Work

SKB is carrying out a feasibility study on a rock characterization system (acronym: RoCS, Project ID: F134). Regarding to the current project plan of RoCS (Version: 1.0, Date: 2005-04-08) DMT has got a contract on consulting services, including an input of technical expertise knowledge and evaluation of technical content with a total amount of 80 hours within the period May to December 2005.

So far, DMT is member of the Scientific Committee of this project represented by Norbert Benecke, a certified mine surveyor with long term experience in different field of mine planning, mine surveying, geology and geophysics. His responsibility and authority is on evaluation of the technical content in the project as an advisor to the project manager with respect to possible changes in the project concerning technical content. Norbert Benecke gets support by different experts from DMT, like geologists, geophysicians or mine surveyors, depending on the detailed objectives of the feasibility study. Co-authors of this report are:

Item:	Author:
Rock face data capturing <ul style="list-style-type: none"> • Laserscanners • Hard- and software 	Dipl.-Ing. Rainer Kuchenbecker (certified Mine Surveyor)
Geodetic underground survey system	Dipl.-Ing. Uwe Kalz (Senior Mine Surveyor)
Geological Mapping and Modelling System	Dipl.-Ing. Bernd Loske (Senior Geologist)

This Status Report 2 is the final report documenting the results of our consulting services associated with the named contract.

2. Results of Discussion Meeting

The results of the discussion meeting held at Äspö Laboratory on June 13th and 14th 2005 have be summarized as followed.

For the success of the project the detailed knowledge about user requirements to RoCS is very important. From a today point-of-view the main user requirements to the future operational RoCS are:

- Online data processing from data capture at the rock face to data integration into 3D-models,
- Fast and complete data capture within 2 hours maximum at the rock face
- Objectivity of data capture by three-dimensional digital data capture (e.g. using digital photogrammetry, 3D-laserscanning and/or other comparable methods),

- High spatial resolution of data capture
- High accurate geo-referencing of captured data to the main underground coordinate system,
- Interactive data manipulation and mapping features directly during the data capture,
- Integration of data from other sources (e.g. borehole data, geophysics),
- A powerful spatial data bank system for all relevant data must be available,
- A powerful 3D-mapping and 3D-modelling system must be integrated part of RoCS,
- Open data interface to:
 - Existing data bank system (based on INGRES) or any new future data bank system,
 - Existing RVS mapping system,
 - Possible future 3D mapping and modelling systems,
 - Other systems running at SKB for different purposes (e.g. hydrology, geodesy)

The principal process chain of RoCS and the interaction with other systems at SKB is visualized in figure 1.

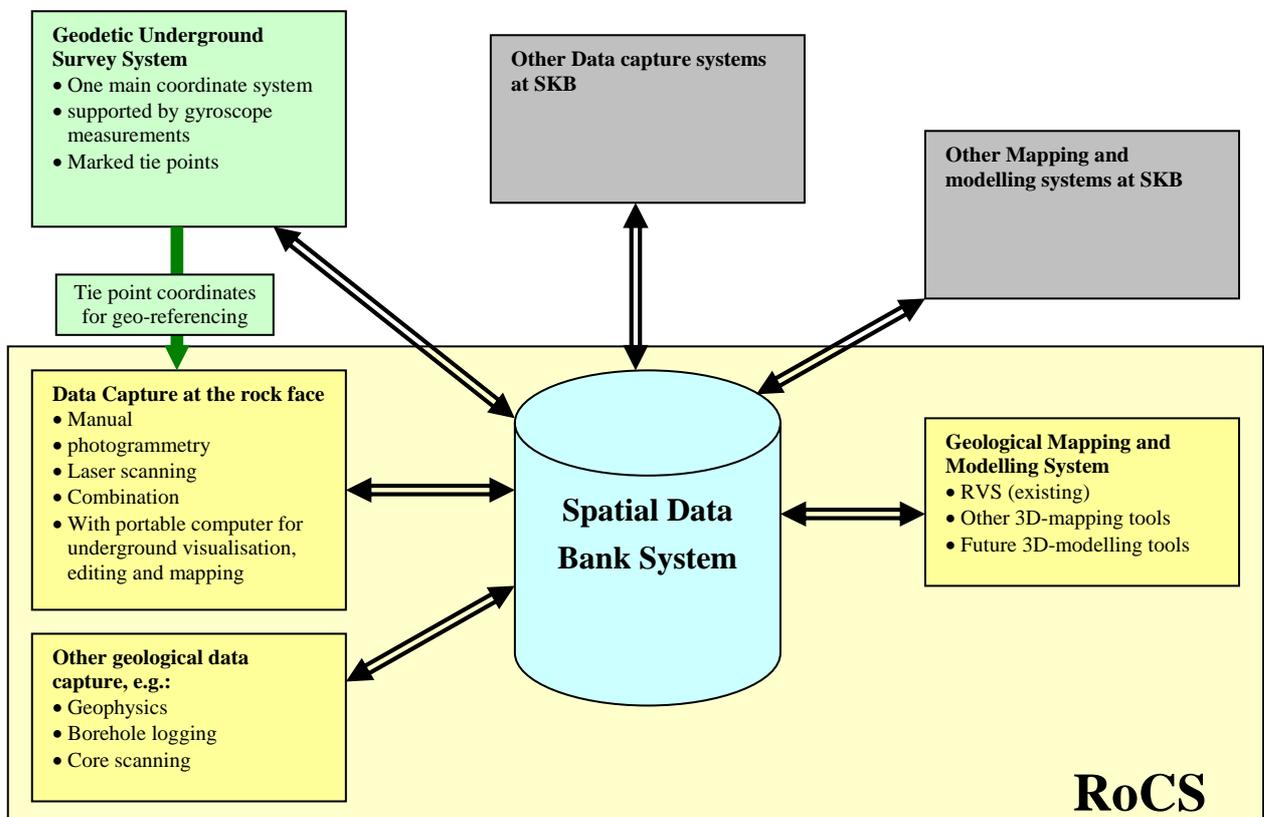


Figure 1: Principle process chain of RoCS

The discussion of all participants has had the following main results:

- For the single components of RoCS alternative solutions are available at SKB (e.g. RVS system) or at the market (e.g. laserscanners, digital cameras, 3D-mapping and modelling systems),
- But the specific application fulfilling the user needs of RoCS are not available as standard products,
- The integrated process chain of RoCS is currently not available at the market,
- The interaction of RoCS with other systems at the underground repository must be analysed very carefully (e.g. the process chain of the geodetic underground survey system must be coordinated with RoCS).

3. Conclusions from the Discussion Meeting

The results led the discussion to following conclusions:

- In general it will be possible to develop the operational RoCS
- The planned procedure with 3 stages (see current Project Plan) will be the most suitable way to reach the aim,
- Following working steps have to be done within the Stage 1 - Feasibility Study (as described in the current project plan):
 - Searching the global market for possible systems and techniques to use in a characterisation system. The search should cover all existing systems at present in operation and also techniques from known users of 3D digital data,
 - Establishing requirements for rock characterisation in a future deep repository, both internally (SKB/Posiva) and externally,
 - Definition of requirements to other systems from RoCS (e.g. geodetic underground survey system),
 - Brief specification of user requirements,
 - Brief cost estimate,
- In stage 2 (Benchmarking) the systems and techniques discovered during the feasibility study must be evaluated and compared:
 - Detailed specification of user requirements,
 - Selection of system and/or techniques to develop into an operative rock characterisation system (his selection defines the milestone between stages 2 and 3),
 - Crossbreed that the requirements of RoCS to other systems are fulfilled,
 - Stage 2 will consume 1 year time and has to be started in 2006,

- In stage 3 (RoCS Development) the selected system and or techniques to a rock characterisation system suitable for SKB and POSIVA requirements:
 - Have to be developed,
 - Cyclic work with development-tests-improvements have to been carried out until the system is considered operational by SKB and POSIVA,
 - Depending on the selected system stage 3 will consume 2 to 3 years time and has to be started directly after end of stage 2.

4. Investigations

Under consideration of the results of the discussion meeting DMT has done the following investigations in stage 1 (June to November 2005):

- Searching the global market for possible laserscanners and combination of laserscanners with digital cameras,
- Searching the global market for specific software for the visualisation, evaluation and analysis of geological data from laser scanning and/or combined laser scanning/digital camera,
- Searching the global market for 3D mapping and modelling tools,
- Summary of a draft conception for a geodetic underground survey system (GUSS).

4.1 Investigations Laserscanners

4.1.1 Hardware

A broad overview of 3D Laser Scanner Hardware and Software is given in the attached file:

Annex 1: Laserscanner-Overview_2005.pdf [<http://www.pobonline.com/>].

Of course, there is a great variation in construction, technical specifications and the software used to process the data.

As a result of the investigations and DMT's experience, the following laserscanners are selected from the list of Annex 1, because they are in general applicable in underground environments. Annex 2 contains additional information about these scanners from brochures or web pages.

Company	Scanner	Digital camera integrated?	Scanning technique	Internet link
Optech	Ilris 3D	Yes	TOF ¹	www.optech.ca
	CMS (Cavity Monitoring System)	No		www.ilris-3d.com www.topscan.de
Callidus ²	CP 3200	Yes	TOF	www.callidus.de
Faro (iQ volution)	sun880	No	Phase shift	www.faro.com
Leica	HDS3000	Yes	TOF	hds.leica-geosystems.com
Leica/Z+F	HDS4500/Imager 5003	No	Phase shift	www.zf-laser.com
Mensi/Trimble	GS200	Yes	TOF	www.mensi.com www.trimble.com
Riegl	LS420i	Yes	LIDAR ³	www.riegl.co.at ; www.riegl.com

DMT has done several tests in practice in underground coalmines and tunnels with Faro sun880 and with Leica HDS 4500/ Zoller + Fröhlich Imager 5003. All tests have been very successful. Both systems are working with the phase shift technique. The main differences in comparison to TOF/LIDAR Scanners are:

- Shorter measurement range
- Higher data acquisition rate (short data acquisition time)
- Higher spatial resolution
- Larger field of view (360°)

¹ TOF = Time of flight

² Scanner not listed in Annex 1

³ LIDAR = light detection and ranging

In underground environments mostly measurement ranges are not longer than 20 to 30 m, so long measurement ranges are not necessary. All other named features are big advantages for phase shift scanners against TOF/LIDAR scanners.

4.1.2 Integrated Digital Cameras

Every kind of Laser Scanners may have a digital camera integrated to capture RGB values. Main advantages of using a digital camera and capturing RGB data are:

- More realistic view of the scanned object
- Easier identification of small relevant elements (e.g. geological fractures)

At present in all laserscanners with integrated digital camera RGB values will joint one to one to each pixel of laserscanners. In future it might become possible to use the total high resolution of digital cameras (up to more than 8.0 Mega pixels) for more detailed data interpretation.

Nevertheless texture mapping is an available the possibility to drape the picture upon the solid model. Some digital photogrammetric software allows to calculate the internal and external orientation parameters of the images and the following “ortho-projection” upon the triangulated solid model.

4.1.3 Software

3D point cloud software is specially designed for viewing, administration, and ongoing workflow of extensive 3D scan point clouds from high-resolution 3D laser scanners. This software allows manipulating raw 3D scan points and acquiring initial point cloud data comprehension with analysis functions. Through data analysis and manipulation, scan points can be prepared for export into the user’s CAD system.

Most important general features of this software packages are:

- Acquisition of point cloud data
- Data management / administration / manipulation
- Registration of scans
- Eliminate error and measurement noise
- Measuring of distances, areas, surfaces, volumes
- Modelling tools (Planes, Boxes, Spheres, Cylinders etc.)

- Make complex surfaces and 3D meshing
- Collision, deviation and evenness control
- Import/Export of CAD Data
- Free selection of point of view
- Visualisation and Animation tools (Video File formats, VRML)
- The following table give an overview on typical Laserscanning software packages:

Company	Software	Web
3G	Joint Metrix	www.3gsm.at
Amberg MT	TMS	www.amberg.ch
Faro	Faro Scene	www.faro.com
Geo-Byte	Tectoni-CAD	www.geo-byte.at
Geodata		www.geodata.at
Mensi/Trimble	Realworks 3Dipsos	www.trimble.com
Riegl	RiScan	www.riegl.co.at ; www.riegl.com
Leica/Z+F	Cyclone / CloudWorx	hds.leica-geosystems.com www.zf-laser.com

Annex 3 contains additional information about this software packages from brochures or web pages.

4.1.4 Specific Software for Applications in Geology

For RoCS it seems necessary to have an additional software package with specific geological functionalities available. In this stage of the project we don't have done an intensive investigation on such software. But here are some general remarks:

- Geological mapping is a traditionally paper-based process requiring a degree of abstraction and simplification
- Laserscanning enables digital mapping methodology
- Scans are highly detailed, spatially and geometrically precise models of real-world surface exposures

- Geoscientist can reduce the time for the geological field work
- The data from the laserscanner can be visualized directly for quality control and input of additional information
- Analysing and interpretation of the scanned data can be done at any place and any time
- All parts of the exposure are accessible to study without recourse to the field
- Geologist can pick surfaces such as bedding, faults and 3D fracture networks and sedimentary architectures
- Specific Software allows the user to interact directly with the virtual data
- 3D visualisation will be possible by using full colour auto-stereoscopic 3D screens or fully immersive stereo projection

4.2 Conclusions

A 3D laser scanner system based on the phase shift method, combined with a digital camera and some specific software package for visualisation, administration, manipulation, analysis modelling and geological interpretation of the data seems to be the adequate system to fulfil the user requirements of RoCS. Possibly stereo-photogrammetric tools can be alternative or additional tools. Of course, in phase 2 of the project the requirements have to be outlined in detail by the users. Starting from these user requirements a benchmark on available systems has to be executed.

Nevertheless it cannot be exclude that some elements of the best fitting system (e.g. specific geological interpretation and visualisation tools) are not developed yet and have to be developed within RoCS project phase 3.

5. Geodetic Underground Survey System

Beginning in the planning phase, but mostly during the construction and running phase of the deep underground repository a homogenous geodetic survey system with special emphasis to underground activities is essential for the technical and economical success of the construction:

- Any failure in navigation of tunneling or shaft construction activities have direct consequences to all following processes and threaten the economical success of the project
- Any data captured during construction phase (especially geological data capture by laser scanning) have to be located to a three-dimensional coordinate with high accuracy and reliability

- The final acceptance of any construction activity by the principal needs objective data
- The final storage of the radio-active waste has to be documented in detail with very high precision and reliability
- Geometric deformation of tunnels and chambers must be monitored in absolute position

Main activities for the development of a suitable geodetic survey system are:

- Design and implementation of a general surface survey grid as reference for all following measurements (typically with GPS techniques), typically based on national authority survey grid
- Navigation of tunneling direction (with total station and gyroscope) and incline (with levelling instrument and/or total station)
- Marking and measuring of tie points, e.g. for laser scanning or deformation measurements (with tachymeter)
- Survey point plumbing through shafts (with specific electro-optical or laser plumbing instruments)
- Control measurements for checking the homogeneity of the survey system (with GPS on the surface as well as total station and gyroscope underground)

5.1 Conclusions

Due to the high relevance of a geodetic survey system to the technical and economical success of the whole project as well as the RoCS project, we recommend expressly for phase 2 of RoCS to develop a concept for the future geodetic survey system directly linked with the requirements of RoCS.

6. 3D Modelling Software

The following documentation encompasses the results of a global search for commercial and well-established 3D modelling software packages, which could be in principle suitable to be integrated into a rock characterization system. It gives an overview of available software and does not represent a benchmarking.

Provided are brief descriptions of the screened software packages and vendor's documentation sheets as provided on their Internet pages. Furthermore, vendor's contact details are given.

A rapidly increasing number of software products are available on the market, which are tailored to create static geocellular models (or evenly

named block models) for geological tasks. In general, 3D modelling software is widely used in four geoscientific branches: in the petroleum industry, in the mining industry, for geotechnical numerical simulation and in hydrogeology for groundwater modelling.

Excluded from the selection were so-called 2½D packages, which provide 3D visualisation of model elements, but include only 2D processing options.

Also not included was software, which is primarily designed for dynamic modelling as black oil simulators, or dynamic simulators for water flow, mass or heat. Pre-screening of this software revealed that such packages always require pre-processing by more “geologically orientated” applications.

6.1 Results of the Search

The software screening was limited to products available on market, which are recognised as major products in the specific branch. A total of 14 3D modelling software packages were found to meet the objectives of the search:

Market Area	Key Geoscientific Discipline	Product
Exploration Geology	Geophysics, Petrophysics, Borehole Geology, GIS	Target, Montaj
Oil & Gas	Geophysics, Structural Geology, Sedimentology, Reservoir Simulation	Earthvision, IRAP-RMS, Petrel, GOCAD,
Mining	Surveying, Mine Planning, Geostatistics	Datamine, Surpac, Vulcan, Minesight, DUDE
Geotechnics	Geomechanics	Eram-SIS, UDEC, Flac3D

Vendors' addresses and web pages are provided in Annex 4. Annex 5 contains more detailed information about some of the software packages from brochures or web pages.

All screened modelling packages provide 3D visualisation and options to generate cross-sections and maps based on gridded surfaces.

During the evaluation it was found that among the products of each market the contained modules resemble very much. Therefore, in the following brief software descriptions only outstanding modules are mentioned which are particularly suitable for rock characterisation.

Special emphasis in the evaluation was laid on Database functionality and programming and macro options.

6.2 Summary of Software Functionalities

6.2.1 Market Area: Exploration Geology

Target (Geosoft)

- Borehole Database with dynamic data linking with visualisation windows, compatible with GIS systems (plug-ins for ArcMap, MapInfo and ER Mapper), database processing built on Oasis Montaj
- Data Sharing with ODBC, acquire, MapInfo, ArcGis, Microstation and Surpac
- Macro functionality
- Statistical Analysis of borehole and spatial data

Oasis Montaj (Geosoft)

- Database designed for large data sets with dynamic linking with visualisation windows, compatible with GIS systems (plug-ins for, MapInfo and ER Mapper), client for DAP (Data Access Protocol) server
- Extensions for e.g. geophysics, geochemistry, gravimetry, magnetics

6.2.2 Market Area: Oil & Gas

The 3D modelling packages for the oil & gas branch commonly focus on the generation of structural models in faulted areas by combining borehole and seismic data. 3D block model design parameter allow to mimic structural and sedimentary settings. Generally, deterministic and stochastic modelling of geobodies and rock properties is enabled. The construction of mining infrastructure as shafts and galleries might not be included.

Earthvision (Dynamic Graphics)

- Apparently no internal database
- Workflow Manager with updating capability
- Focus on fault analysis and well path planning
- No generation of geobodies

Irap RMS (Roxar)

- Consists of eleven modules
- Apparently no internal database
- Workflow Manager with updating capability
- Facies Modelling (Geobodies)
- Fault Analysis
- Borehole correlation
- Fracture Modelling

Petrel (Schlumberger)

- Consists of 18 modules
- Similar capabilities as Irap RMS without Fracture Modelling
- Seismic Interpretation Modules

GOCAD (Earth Decision Sciences)

- Consists of 19 modules
- Similar capabilities as Petrel

6.2.3 Market Area: Mining

The functionalities of the market leading software packages as namely Datamine, Surpac, Vulcan and Gemcom resemble to a large extent. They provide databases for drill hole data which in some packages (Datamine) are dynamically linked to the visualisation windows. The Underground mining inventory is usually described by 3D polygons. Differences exist in the approach of handling faults and block model generation in tectonically complex areas. Property Modelling is usually based on geostatistic (namely kriging) methods. Generation of complex geological or mining bodies (as caverns) is common standard, stochastic geobody modelling is not enabled. Data Exchange or Interfaces with CAD and GIS is included.

DUDE represents a special solution for modelling and display of the mining inventory according to the norms of the German hard coal mining.

DMT is holding software licences for Surpac, Datamine and DUDE.

Datamine (Datamine Inc.)

- Several modules
- Internal project file structure
- Web Based Scripting

- Stereonet Viewer
- Underground Mine Planning module
- Stand-alone Viewer

Surpac (Suppac Minex Group Pty Ltd)

- Several modules
- Internet Access to projects
- Macro Programming Language
- Underground Mine Planning module for stratified deposits (Eclipse)

Vulcan (Maptek)

- Hierarchical data structure
- Underground Mine Modeller

Minesight (Mintec Inc.)

- Full database coverage of model elements
- Underground design

DUDE (SBI Ruhr)

- Full dynamic database coverage of model elements by Oracle Database
- Update functionality for geological surfaces and planes
- No block models
- Displays according to German coal industry norms
- Currently only available in German
- DMT has direct access to developers

6.2.4 Market Area: Geotechnics

EramSIS (Colenco Power Engineering Ltd)

- Spatial information system for visualisation and data management

UDEC (ITASCA Consulting Group Inc.)

- Simulation of displacement behaviour involving jointed rock systems
- No database

FLAC3D

- Stress/strain simulation of finite rock and soil elements
- Coupled to groundwater flow
- No database

6.3 Conclusions

Several well-performing 3D modelling tools for geological purpose are available on the market.

Therefore also for 3D modelling software the user requirements have to be outlined in detail in phase 2 of the project. Starting from this user requirements a benchmark on available systems has to be executed. Important items of this benchmark have to be:

- The potentials of the system to work easily with big amount of laser scanner data
- The interaction with geological software tools
- The interaction with existing databank system

Especially the existing RVS system has to be included into the benchmark.

7. Final Statement

The most important results of the consulting services carried out by DMT can be resumed as follows:

- For the main components of RoCS the market provides principal solutions
- The definition of user requirements in phase 2 of the project is an essential base for the benchmarking to choice the best fitting tools
- In all probability it will be necessary to customize the links between the single components of RoCS to come to an optimal system
- Additionally the conception of a geodetic survey system is inevitable for the success of the project.