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INTERNATIONAL COOPERATION REPORT

93-02

Development of ROCK-CAD model for Äspö Hard Rock Laboratory Site

Pauli Saksa, Juha Lindh, Eero Heikkinen
Fintact Ky, Helsinki, Finland

December 1993

Supported by TVO, Finland

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DEVELOPMENT OF ROCK-CAD MODEL FOR ÄSPÖ HARD ROCK LABORATORY SITE

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FOREWORD

The scientific investigations within SKB's programme are part of the work to support the design and construction of a deep repository and to identify and investigate a suitable site for such a repository.

In 1986 a balanced appraisal of the available facts, requirements and assessments led to the proposal to construct an underground research laboratory at the Äspö island.

Field work for the Äspö Hard Rock Laboratory was initiated in the fall of 1986. The excavation of the facility started 1990. In conjunction with the excavation work several investigations have been carried out.

The Äspö Hard Rock Laboratory - HRL - provides an opportunity for research, technical development and demonstration. Methods for investigation of rock for the deep repository for spent fuel are tested. The laboratory also provides an opportunity for practical testing of different aspects of the design of the deep repository. Large scale field studies of the interaction between engineered barriers and the surrounding rock can be conducted before the deep repository is built.

Several international organizations are participating in joint research projects at the Äspö HRL. The international experts enhance the scientific quality of the work at Äspö.

This International Cooperation Report has been produced as a part of a joint project of SKB and TVO.

ABSTRACT

Conceptualized geometrical rock model of the Äspö site was created with computer aided geological modelling system named as ROCK-CAD™. The model describes the structural and lithological interpretations made during pre-investigation phase. Modelling as a whole comprises three-dimensional geometrical volume data, borehole data set, planned rock rooms and geographical auxiliary reference data.

Report explains the composition of the CAD-model in detail. A set of plots was created and explained to familiarize the rock conditions of the Äspö site. Conceptual model and modelling work related matters are discussed.

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VERSION	ORIGINATORS DETAILS	
	Prepared by: Signature/date	Checked and accepted by: Signature/date
1.1 / 13.12.1993	13.12.1993	13.12.1993

SUMMARY

Three-dimensional (3-D) modelling of the Äspö Hard Rock Laboratory (HRL) site was conducted at FINTACT during 1992 - 93. The extent of the work that has taken place covers the build-up of basic structural, fracture zone rock model of the site together with related basic borehole data. The work was made with ROCK-CAD™ named geological 3-D rock modelling package. ROCK-CAD is based on Computervision's Medusa 12 2-D/ Drafting and 3-D Modeler CAD-modules. The developed ROCK-CAD application software is a shell around Medusa 3-D that provides the tools needed to model complex geological properties and geometries. Modelling system is project-type work procedure and object oriented. Classification and definition criteria used conforms with the ones documented earlier at Äspö site studies.

The 3-D rock model development has been limited to the basic extent at this stage. This means that main geological and conceptual modelling work results have been studied and gathered into ROCK-CAD database. The main emphasis has been in inclusion of previously conceptualized rock fracture and hydraulic zone structures. Borehole data concerning structures and fracturing was used to verify geometrical interpretations and to illustrate the intersection locations of the fracture zone structures in the boreholes. Mainly boreholes KBH02, KAS02, KAS05 and KAS16 has been considered. A new classification method for RQD-data was developed and discussed. It is specifically applicable to larger, site scale geometrical modelling purposes.

CAD-model composition is explained and documented in detail to familiarize how the system is configured and works. Definitions, coordinate systems, accuracy and resolution factors are discussed.

Report contains basic set of figures which present 3-D modelling information collected. There is a set of general maps and cross-sections covering the whole model or local excerpts of it. Borehole focused, local model cuts to allow closer comparison are shown. Graphics is either vector or raster type in form. Pictures are discussed and some notes concerning fracture zone classification and geometry is presented.

Keywords: nculear waste disposal, Äspö hard rock laboratory, ROCK-CAD, conceptual rock modelling, geological modelling

1. INTRODUCTION

Three-dimensional modelling (3-D) of the Äspö Hard Rock Laboratory (HRL) site was conducted at FINTACT company during 1992 - 93. The work was commissioned by Teollisuuden Voima Oy (TVO) in Finland. It is a part of the joint project between TVO and SKB agreed in 1992. During this starting phase the scope of the work consisted of the development and compilation of structural model of Äspö HRL site.

The extent of the work that has taken place covers the build-up of basic structural, fracture zone rock model of the site together with related basic borehole data. Results and benefits from the modelling exercise are realized through maps, cross-sections and illustrative 3-D cuts and views produced. Especially from TVO's viewpoint it is important for those participating into the HRL project to get a simplified but still realistic 3-D description of the rock structures and properties deduced from interpretations and earth conceptualizations. Hence, this deeper understanding may help to make more qualified analysis of the experiments and numerical simulations to be conducted in the future.

The main uses of the results presented in this report are:

- to construct a 3-D database of the Äspö site,
- to gain more detailed knowledge of the interpretations and modelling work conducted at Äspö site,
- to familiarize the interpreted rock conditions to Finnish participants of the project,
- to familiarize the interpreted rock conditions to other interested Äspö HRL project participants,
- to indicate possibilities of the ROCK-CAD system in the future.

The work was made with ROCK-CAD™ named geological 3-D rock modelling package described more in detail in Chapter 2. ROCK-CAD software is a property of TVO and is a registered trademark of FINTACT company.

2. DESCRIPTION OF ROCK-CAD SYSTEM IN BRIEF

ROCK-CAD™ is a new and complete subsurface geological modelling system based on CAD-type approach. The nucleus of ROCK-CAD is Computervision's Medusa 12 2-D/Drafting and 3-D Modeler CAD-modules. The developed ROCK-CAD application software is a shell around Medusa 3-D that gives all the tools needed to successfully model complex geological properties and geometry (Saksa 1992). Application software is mainly coded with FORTRAN-77 and Medusa Bacis 1 languages. The software is now running in a UNIX-based Sun Sparcstation workstation.

After decision to model a site, a new work project and the volume that will be modelled (and illustrated later) is set. Typically, model volume is rectangular in shape. The system is configured so that the one and same volume can contain several different types of subsurface models. The basic system handles lithological (rock types), structural (faults, fracture zones and fracturing) and hydraulic (hydraulic structures) models separately. This setting can be expanded or changed to specific needs. Topographical variation can be included also as upper surface boundary. However, in many cases topographical undulation of upper model surface (ground surface) is so small that it can be neglected (planar). Subsurface structures that extend to or are situated outside the fixed modelling volume are automatically clipped.

One model consists of a set of objects having both geometry definitions and related attributes. Geometrical boundary representation for each object can be done either numerically or graphically. Geometry is numerically defined by using geology oriented high-level Geometry Description Language (GDL) developed. GDL is an aid to speed up object generation. Objects created with GDL are processed through Medusa Interpolator module to form explicit 3-D objects. Actually, with GDL one can build the 3-D subsurface objects numerically in a personal computer. Graphically, each object volume is sketched with the help of Medusa-systems graphical design interface. Also digitizing is used as a normal import tool to collect information like maps into 3-D database and further extrude and shape them to 3-D objects. Due to the fact that solid objects are used throughout, all Boolean and volumetric operations are applicable.

The maximum number of volumetric objects in one ROCK-CAD model is 1000, the limitation of which is not absolute because the set of objects can be grouped to form one object. Hierarchy of the models and the objects is tree structured.

Each object or a set of objects is linked with attributes. Attributes used are property of an object (fill pattern code or colour), its degree of certainty, geological age, significance, descriptive name for an object etc. After the definition phase is completed, model assembly takes place in Medusa CAD-system. The composition of ROCK-CAD package and related work phases are shown in Figure 2-1.

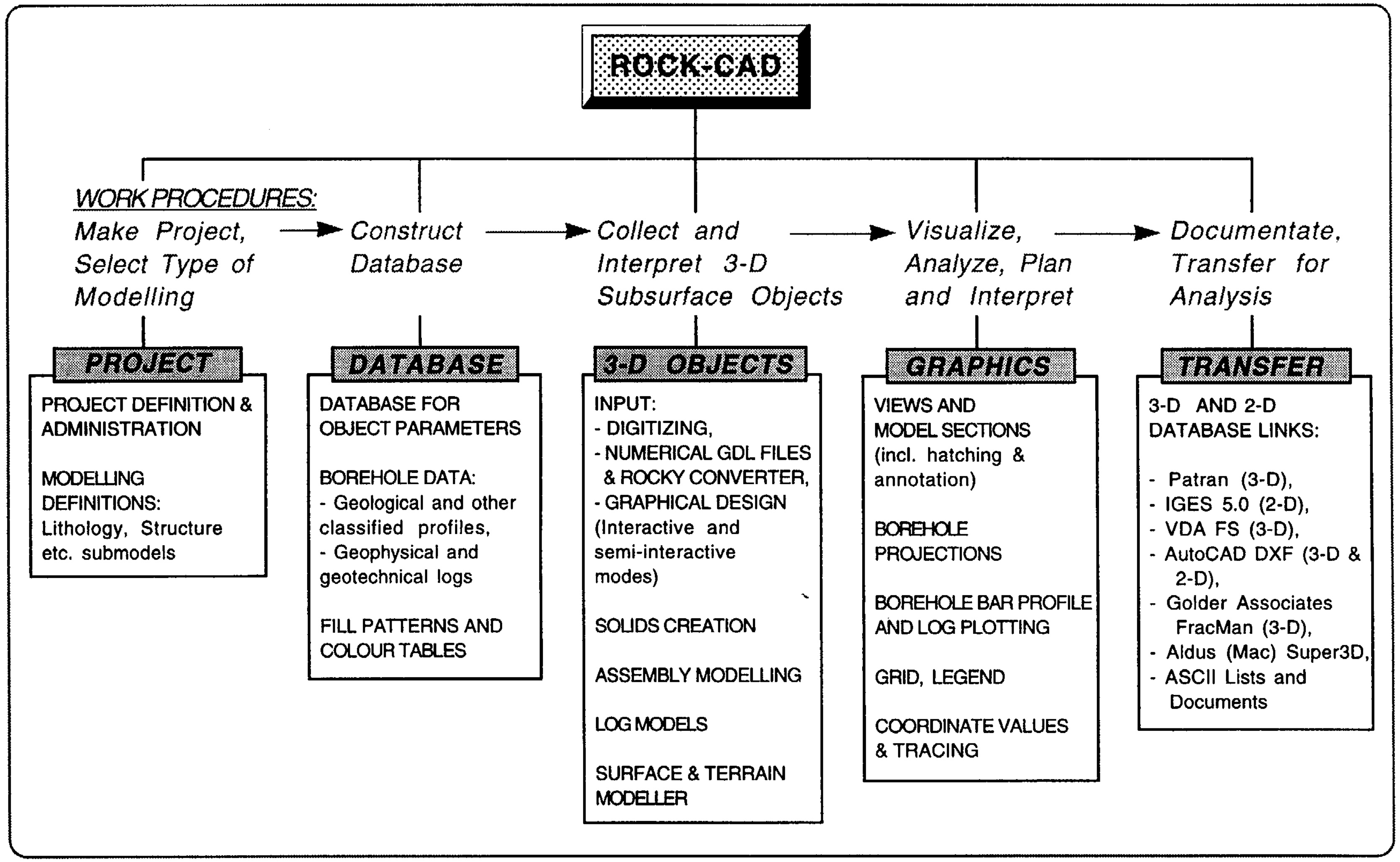


Figure 2-1. ROCK-CAD software composition and related work phases.

Boreholes and wells as "data sampling lines" are essential in the geoscience. Each borehole is described in a model as a deviated 3-D bar with varying property profile along it. Boreholes are projected to taken cross-section view planes. The variation of the property along borehole is shown with fill pattern, colour and/or explaining text labels. Displayed diameter of a borehole is a selectable parameter. Also, continuous geophysical/geotechnical profile data (logs) can be included to the model database and displayed in 3-D space.

Coordinate system in ROCK-CAD system is as a default the national geographic coordinate system in use. Input and output happens in those world coordinate values. Local or user defined other coordinates are possible (like the one used at Äspö site).

The viewing and output possibilities are numerous. Most useful ones in technical planning work are vertical and horizontal cross-sections (drawn in scale). Perspective and axonometric views are often used for presentation purposes. Special cuts of the model with arbitrarily oriented plane can be produced but especially in complex geological environment they are difficult to utilize and analyze in practice. Calculated cross-section graphics can be appended with coordinate network and subsurface objects can be identified and labelled from database. Quite often smoothing is applied. Fill patterns in use have generally been selected to conform the established practice of the project.

It is important to note a difference between 3-D interpretation and 3-D modelling. Interpretation and data analysis is an extensive phase of work that precedes the creation of a 3-D model. Multidisciplinary interpretations in different geofields result in lithological and structural indications, estimations and concepts differing in their detail and accuracy. These interpretations are transferred to 3-D modelling. Further study of earth structures can be conducted with 3-D views from modelling system by expert discussions and judgment. This often leads iteratively back to interpretation and 3-D model revisions (Saksa 1992).

The use of 3-D modelling techniques requires necessarily classification and definition criteria to be determined and documented. Classification principles can be sometimes difficult to set: for example, cut-off type criteria for the detection of a fracture zone. Conceptualization of the rock structures takes place through such a definition-limited data sorting.

Established and unchanging nomenclature of the rock structures within the modelling work team is desirable to be achieved. Definitions for the fracture zones and structures in general or rock types and their names serve as examples.

The use of ROCK-CAD system during different stages of investigations is depicted in Table 2-1. The modelling system has been in operation for TVO's preliminary site studies for nuclear waste since 1989 (Saksa 1992).

Table 2-1. ROCK-CAD functions during an investigation program.

Phase of investigation project	**ROCK-CAD use**
Reconnaissance and standard investigations	• Tentative conceptualization • Creation of tentative volume model • Planning of supplementary investigations • General visualization purposes
Supplementary investigations	• Conceptualization (fine tuning) • 3-D model updating and analysis • Planning of detailed studies / verification
Finishing and verifying investigations	• Visualization for decision purposes • Design of underground rock caverns • Documentation of the state-of-the-art rock volume knowledge

3. MODELLING WORK AND GEOLOGICAL MATERIAL

3.1. GENERAL

The 3-D rock model development has been limited to the basic extent at this stage. This means that main geological and conceptual modelling work results have been studied and gathered into ROCK-CAD database. The most comprehensive piece of the study material used has been the site geology interpretation report (Wikberg et al. 1991). Also a list of the investigations carried out has been utilized (Stanfors et al. 1991). As a supplement the interpretation work carried out by another study group of geology has been evaluated briefly (Palmqvist et al. 1992).

Drawings and other material concerning the planned rock rooms and geographical coordinate systems applied at the site were kindly provided by Vattenfall Energisystem AB (Widing 1992).

Borehole data including (x,y,z)-deviation profiles and a subset of geology and fracturing data profiles has been provided by SKB from GEOTAB database (Ohlsson 1992). This was transferred into ROCK-CAD borehole database. Some geophysical logging data was initially also intended to be collected as reference material. Data in different formats was easily transferred to ROCK-CAD format files.

Geographical background material and pictures were provided by SKB's technical CAD-consultant Sydkraft Konsult as DXF-format files (Markström 1992).

3.2. LIST OF GEOLOGICAL MATERIAL INCLUDED INTO THE MODEL

3.2.1. Adopted Äspö Rock Model Data

The main emphasis has been in inclusion of previously conceptualized rock fracture and hydraulic zone structures (Wikberg et al. 1991). They have been classified mainly to major and minor type ones. Orientation related notation "EW-", "NE-" and "NW-" and "NNW-" was copied and used throughout. Three east-west oriented and previously unnamed minor fracture zone structures were labelled as EW-S1 - EW-S3 in the ROCK-CAD model. Interpreted main fracture zones have been modelled mostly as planar-like or gently curved 3-D zones within Äspö study area.

Two supplementary fracture zone structures were collected from interpretations conducted by Palmqvist et al. (1992). They were named as "Zone J" and "Zone L" according to used notation in that report. Those zones differ considerably from the main conceptual model (Wikberg et al. 1991).

The ENE-oriented and subhorizontally dipping zone named as EW-X has not been included in the current model. The structure is said to consist of thicker section of more or less parallel local fracture zones under southern part of Äspö island and beneath the sea. It is geometrically relatively free-form shaped and its location in space is not well defined.

All the zone coordinates at the earth surface were derived from the map figures by digitizing them.

The lithology was included by digitizing the surface rock map of the Äspö island and extruding that directly along the Z-dimension. One highly fractured, fine-grained granite inclusion which forms a part of the fracture zone EW-5 and hydraulic zone EW-5W was collected into model (also called as Zone K fine-grained granite) (Palmqvist et al. 1992).

For each fracture zone structure the line point coordinates were first collected into a file. Then every structure was recorded into its own GDL model file. GDL coded, high-level syntax files are input to Rocky converter program. Rocky produces a Medusa Interpolator format file. This file in turn can be run further as a macro file from Interpolator utility program within Medusa system to produce binary coded 3-D object model files.

Fracture and hydraulic zones describing geometrical parts (objects) are discussed further in Chapter 3.3 section "Model structure".

3.2.2. Borehole Data

Borehole data serves as its best in verifying geometrical interpretations and in illustration the intersection locations of the structures in the boreholes. Fracturing and geophysical logging data can be used to compare conceptual modelling interpretations with the actual measurement results. Hence, following data shown in Table 3-1 was collected from the selected set of the Äspö core drilled boreholes.

Table 3-1. Data available and included in the Äspö model.

Borehole name	Deviation profile	Fracture zone inter-sections	RQD profile	Rock type profile	Geophys. profiles
KBH02	INCL.	INCL.	INCL.	NOT IN.	NOT AV.
KAS02	INCL.	INCL.	INCL.	NOT IN.	MISSING
KAS03	INCL.	INCL.	INCL.	NOT IN.	NOT IN.
KAS04	INCL.	INCL.	INCL.	NOT IN.	NOT IN.
KAS05	INCL.	INCL.	NOT AV.	NOT IN.	NOT IN.
KAS06	INCL.	INCL.	INCL.	NOT IN.	NOT IN.
KAS07	INCL.	INCL.	INCL.	NOT IN.	NOT IN.
KAS08	INCL.	INCL.	INCL.	NOT IN.	NOT IN.
KAS09	INCL.	INCL.	INCL.	NOT IN.	NOT IN.
KAS11	INCL.	INCL.	INCL.	NOT IN.	NOT IN.
KAS12	INCL.	INCL.	INCL.	NOT IN.	NOT IN.
KAS13	INCL.	INCL.	INCL.	NOT IN.	NOT IN.
KAS14	INCL.	INCL.	INCL.	NOT IN.	NOT IN.
KAS16	INCL.	INCL.	NOT AV.	NOT IN.	MISSING

Explanations:
INCL. = included into model, NOT IN. = available, not included into model, NOT AV. = not available, MISSING = available ,not delivered.

Unfortunately, our idea to use some specified geophysical logs as a reference measurement data could not be fulfilled due to non-delivery of the data. We intended to show relationships between geophysical logs and conceptual model structures in boreholes KAS02 and KAS16.

3.2.3. Fracture Zones in the Boreholes

Structure intersections with Äspö Hard Rock Laboratory boreholes KAS02 - KAS09, KAS11 - KAS14 and KBH02 have been sorted out to present the borehole findings in vertical sections and in 3-D views. The compilation of borehole profiles is based on conceptual modelling report (Wikberg et al. 1991) (Table 4.1 checked against Figures 3.18 - 3.19 and 4.2 - 4.8).

Geological and geohydrological types of information of the column "Borehole identification" in Table 4.1 (Wikberg et al. 1991) was combined to simplify the presentation. Thus, the geological and geohydrological sections shown for any borehole have always the outermost edges given. However, structures EW-1 and EW-1W, and EW-5 and EW-5W, respectively, were handled separately due to their varying dipping angles. If the geological finding was given only to one discrete depth value instead of an interval, 10 meters has been used as a minimum thickness of a structure (edges around ±5 m of the given depth).

In the following a short description or comment is given for each borehole and structure included in the model (see also Table 3-2 later in this chapter). Note, that a gently dipping fracture zone structure EW-X is not in ROCK-CAD model at this moment.

- Borehole KAS02 intersects the zonees EW-5 (EW-5W), EW-X and NE-1. Zone NE-1 is not shown in Figure 4.6 (Wikberg et al. 1991) and it could not be checked.

- Borehole KAS03 penetrates the structure EW-1W.

- Borehole KAS04 penetrates the structures EW-1, EW-1W, EW-5, NE-2 and zone L. Intersection of the structure NNW-2 is uncertain.

- Borehole KAS05 penetrates the structures EW-5 and EW-X. Intersection of the structure NNW-2 is uncertain.

- Borehole KAS06 penetrates the structures EW-3, EW-5, NNW-1W and NNW-2W. Zone EW-X is shown in Figure 4.4, but no geological identification is referenced in Table 4.1 (Wikberg et al. 1991).

- Borehole KAS07 penetrates the structures EW-3, EW-5, NE-1 and NNW-1W.

- Borehole KAS08 cuts the zones NE-1, NE-2 and NNW-2W.

- Borehole KAS09 penetrates the structures EW-5, EW5-W, EW-X and NE-1.

- Borehole KAS11 penetrates the structures EW-5, NE-1 and EW-X. Major zone NE-1 is not shown in Figure 4.6, though listed in Table 4.1 (Wikberg et al. 1991).

- Borehole KAS12 penetrates the structures EW-1 and NE-2. There is a discrepancy between the surface location of EW-1 and listed finding of it in the borehole. Borehole KAS12 is located outside the conceptualized zone, see Fig. 4-3 later in this report. However, EW-1 is a thick and complex zone when it is difficult to define where it begins and ends.

- Borehole KAS13 penetrates the structures NE-2, NNW-1 and NNW-2. Location of hydraulic structure NNW-1W in the borehole is uncertain.

- Borehole KAS14 penetrates the structures EW-5, EW-5W, EW-X and NE-1 (last one is not shown in Figure 4.6, but is listed in Table 4.1).

- Borehole KAS16 penetrates the structure NNW-2W. It is not shown in any figure, but is referenced in Table 4.1, (Wikberg et al. 1991).

- Borehole KBH02 penetrates the structures EW-7 (same intersection also for zone J), NE-4 (and NE-4B), NE-3 and NE-1. Major structure NE-1 is defined in the borehole section 600 - 760 m.

Table 3-2. (next page) Structure intersections in boreholes, as they were included in the Äspö HRL ROCK-CAD model. Borehole values in brackets ( ) describe locations where sections of hydraulical and geological indications for the structures differ significantly (exists between the extreme values) or only one discrete depth for structure is given (after expanded range exact depth value).

Structure intersections (? = uncertain, questionable)

Borehole, length	EW-1	EW-1W	EW-3	EW-5	EW-5W	EW-7	*EW-X*	NE-1A	NE-1B	NE-2	NE-3	NE-4	NE-4B	NNW-1W	NNW-2W	NNW-3W	NNW-5W	NNW-1	NNW-2	NW-1	ZONE J	ZONE L
KAS-02, 924 m																						
120 - 130 m				X																		
270 - 280 (275) m				X																		
309 - 343 m				X																		
395 - 405 (400) m							*X*															
485 - 490 (490) m							*X*															
803 - 920 m								X	X													
KAS-03, 1002 m																						
349 - 373 m		X																				
455 - 475 m		X																				
610 - 622 m		X																				
691 - 694 m		X																				
KAS-04, 481 m																						
0 - 55 m		X																				
55 - 70 m	X	X																	?			
70 - 110 m		X																	?			
110 - 120 (115) m	X	X																				
120 - 175 m		X																				
175 - 185 m	X	X																				
185 - 190 m	X																					
325 - 334 m				X																		
334 - 340 m																						X
388 - 436 m										X												
KAS-05, 560 m																						
100 - 115 m				X															?			
210 - 220 m				X															?			
274 - 383 m				X															?			
395 - 405 (400) m							*X*												?			
475 - 485 (480) m							*X*												?			
KAS-06, 602 m																						
60 - 70 m			X	X																		
208 - 234 m														X								
351 - 354 m				X																		
362 - 365 m				X																		
447 - 450 m															X							
KAS-07, 604 m																						
50 - 80 m														X								
222 - 224 m				X																		
235 - 246 m				X																		
383 - 451 m			X																			
508 - 604 m								X	X													
KAS-08, 601 m																						
40 - 60 m										X												
183 - 186 m															X							
555 - 601 m								X	X													
KAS-09, 451 m																						
10 - 60 m				X																		
60 - 100 m					X																	
100 - 150 m								X	X													
140 - 160 m							*X*															
245 - 255 (250) m							*X*															
KAS-11, 249 m																						
10 (- 60) - 100 m				X																		
150 - 175 m								X	X													
160 - 180 m							*X*															
245 - 255 (250) m							*X*															
KAS-12, 380 m																						
10 - 70 m	?																					
240 - 325 m										X												
KAS-13, 407 m																						
55 - 65 (60) m														?				X				
160 - 169 (160, 169) m																		X				
210 - 214 (210, 214) m																			X			
255 - 265 (260) m																			X			
370 - 410 m										X												
KAS-14, 212 m																						
10 - 60 m				X																		
60 - 100 m					X																	
100 (- 125) - 160 m								X	X													
150 - 200 m							*X*															
KAS-16, 549 m																						
0 - 120 m															X							
KBH-02, 706 m																						
50 - 75 m						X															X	
100 - 250 m												X	X									
310 - 440 m											X											
600 - 706 m								X	X													

Structure EW-X not included in current version of ROCK-CAD model

3.2.4. Rock Quality Designation (RQD) Values

Numerical RQD profiles of boreholes KAS02 - KAS09, KAS11 - KAS14 and KBH02 have been received from GEOTAB database (Ohlsson 1992). RQD values indicate general fracturing within rock formation. RQD data can be compared with the fracture zones of the 3-D model to see how well the conceptual model explains the occurrences of fractured sections of the rock.

These profiles have dense and varying sampling interval and a lot of very local scale variations. They were classified and simplified prior to model generation to present the information in vertical sections and in 3-D views. Classification aimed to detect main fractured and more continuous sections in the boreholes. The output was preferred to be more averaged in scale of metres instead of centi-decimeters of the original data. The classification was developed for this specific modelling project.

The goal was set to categorize rock types into three classes.
Class 1 - named as "intact rock matrix having low or moderate fracture density" - represents RQD values > 75 %,
Class 2 - "fractured sections" - represents RQD values > 25 and ≤ 75 %,
Class 3 - "highly fractured sections" - represents RQD values ≤ 25 %.

One definition to be used later is needed. As a processing result a "Structure" consists of a single longer or of several shorter sections with RQD class 2 or 3.

Due to large small scale variations, classified profiles were further simplified and short sections were compiled to longer sections. Sections of low RQD values have been emphasized in processing. The following 3-phase processing method has been used in simplification:

Classification phase 1. All values were sorted to classes 1 to 3.

Classification phase 2. All narrow sections of class 1 having threshold thickness $T \leq 2.5$ m and surrounded by class 2 and 3 sections have been changed to surrounding lower class values. If the class 2 and 3 sections were very thin (centimeters - few decimeters) compared to thicker (meters) class 1 sections, the replacement was cancelled. Also neighboring sections having same class 2 or class 3 values were joined.

This was made to sort and combine, and favor narrow, strongly variable low RQD sections which evidently belong to same structural unit.

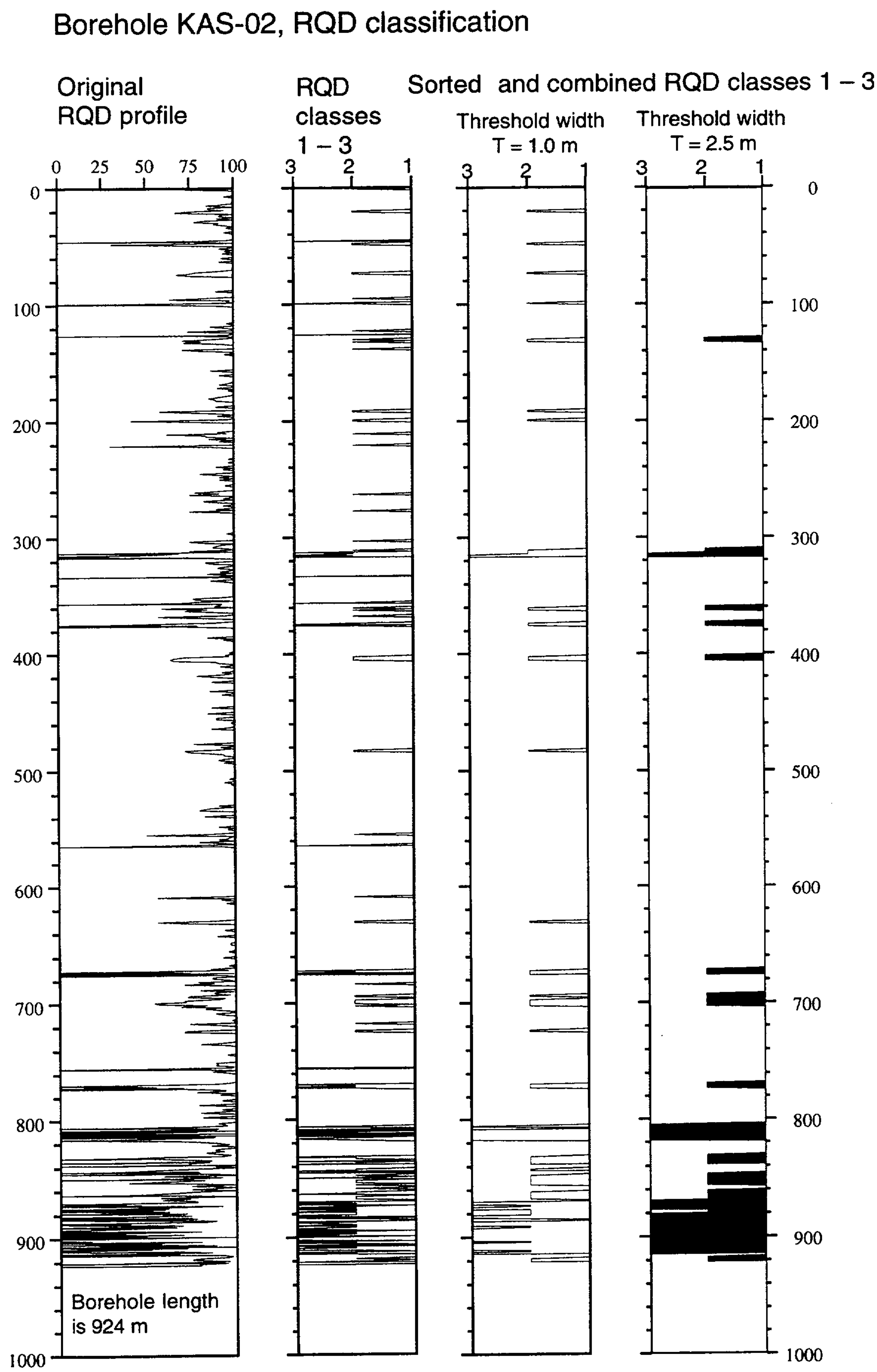
Classification phase 3. All remaining thin ($T \leq 2.5$ m) and separate class 2 and 3 sections have been removed (changed to class 1 value). Within a preserved structure the mutual proportions of class 2 and 3 sections determine the replacing class value for any thin section.

This processing excludes thin fractured rock sections, which are difficult to be distinguished in view plots but favors them when situated spatially close together.

Now the narrowest sections are ca. 3 m wide. Several tests were made to design this processing concept and an example of these is presented in Figure 3-1 from borehole KAS02. Threshold value T = 1 m for a structure was found to produce fairly strongly varying feature set. Use of any smoothing of original profile prior to classification (e.g. moving average filters or binomial smoothing) seemed to leave out fractured sections randomly and changed too much also the location of the edges of the fractured sections. Classified profiles were compared to the classified presentation in conceptual modelling report (Wikberg et al. 1991), and they were found to basically contain much of the same information.

Transmitted RQD profile data of borehole KAS05 from GEOTAB database was damaged containing only values of 100.0 (figure 3.18 in report 91-22, page 42, shows real variation in values).

Figure 3-1 (next page). Original and classified RQD profiles in Äspö borehole KAS02. RQD-value classification basis is as described in the body text. From left to right: Profile 1 represents original values, Profile 2 shows classified values without sorting and combination, and Profiles 3-4 sorted and combined classes. In Profiles 3 and 4 threshold values T = 1 m and 2.5 m have been applied, respectively. Profile 4 has been used further in modelling.


Borehole KAS-02, RQD classification
Original RQD profile
RQD classes 1 – 3
Sorted and combined RQD classes 1 – 3
Threshold width T = 1.0 m
Threshold width T = 2.5 m
0 25 50 75 100
3 2 1
0
100
200
300
400
500
600
700
800
900
1000
Borehole length is 924 m

Discussion

Originally Deere (1964) proposed the following relationship between the numerical value of RQD and the engineering quality of rock:
RQD < 25 %, very poor quality of rock,
RQD 25 - 75 %, poor to fair quality rock,
RQD > 75 %, good to very good quality rock.

Theoretically all fractured sections which represent class 2 type of rock have fracture density ≥ 4 pcs/m and all those of class 3 highly fractured sections have fracture density ≥ 10 pcs/m. Generally speaking, all the fractured sections have much higher fracture density than the theoretical minima. Classification of RQD-sections into three classes reduces also the well-known ambiguity of the absolute RQD-values. RQD can not be directly compared to fracture frequency etc. values. Applied processing method has a general low-pass filtering effect.

According to studies reported by Sjögren et al. (1979) it can be estimated that Class 2 "fractured sections" have fracture frequency between 7 - 19 pcs/m and Class 3 "highly fractured sections" more than 19 pcs/m. This yields P-wave longitudinal velocities 3000 - 4500 m/s and less than 3000 m/s for the named classes 2 and 3, respectively. Thus, RQD-sections could also be used as indicators for the seismic velocities and reflection boundaries. The processed RQD-sections in this report do not show so dense and small scale variation as, for example, geophysical sonic logs but properties within larger rock volume units. The relationship between RQD and seismic velocity does not apply if the rock presents a higher degree of alteration and weathering.

3.2.5. Geophysical Measurements

Geophysical data included into the model database was intended to be discussed in this section. It is meant for comparison with conceptual modelling results. However, it is not included to this model version due to delayed and finally, not received data.

3.2.6. Geographical and Rock Room Data

The shoreline of the Äspö island was digitized for the localization purpose. Surrounding other islands and shorelines were copied into the model as DXF-format files (Markström 1992). Äspö and Hålö islands and some other nearby smaller islands have been modelled as 3-D solid objects (flat outlines). Other islands and shorelines are background graphics reference lines.

The access tunnel part was modelled as a tunnel profile and spiral in tube shaped form. Planned shaft and shaft connection have been modelled, too. Rock rooms are the planned ones (version dated -91.11.08), not the ones excavated due to changes made during the tunneling work (Widing 1992).

3.3. COMPOSITION OF CAD-MODEL

Project build-up

ASPO-named project was created into ROCK-CAD system and database for the structural model was initiated. The database is simply a hierachical set of files containing:

- project definition files containing coordinate system settings etc.,
- high-level GDL coded files of the solid rock objects,
- rock object files designed with Medusa graphical interface (sheet definitions),
- database of object parameters (called PARAMS),
- borehole files: deviation and property profiles,
- supplementary picture files of reference geography,
- rock room files designed with Medusa's graphical interface.

Coordinate systems and accuracy considerations

Work is done in the local Äspö coordinate system, where X axis points northwards (horizontal, close to the north), Y points eastwards (horizontal) and positive Z axis (vertical) points upwards. In the study area exists also another local coordinate system called OKG. There is a small difference between Äspö and OKG systems (see Figure 3-2) but this is negligible when compared to the tolerance and the absolute accuracy of the modelling input data (original maps, interpretation accuracy etc.).

Äspö coordinate system is rotated counterclockwise in respect to national coordinate grid (abbreviated as RAK) (SKB 1992). Location of Äspö coordinate system origo in RAK-system X,Y,Z values is not known to us. All ROCK-CAD coordinate information is according to Äspö system.

Accuracy of actual coordinate values in the model is difficult to determine. Some errors come from digitizing the input data maps. Some smoothing of real geographical features come from attached DXF-files. Comparison with Wikberg et al. (1991) maps indicate 0 - 5 m differences between similar type geographical maps and 0 - 15 m differences when concerning modelled fracture zone positions. Differences 10 - 15 m was found between some N-S oriented structures NNW-5W and NNW-3W probably originating from our digitizing work which utilized copied, inaccurate (large scale) report pages.

The planned access tunnel part could be positioned with accuracy of about 0.1 m. The spiral part is more tentative in location, especially its bearing in respect to the access tunnel part.

Internal Medusa CAD-system modelling tolerance was preset to value of 1 m for all the modelled 3-D rock objects. Received borehole x,y,z-deviation and profile data files have relative accuracy of centimeters at the highest. Absolute accuracy is probably within a few metres.

The resolution in vector graphics plots is limited by physical pen location accuracy and line thickness used. Line thickness 0.2 mm means 0.2 m and 2 m accuracy in the scales 1:1000 and 1:10000, respectively. In raster graphics plots the screen pixel resolution limits the detectable details of the model objects. View area 1000 m • 1000 m on the screen (~ 1000 • 1000 pixels) gives 1 m resolution for each pixel. Visibility of the details less than 1 m in actual size is varying case by case and depends on the z-buffering scheme of the system and on the treatment of interfering voxels (volumetric pixels).

The accuracy of interpretations is discussed in chapter 4.2. However, generally the internal accuracy of the model geometry data is in normal case much better than the accuracy of the deduced interpretations.

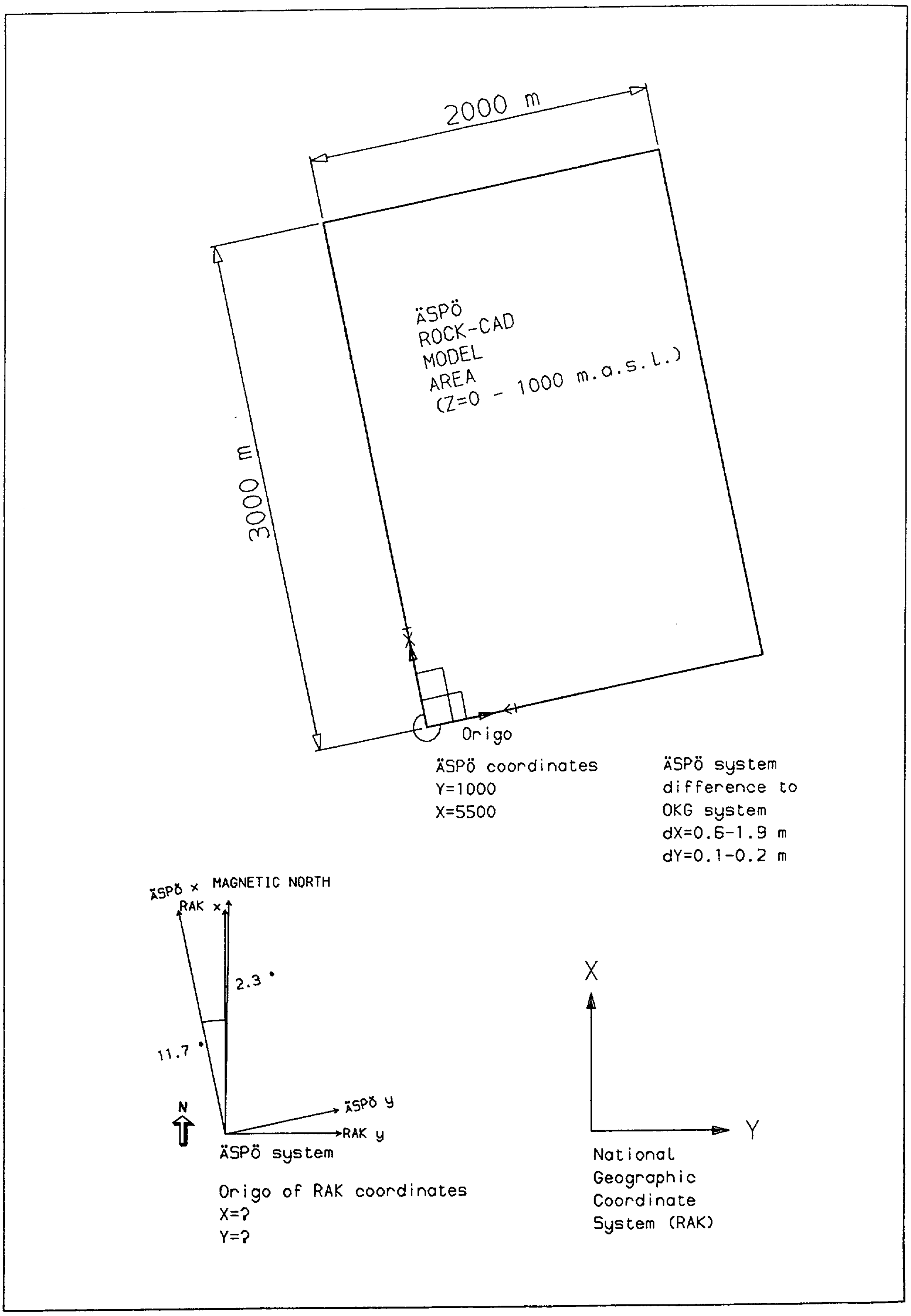


Figure 3-2. Coordinate systems in the vicinity of the Oskarshamn nuclear facilities.

Modelled rock volume and local origin

Internal ROCK-CAD local origin of the modelled volume is at Äspö coordinate system point: X = 5500 m, Y = 1000 m and Z = 0 m. Origin is at lower, southwest corner of modelled rock volume. This setting is invisible to the user in practice and can not been seen from produced plots and prints.

Modelled rock volume is defined by rectangle dimensions: X = 3000 m, Y = 2000 m and Z = 1000 m. This is the bounded total volume of the solid model assembly and presented in Figure 3-2. All rock objects are clipped against this area and volume if they cross the boundaries. If the rock model has to be extended later areally or by volume, ROCK-CAD local origin and dimensions have to be changed. However, all the modelled objects are re-usable in a normal manner.

Model structure

The model structure is hierarchical and consists of several assemblies and subassemblies. It contains logical assemblies of geographical, engineered rock rooms, fracture zones, hydraulic zones and rock units objects. Borehole 3-D assemblies consist of property profiles and measurement data profiles. The assemblies are documented into the following table sheets 3-3 - 3-6.

Numeric input means a GDL file. Certainty degree coding is 0 = certain, 1 = probable and 2 = possible. The dip values are in gons, 100^g equals vertical and 0^g horizontal dip. Dip values greater than 100^g refer to southward dipping objects when viewed from the west.

Table 3-3. Lists of geographical and engineered rock room objects.

Assembly name:**GEOGRAPH**			
Object name	Description	Input to model	Shader colour
.ASPO	ÄSPÖ ISLAND	Graphic	Dark grey
.INSPAREA	INSPECTION AREA	Graphic	Grey
.ISLEREF	ISLAND "SHADOW"	Graphic	Grey
.HALO	HÅLÖ ISLAND	Graphic	Dark grey
.ISLANDS	OTHER NEAR-BY ISLANDS	Graphic	Dark grey

Assembly name:**ROCK ROOMS**			
Object name	Description	Input to model	Shader colour
.SPIRAL	SPIRAL SECTION	Graphic	Red
.SHAFT	LIFT SHAFT	Graphic	Red
.SHAFTEXT	SHAFT CONNECTION	Graphic	Red
.TUNNEL	ACCESS TUNNEL	Graphic	Red

Table 3-4. Lists of fracture and hydraulic zone objects.

Assembly name: **FRAC ZONES**

Object name	Description	Input to model	"Certainty degree"	Character	Dip in gons	Depth (z) range	Shader colour
.EW-1	Zone EW-1	Numeric	0	Major	89	0, -1000	Brown
.EW-3	Zone EW-3	Numeric	0	Major	105	0, -600	Brown
.EW-5	Zone EW-5	Numeric	2	Major	28	0, -500	Brown
.EW-7	Zone EW-7	Numeric	1	Major	128	0, -500	Brown
.EW-S1	Zone EW-S1	Numeric	2	Minor	119	0, -150	Green
.EW-S2	Zone EW-S2	Numeric	0	Minor	100	0, -200	Green
.EW-S3	Zone EW-S3	Numeric	0	Major	100	0, -500	Brown
.NE-1A	Zone NE-1A	Numeric	0	Major	80	0, -1000	Brown
.NE-1B	Zone NE-1B	Numeric	0	Major	76	0, -1000	Brown
.NE-2	Zone NE-2	Numeric	0	Major	86	0, -1000	Brown
.NE-3	Zone NE-3	Numeric	0	Major	78	0, -1000	Brown
.NE-4	Zone NE-4	Numeric	0	Major	128	0, -400	Brown
.NE-4B	Zone NE-4B	Numeric	0	Major	128	0, -1000	Brown
.NNW-1	Zone NNW-1	Numeric	2	Minor	100	0, -300	Green
.NNW-2	Zone NNW-2	Numeric	1	Minor	100	0, -600	Green
.ZONE L	Zone L (BERGAB)	Numeric	1	Minor	89	0, -300	Green
.ZONE J	Zone J (BERGAB)	Numeric	2	Minor	33	0, -300	Green

Assembly name: **HYDR ZONES**

Object name	Description	Input to model	"Certainty degree"	Character	Dip in gons	Depth (z) range	Shader colour
.NNW-1W	Hydraulic zone NNW-1W	Numeric	0	Minor	100	0, -400	Blue
.NNW-2W	Hydraulic zone NNW-2W	Numeric	0	Minor	100	0, -500	Blue
.NNW-3W	Hydraulic zone NNW-3W	Numeric	0	Minor	90	0, -200	Blue
.NNW-5W	Hydraulic zone NNW-5W	Numeric	0	Minor	100	0, -1000	Blue
.NW-1	Hydraulic zone NW-1	Numeric	0	Minor	167	0, -900	Blue
.EW-1W	Hydraulic zone EW-1	Numeric	0	Major	67	0, -500	Blue
.EW-5W	Hydraulic zone EW-5	Numeric	2	Minor	41	0, -500	Blue

Table 3-5. List of (lithological) rock unit objects.

Assembly name: **ROCK UNITS**							
Object name	Description	Input to model	"Certainty degree"	Character	Dip in gons	Depth (z) range	Shader colour
.GREENSTONE	Greenstone	Graphic	0	Lithological	100	0, -50	Green
.MYLONITE	Mylonite	Graphic	0	Lithological	100	0, -50	Grey
.FG-GRANITE	Fine-grained granite	Graphic	0	Lithological	100	0, -50	Violet
.METAVOL	Metavolcanite	Graphic	0	Lithological	100	0, -50	Yellow
.MG-GRANITE	Medium-grained granite	Graphic	0	Lithological	100	0, -50	Red
.FG-ZONE K	Zone K assoc. granite	Numeric	0	Lithological	33	0, -300	Violet
.ASPO	Granite,granodiorite	Graphic	0	Lithological	100	0,-10	Dark grey

Table 3-6. Lists of borehole submodels and borehole measurement objects.

BOREHOLE MODELS			
(Sub)model name	Description	Input to model	Shader colour(s)
m.kas02.rak	Structures in KAS02	Numeric	Table 3-7
m.kas05.rak	Structures in KAS05	Numeric	Table 3-7
m.kas16.rak	Structures in KAS16	Numeric	Table 3-7
m.kbh02.rak	Structures in KBH02	Numeric	Table 3-7
m.kas02.hyd	RQD bar in KAS02	Numeric	Table 3-8

BOREHOLE MEASUREMENT MODELS			
Object(model) name	Description	Input to model	Shader colour(s)
m.kas02.rqd	RQD profile as surface	Numeric	Green&Blue
	model		
...			

Fixed fill patterns, boundary line types and colours have been selected for graphical representation of objects according to previously conducted classification of fracture and hydraulic zones (Wikberg et al. 1991). They differentiate between structural zone types (fracture/hydraulic zone etc.), character (major/minor etc.) and certainty (or significance) degree (certain, probable, possible). This setting is also realized in such a way that the similarity exists between vector graphics and raster graphics output modes. Settings are shown in Table 3-7.

Table 3-7. Vector patterns and colour settings of Äspö model.

TYPE	**CERTAINTY DEGREE**	**VECTOR FILL PATTERN & COLOUR**	**RASTER GRAPHICS COLOUR**
MAJOR FRACTURE ZONE	Certain	Brown line fill, solid boundary line	Brown
- " -	Probable	Only brown line fill	Brown
- " -	Possible	No line fill, dashed brown boundary line	Brown
MINOR FRACTURE ZONE	Certain	Green line fill, solid boundary line	Green
- " -	Probable	Only green line fill	Green
- " -	Possible	No line fill, dashed green boundary line	Green
MINOR HYDRAULIC ZONE	Certain	Blue line fill, solid boundary line	Blue
- " -	Probable	Only blue line fill	Blue
- " -	Possible	No line fill, dashed blue boundary line	Blue

Interpreted fracture and hydraulic zone intersections in the boreholes are presented with the same vector fill patterns and colours as above in Table 3-7. Every borehole section has the same coding as the 3-D model object it represents. Hence, the comparison between any rock structure and its borehole intersection location is straightforward. If two or more major/ minor or fracture/hydraulic type of structures intersect the borehole within the same interpreted depth interval, the applied fill and colour pattern is a mixture.

Classified fracturing intensity (RQD) bar profiles (in chapter 3.2.4) for the boreholes have vector and colour fill patterns shown in Table 3-8.

Table 3-8. Vector patterns and colour settings in Äspö model.

RQD-class	**Type of fracturing: fill & colour**
Class 1	Rock matrix: No fill pattern or white colour
Class 2	Fractured sections: Black line fill pattern or green colour
Class 3	Highly fractured sections: Black dense line fill pattern or black colour

4. RESULTS

The results of the conducted work is best understood and evaluated with produced plots of the model. This report contains the basic set of figures which present the 3-D modelling information collected. There is a set of general maps and cross-sections covering whole model or local excerpt of it. Borehole related local model cuts allow closer and more detailed comparisons to be made.

The graphics is either vector or raster type in form. Vector graphics is a combination of picture elements like lines, polygons, texts etc.. Raster graphics is a picture of calculated pixel values (bit maps). These two different output forms are separated in the following picture list.

4.1. LIST OF THE PLOTS

Vector graphics plots:

4-1. Legend for vector graphics pictures 4-2 - 4-13.

4-2. Structural model surface map presenting the whole modelled surface area (originally in scale 1:10000, reduced here).

4-3. Excerpt of structural model surface map presenting local view into modelled area. Planned rock rooms are projected onto map as outline.

4-4. Structural model vertical cross-section along line A-A' at X = 7250, in scale 1:10000. Boreholes KAS02 and KAS05 are projected onto the cross-section.

4-5. Structural model vertical cross-section along line B-B′ (borehole KBH02), in scale 1:10000. Boreholes KBH02 and KAS05 projected onto the cross-section.

4-6. A set of horizontal section slices. Sectioning at levels 0 m, -500 m and -1000 m. View direction from the south, angle 15° from horizontal.

4-7. Perspective view of the structural model with a vertical cut along the line C-C′. Boreholes KAS02, KAS04 and KAS16 are projected to the cross-section plane. Structure intersection bars are shown for each borehole. Thin borehole outline for KAS02 means that it is projected from further distance (> 20 m). Borehole diameter (bar width) is exaggerated to 30 m in the world coordinate scale.

4-8. General perspective view of the structural model assembly.

4-9. General perspective view of the assembly of the planned rock room objects. View direction is from the southwest.

4-10. Vertical, local cross-section along the borehole KBH02 in scale 1:4000. Bars in KBH02 present identified structure intersections and fracturing intensity variations (RQD based) along the borehole. Colouring and fill patterns are according to Tables 3-7 and 3-8. Displayed borehole diameter is 30 m in natural scale. Borehole bars are aligned to their ends. Arrow indicates the absolute position of the borehole.

4-11. Local cross-section along KAS02 in scale 1:4000. Bars in KAS02 present identified structure intersections and fracturing intensity variations (RQD based) along the borehole. Original RQD mapping profile marked with 50 m tick lines is also presented. Other explanations are the same as in Figure 4-10.

4-12. Local cross-section along KAS05 in scale 1:4000. Bars in KAS05 present identified structure intersections and fracturing intensity variations (RQD based) along the borehole. Display width of the borehole is 15 m for each theme. Currently, RQD data has not been included.

4-13. Local cross-section along KAS16 in scale 1:4000. Bars in KAS16 present identified structure intersections. RQD bar was not determined by now and is left blank in the figure.

Raster graphics (shaded) views:

4-14. Inclined view from southwest into ROCK_UNITS lithological objects assembly. Colouring is set according to Table 3-5. Äspö island outline represents also the occurrence of the dominating medium-grained, greyish red granite (so called Ävrö granite).

4-15. Structural model total assembly (all fracture and hydraulic zones). Colour codings are set according to Table 3-4. View is from the northeast.

4-16. Structural model assembly including all fracture and hydraulic zones identified to "certain"-level. Colour codings are set according to Table 3-4. Planned rock rooms like access tunnel, spiral etc. are taken into model view and they are partly visible.

4-17. Structural model subassembly showing hydraulic zones (NW- and NNW- orienting). View direction is from the north.

4-18. Submodel assembly containing planned rock room objects, Äspö island, major fracture zone NE-1A & NE-1B and borehole profiles KBH02, KAS05 and KAS16. Coloured borehole profiles indicate structure intersections and follow settings in Table 3-7: major zone is brown, hydraulic zone is blue.

4-19. Borehole KAS02 with concentric 3-D bar presentations of structure intersections and fracturing intensity. Outer, larger diameter translucent borehole 3-D bar (pipe) presents structures determined and inner coloured bar classified RQD-sections. Colour coding is according to Tables 3-7 and 3-8. Also, the original RQD-data profile is shown with shaded area 50 m panels (surface model objects). Borehole data is the same as in the figure 4-11 but in the form of raster graphics.

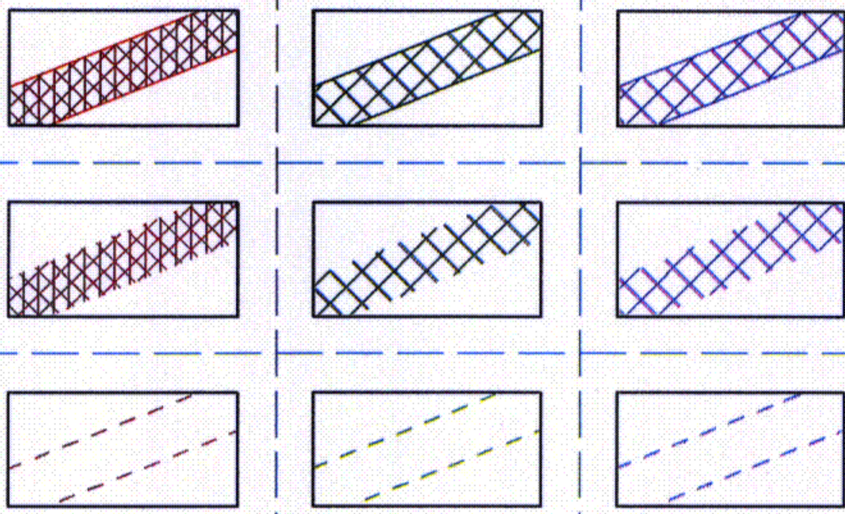
4-20. This is a 500 m block scale presentation of major fracture zones in the southern Äspö island area. Three major zones NE-1, EW-3 and NE-2 are shown. Locations where the planned spiral part of the tunneling intersect the major zones can be seen. Fracture zones are clipped against the 500 m cube boundaries.

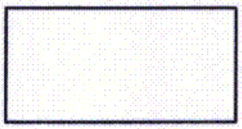
LEGEND /
SELITYKSET

Fig. 4-1

MODEL STRUCTURE FILL PATTERNS /
MALLIKAPPALEIDEN TÄYTÖT

Major fracture zone / Merkittävä rakovyöhyke	Minor fracture zone / Rakovyöhyke	Minor hydraulic zone / Hydraulinen vyöhyke	Certainty / Varmuus-luokka
			Certain / Todettu
			Probable / Todennä-köinen
			Possible / Mahdollinen



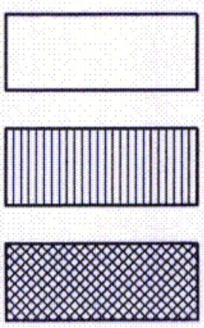


Intact rock /
Ehyt kallio

BOREHOLE PROFILES /
REIKÄPYLVÄÄT

Model structure intersections
shown as for the 3-D model objects /
Leikkauskohdat mallirakenteille
esitetty kuten 3-D kappaleilla

Fracturing intensity
(RQD based) /
Rakoilun voimakkuus
(RQD pohjainen)

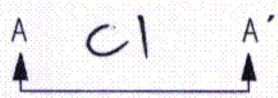


Rock matrix section /
Vähärakoinen kalliojakso

Fractured section /
Rakoillut kalliojakso

Highly fractured section /
Voimakk. rakoillut kalliojakso

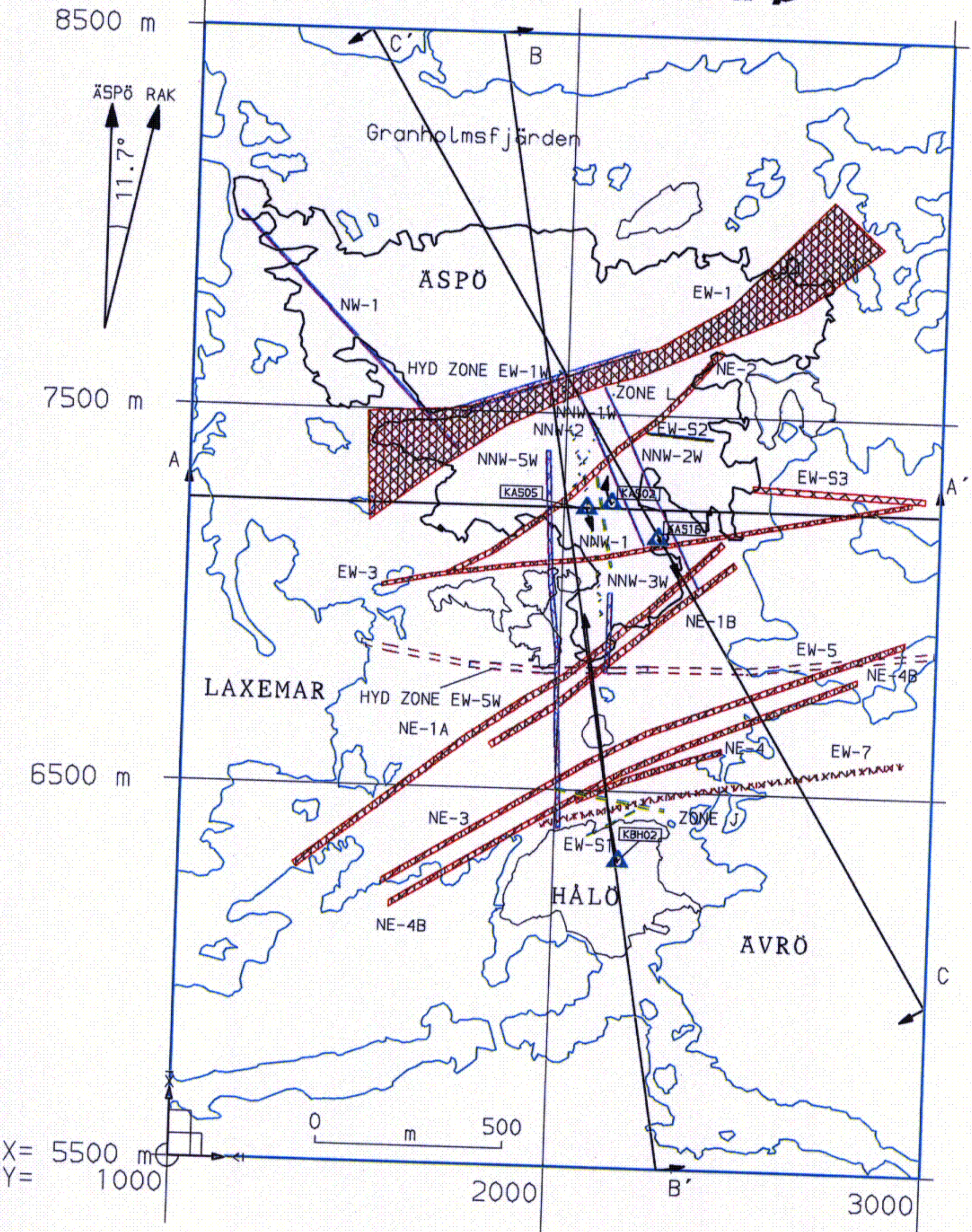
Borehole /
Kairanreikä



Sectioning line /
Leikkauslinja

Äspö, structural model.

Surface map

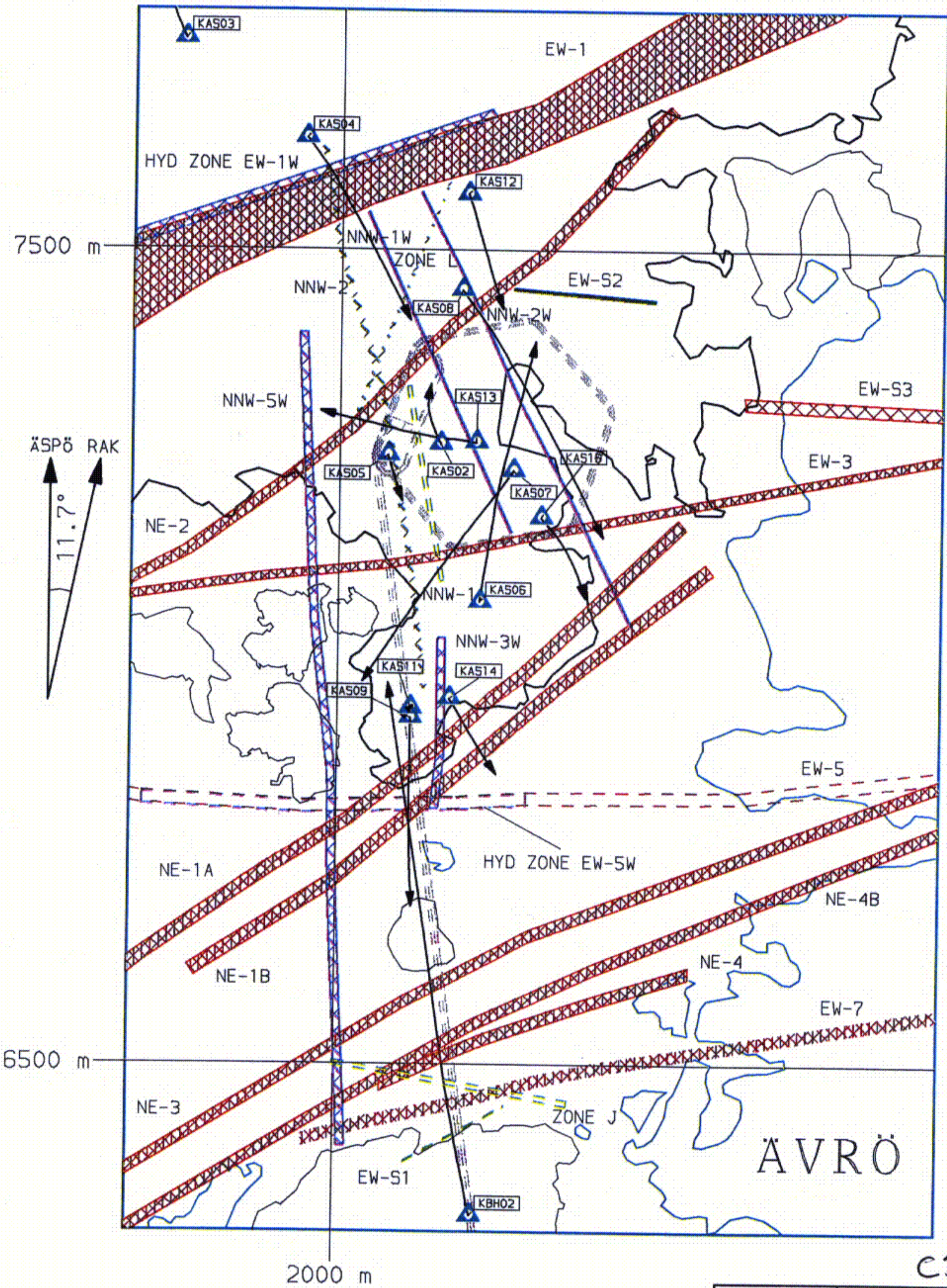


C2

FINTACT Hopeatie 1 B SF-00440 HELSINKI TEL +358 0 503 2172 FAX +358 0 503 2175	ÄSPÖ RC - MODEL
	Fig. 4-2, Surface map
JL1 10.5.93 / PSA 10.5.93 / A3	surfmap-1 A SHEET 1 OF 1

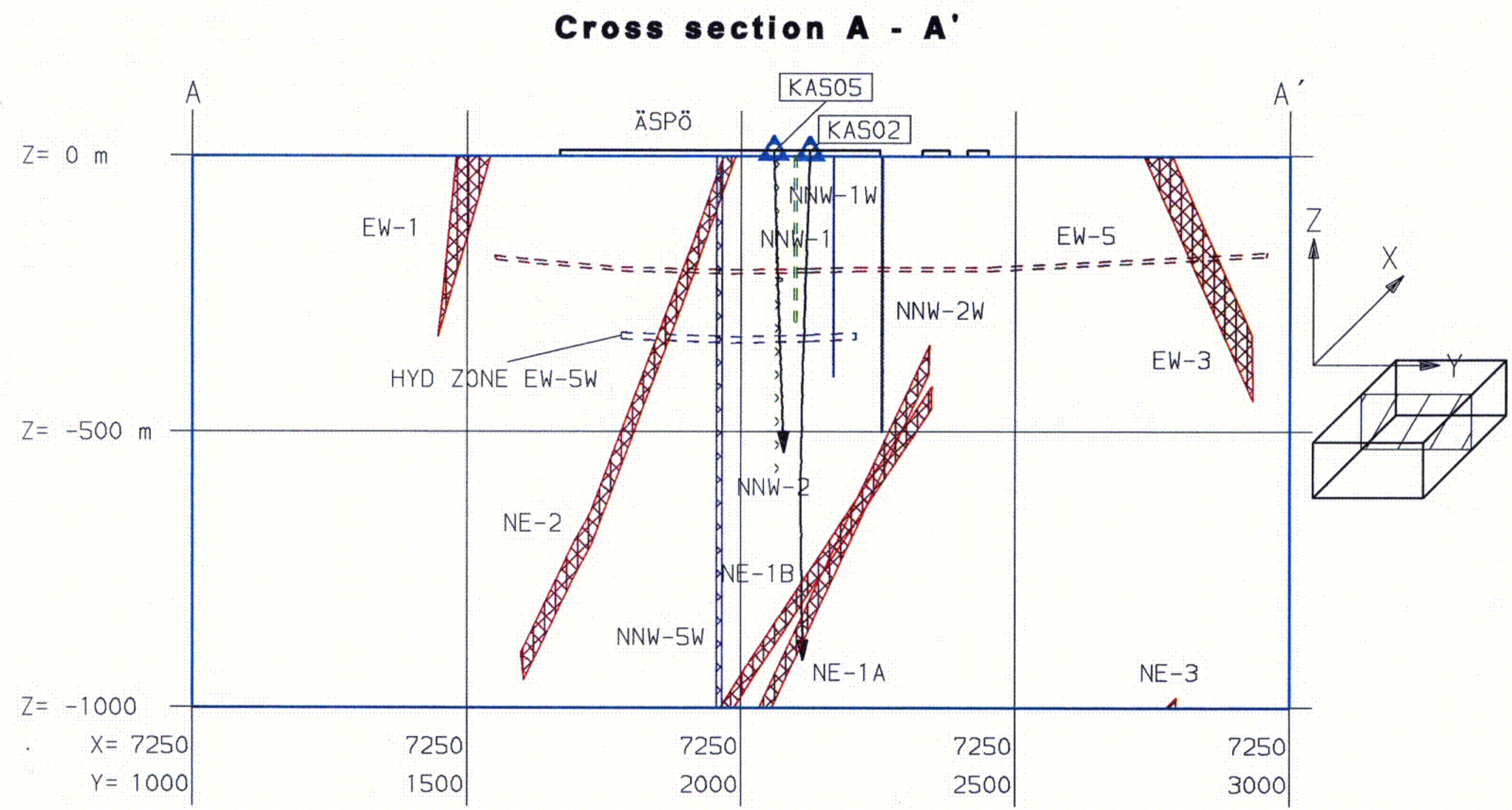
Äspö, structural model.

Local surface map



C3

FINTACT Hopeatie 1 B SF-00440 HELSINKI TEL +358 0 503 2172 FAX +358 0 503 2175	ÄSPÖ RC - MODEL		
	Fig. 4-3, Äspö Local map		
Drawn by JLJ 11.5.93	A3	Localmap	A
Checked by PSA 11.5.93	-	SHEET 1 OF 1	



C4

FINTACT Hopeatie 1 B SF-00440 HELSINKI TEL +358 0 503 2172 FAX +358 0 503 2175	HEADER: ÄSPÖ RC - MODEL		
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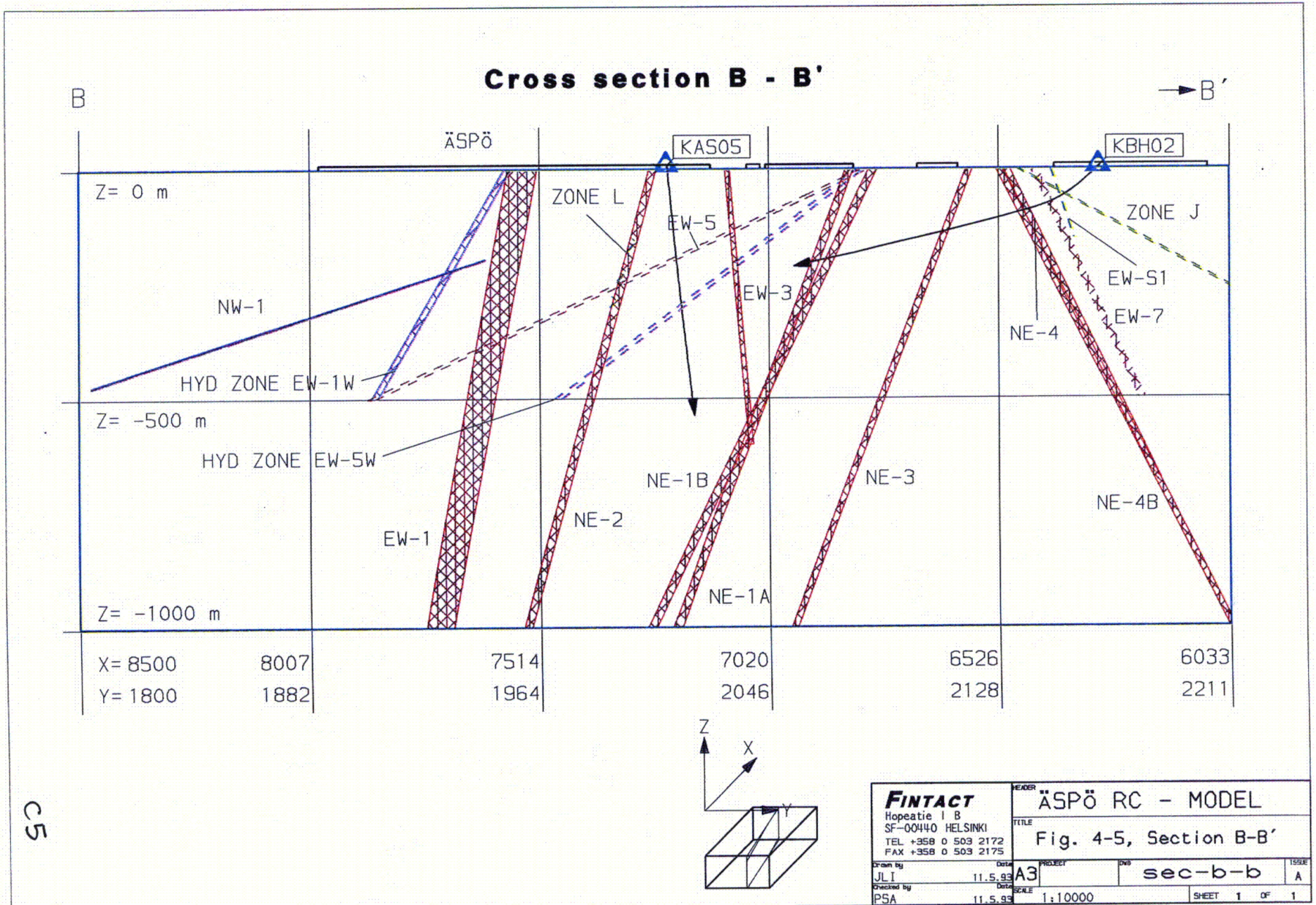
Checked by: PSA, Date: 11.5.93	SCALE: 1:10000		SHEET 1 OF 1


Cross section B - B'
B
B'
ÄSPÖ
KAS05
KBH02
Z= 0 m
Z= -500 m
Z= -1000 m
ZONE L
EW-5
ZONE J
EW-S1
EW-7
EW-3
NE-4
NW-1
HYD ZONE EW-1W
HYD ZONE EW-5W
NE-1B
NE-3
NE-4B
NE-2
EW-1
NE-1A
X= 8500
Y= 1800
8007
1882
7514
1964
7020
2046
6526
2128
6033
2211
Z
X
Y
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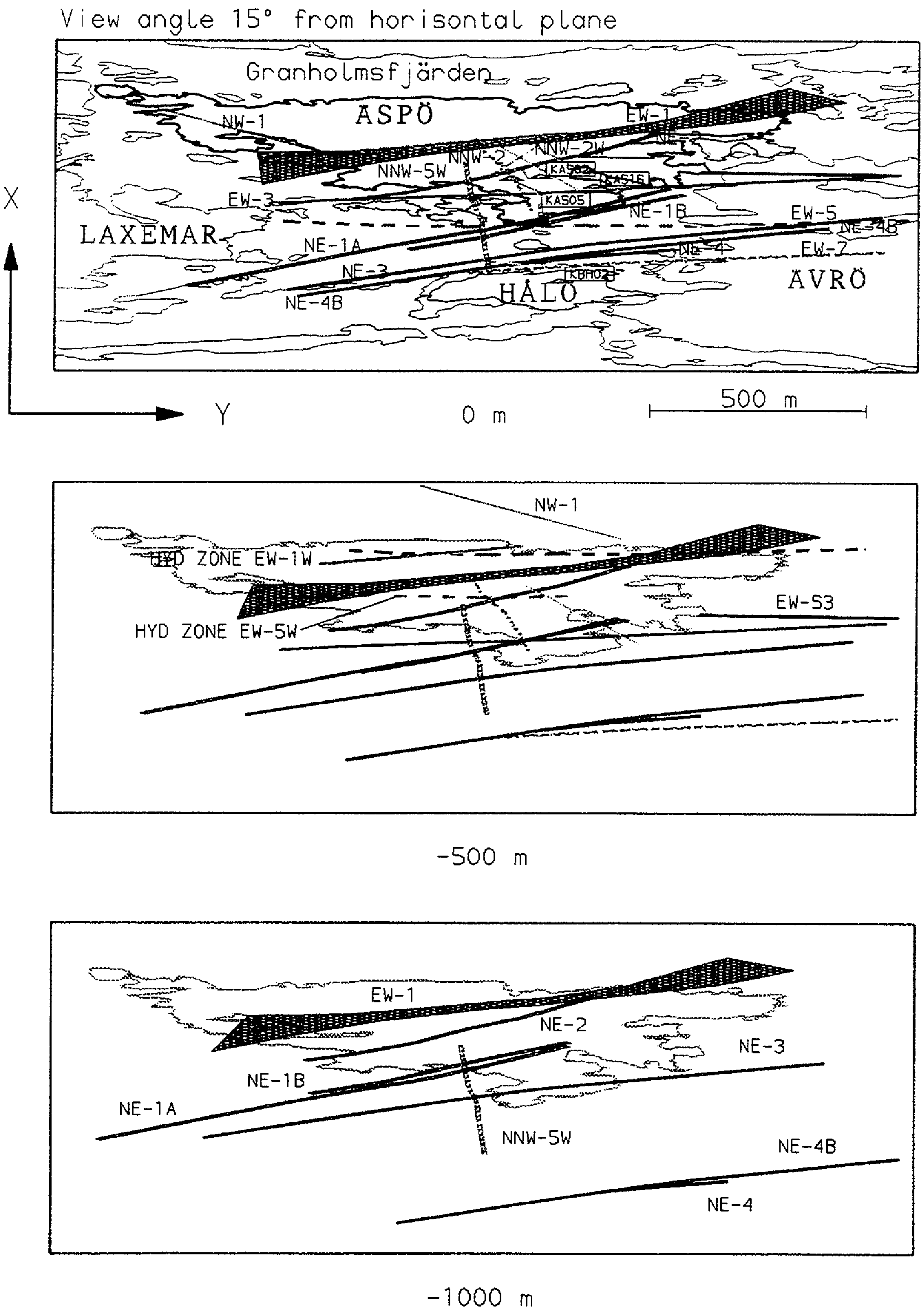
TEL +358 0 503 2172
FAX +358 0 503 2175
Drawn by JLI Date 11.5.93
Checked by PSA Date 11.5.93
ÄSPÖ RC - MODEL
Fig. 4-5, Section B-B'
A3
sec-b-b
ISSUE A
SCALE 1:10000
SHEET 1 OF 1
C5

Set of horizontal sections in perspective



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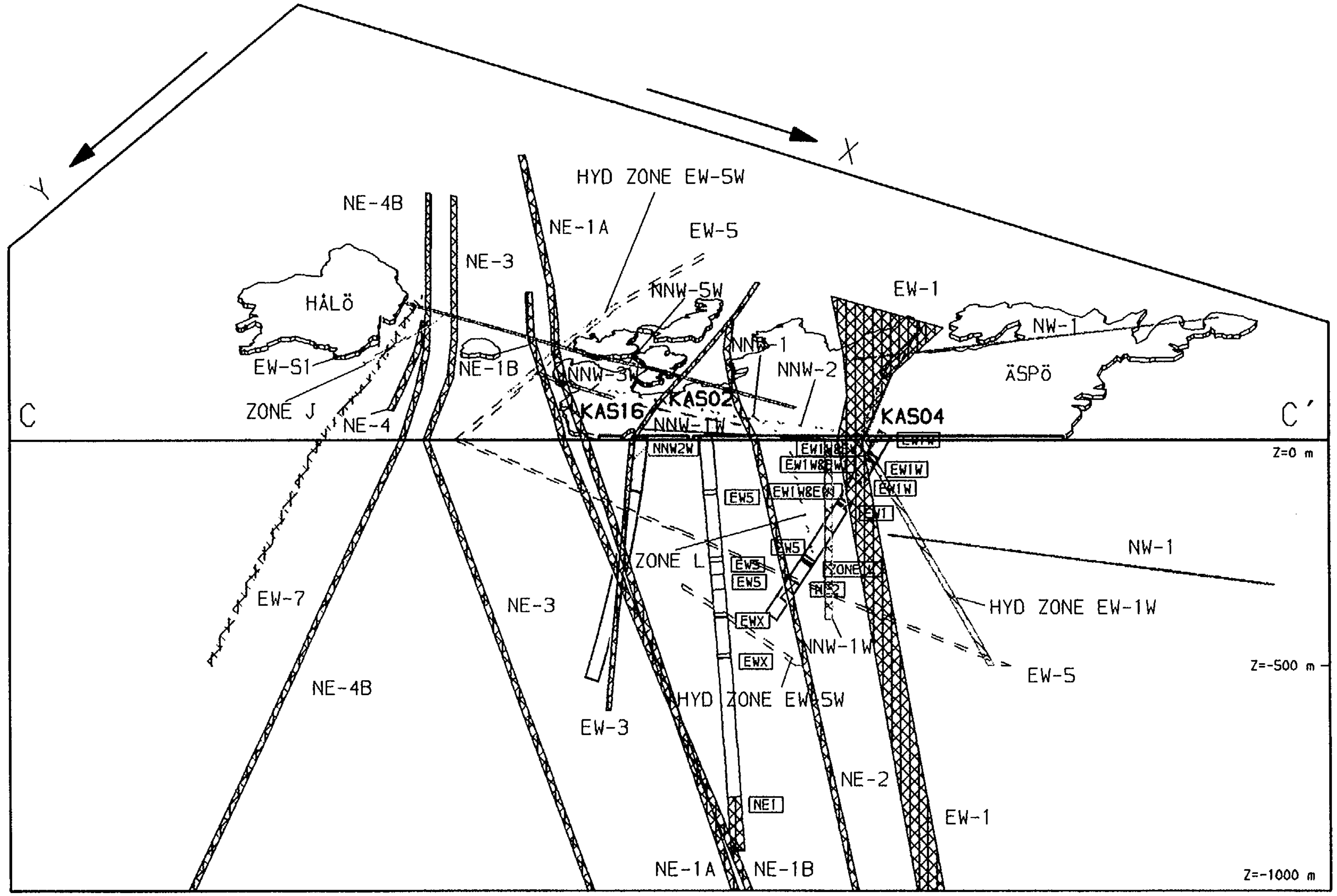
ÄSPÖ RC - MODEL

Fig. 4-6, Section set

JLI	12.5.93	A3	sec-set
PSA	12.5.93	-	SHEET 1 OF 1



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ÄSPÖ RC - MODEL

Fig. 4-7, Perspective view

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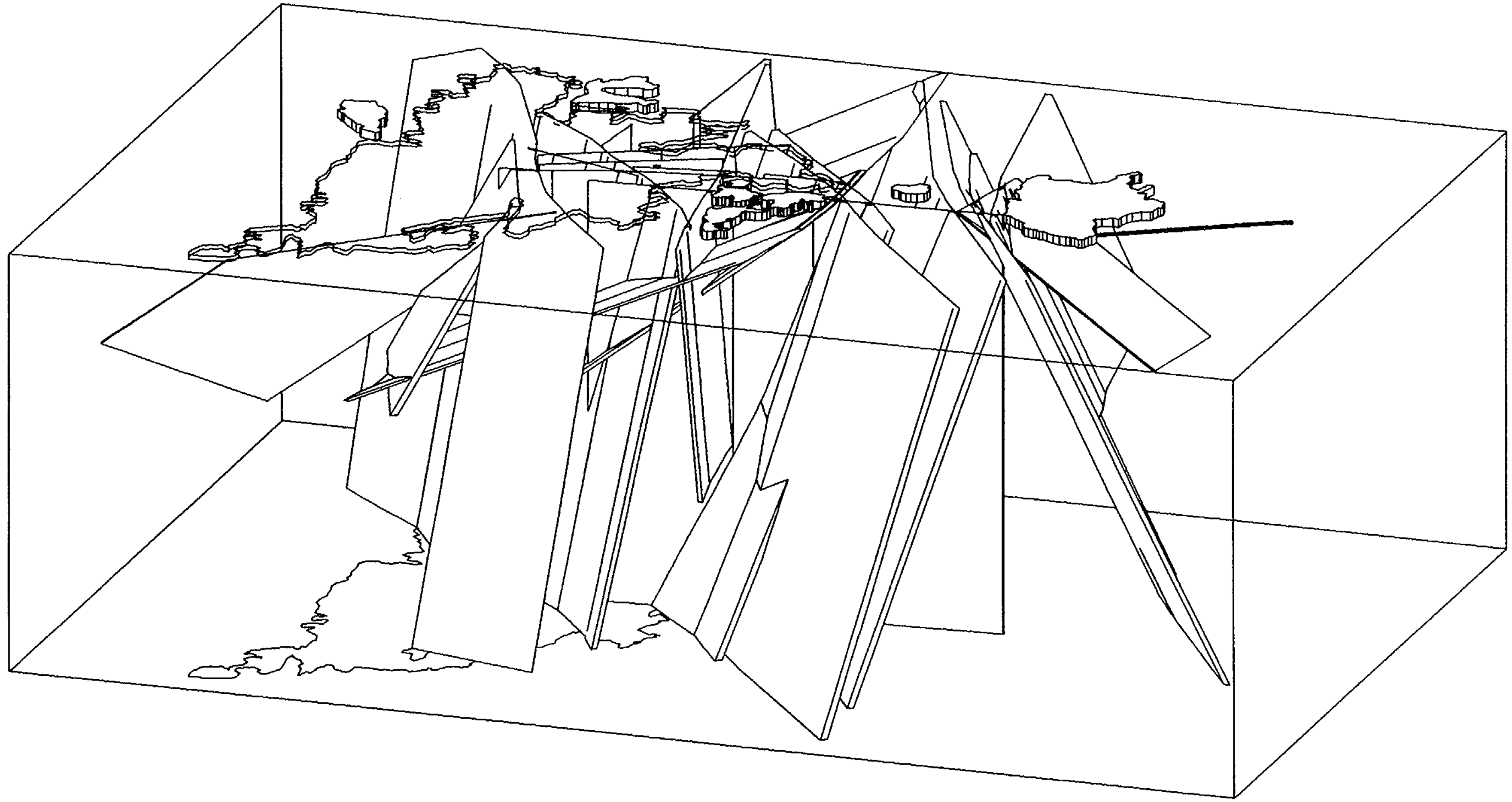
Checked by PSA	12.5.93	-	SHEET 1 OF 1	



FINTACT Hopeatie 1 B SF-00440 HELSINKI TEL +358 0 503 2172 FAX +358 0 503 2175	HEADER ÄSPÖ RC - MODEL	
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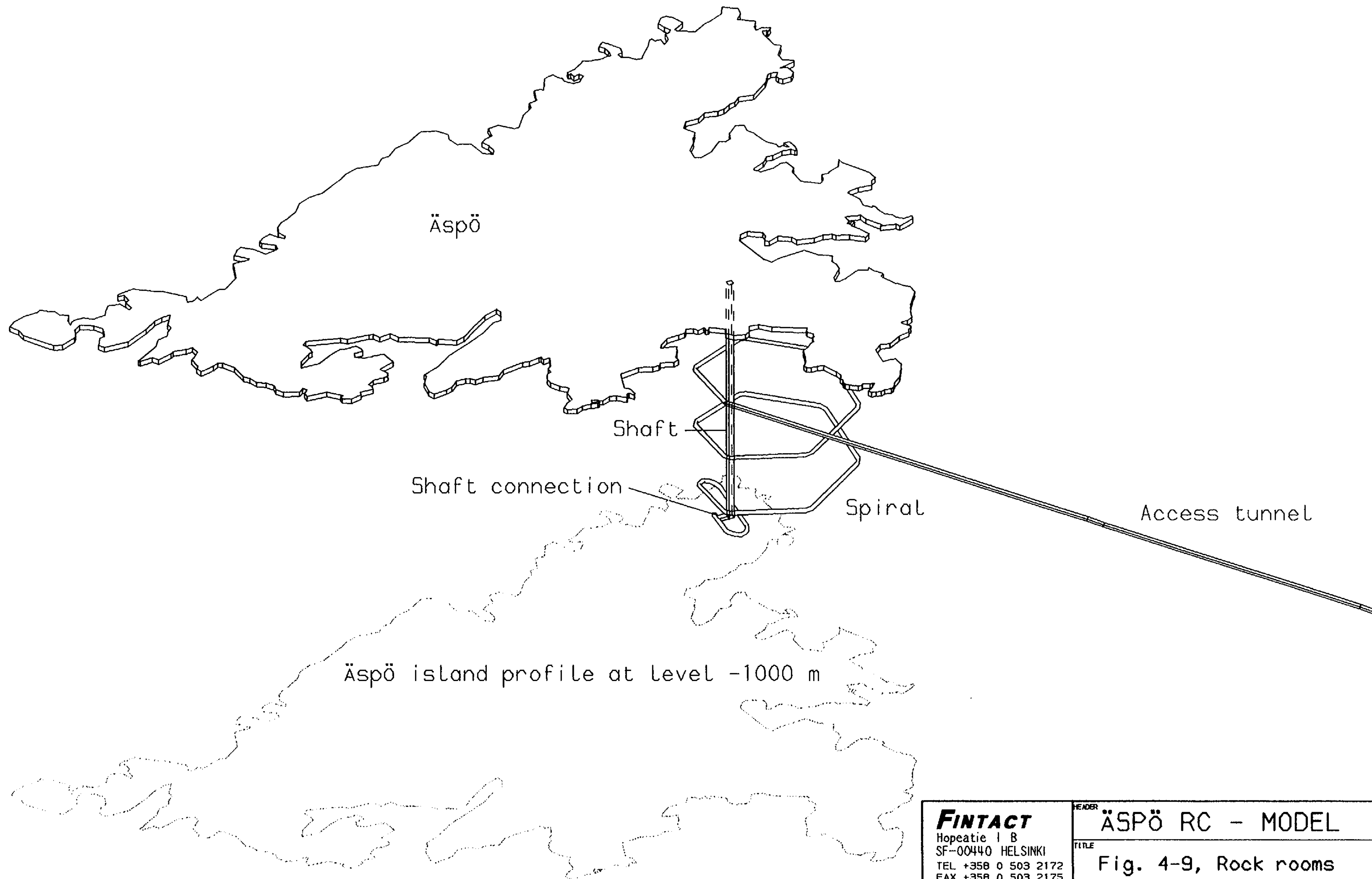

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	TITLE Fig. 4-9, Rock rooms		
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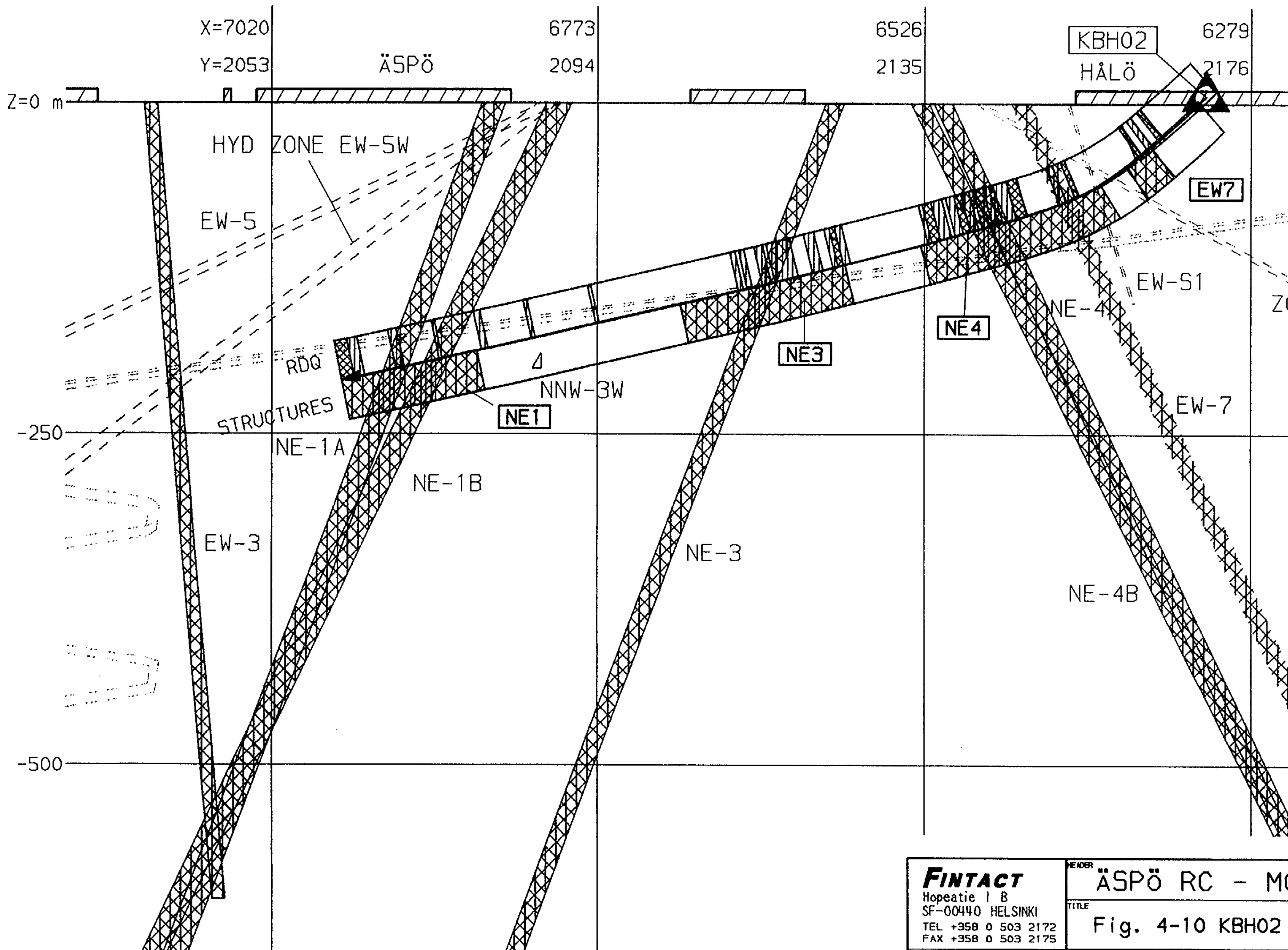

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SF-00440 HELSINKI
TEL +358 0 503 2172
FAX +358 0 503 2175

HEADER	ÄSPÖ RC - MODEL
TITLE	Fig. 4-10 KBH02 section
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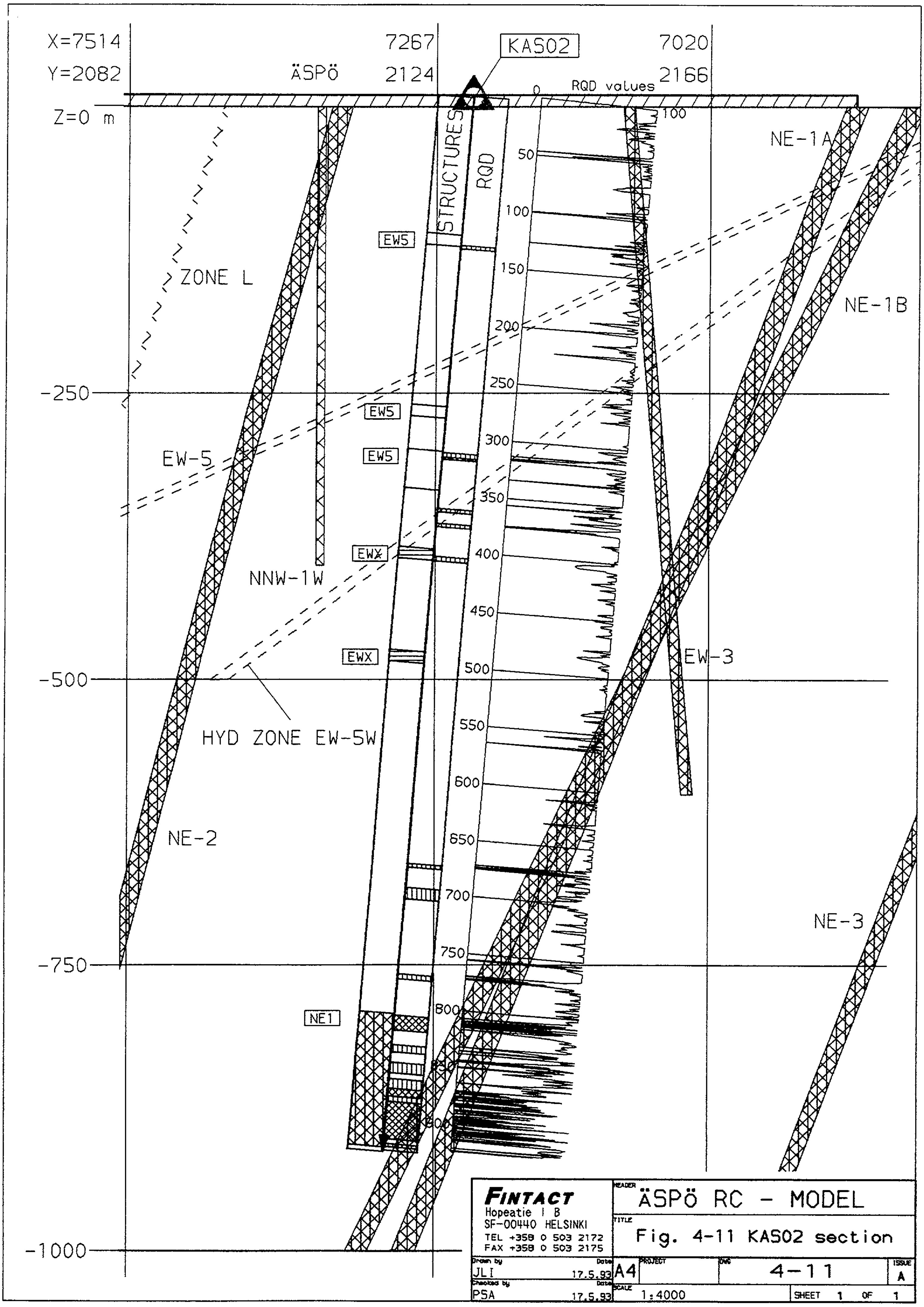
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Y=2082
ÄSPÖ
7267
2124
KAS02
7020
2166
RQD values
Z=0 m
STRUCTURES
RQD
ZONE L
NE-1A
NE-1B
EW5
EW5
EW5
EWX
EWX
NE1
-250
-500
-750
-1000
EW-5
NNW-1W
HYD ZONE EW-5W
NE-2
EW-3
NE-3
0
50
100
150
200
250
300
350
400
450
500
550
600
650
700
750
800
FINTACT
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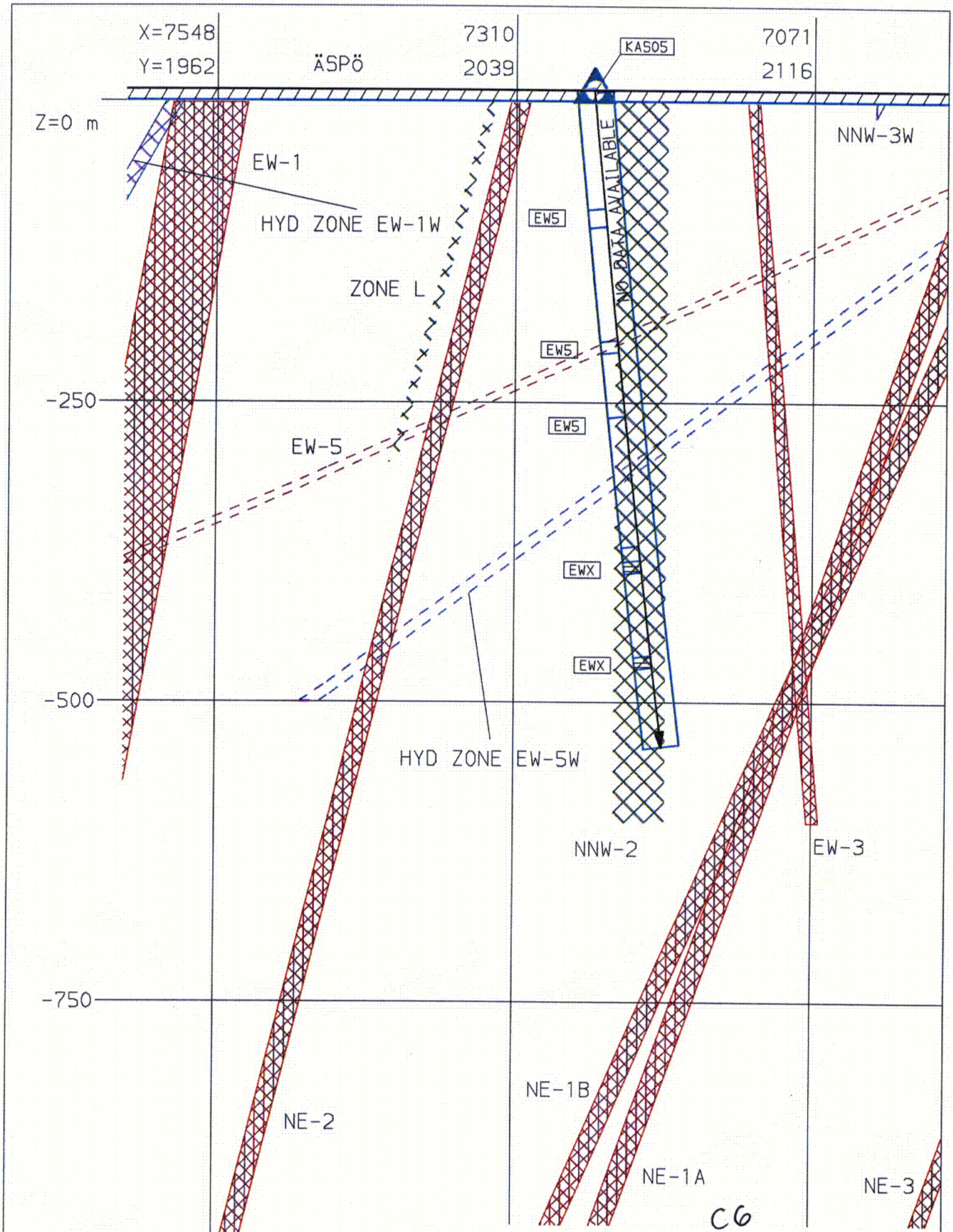
ÄSPÖ RC - MODEL
Fig. 4-11 KAS02 section
Drawn by JLI 17.5.93
Checked by PSA 17.5.93
A4
4-11
ISSUE A
SCALE 1:4000
SHEET 1 OF 1



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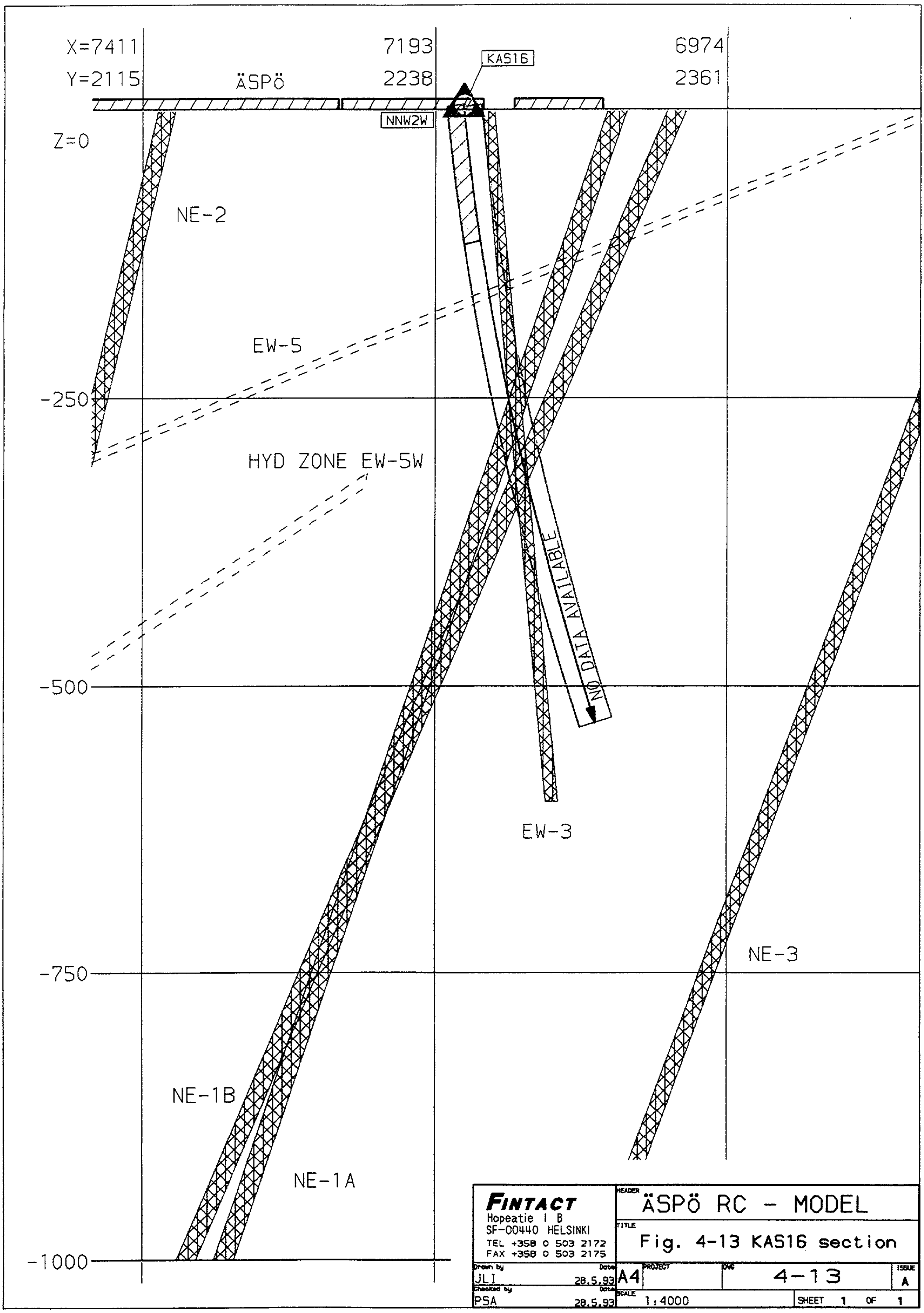
Drawn by JLI Date 28.5.93
Checked by PSA Date 28.5.93

HEADER: ÄSPÖ RC - MODEL

TITLE: Fig. 4-12 KAS05 section

A4 PROJECT DWG 4-12 ISSUE A

SCALE 1:4000 SHEET 1 OF 1



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Y=2115
ÄSPÖ
7193
2238
KAS16
NNW2W
6974
2361
Z=0
NE-2
EW-5
-250
HYD ZONE EW-5W
NO DATA AVAILABLE
-500
EW-3
-750
NE-3
NE-1B
NE-1A
-1000
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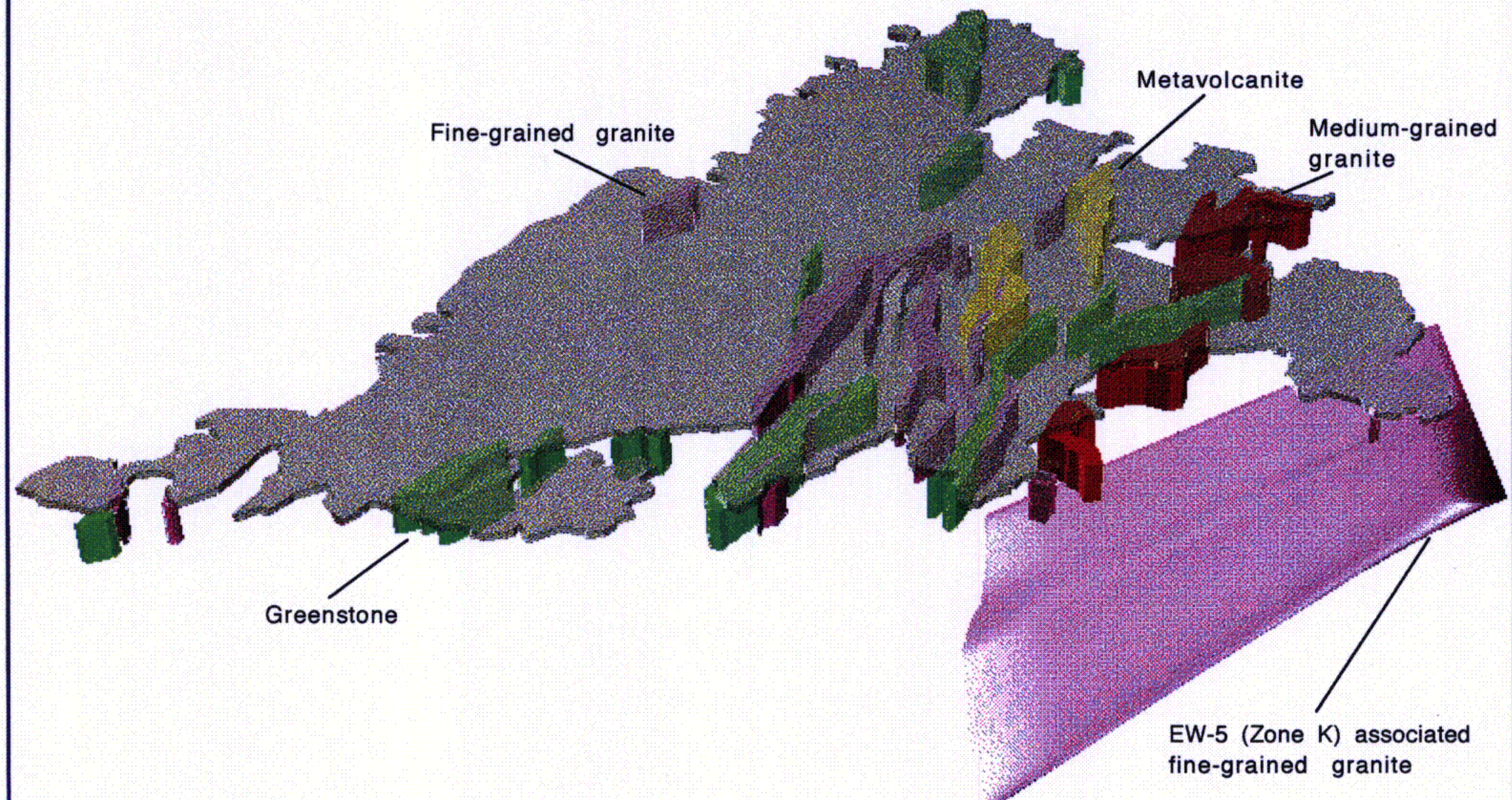
Drawn by JLI Date 28.5.93
Checked by PSA Date 28.5.93
HEADER ÄSPÖ RC - MODEL
TITLE Fig. 4-13 KAS16 section
A4
PROJECT
DWG 4-13
ISSUE A
SCALE 1:4000
SHEET 1 OF 1

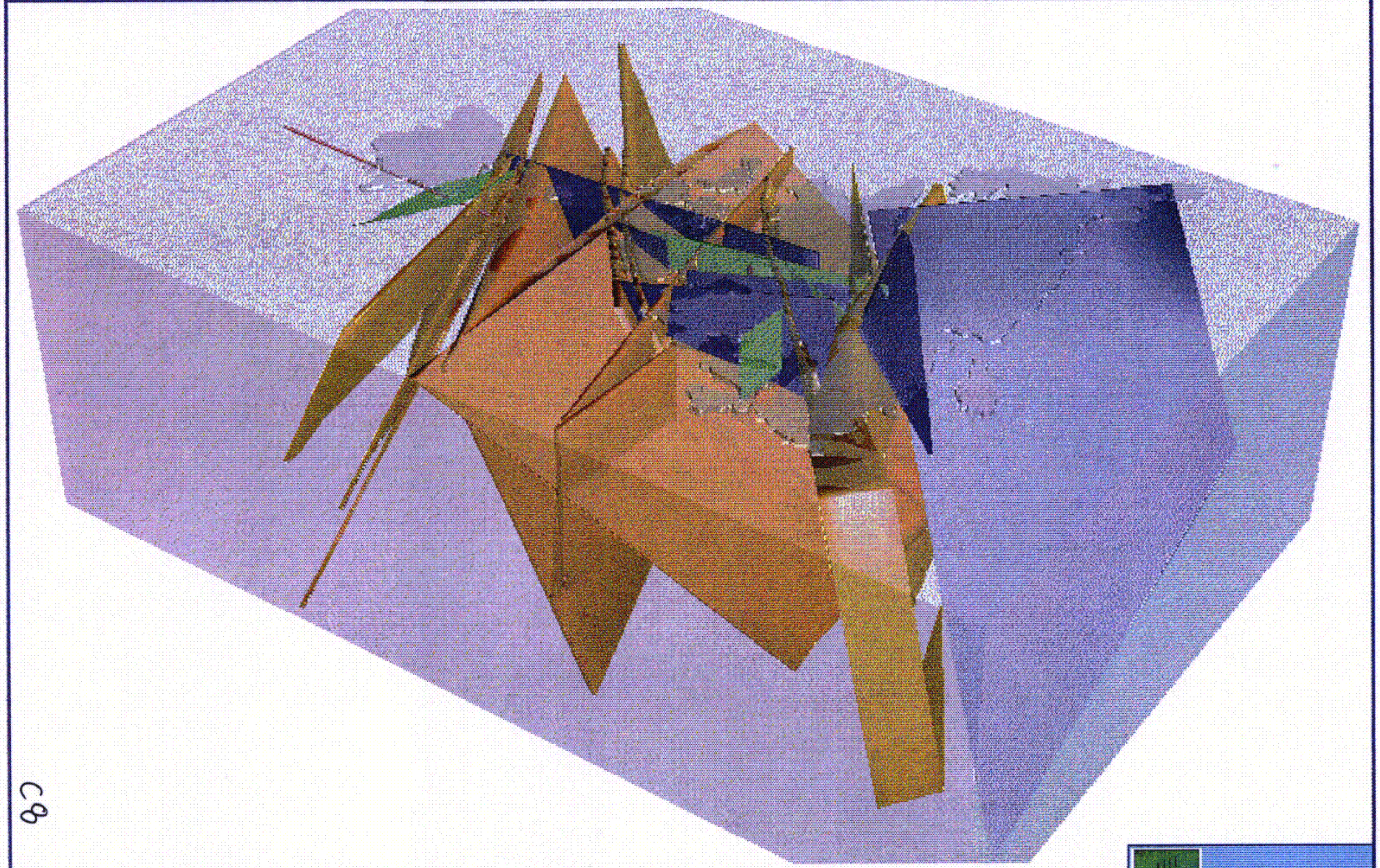
MEDUSA Full Feature Shader	HEADER: ÄSPÖ RC-MODEL	TITLE: Fig. 4-14, Lithology objects



C7

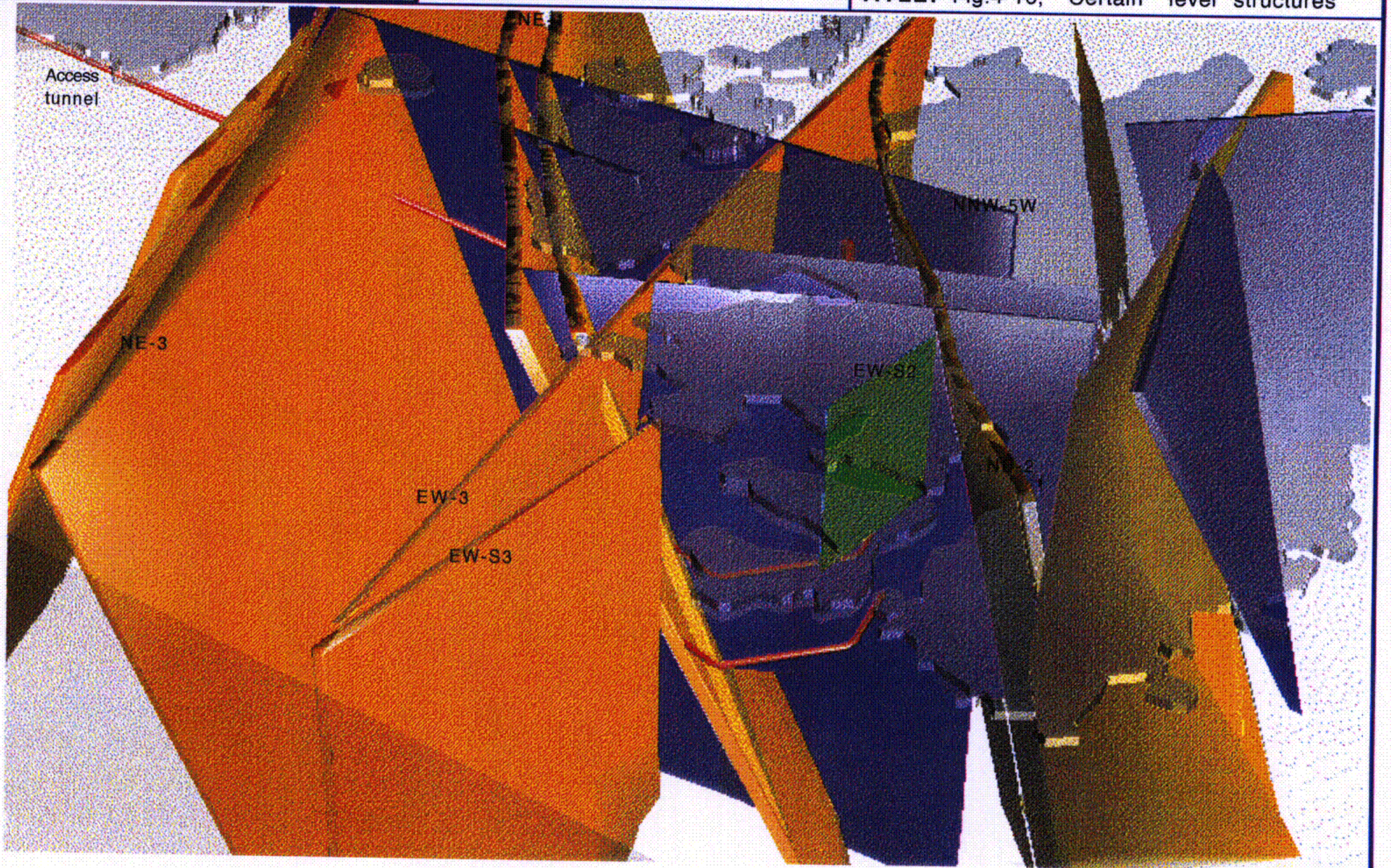
DATE: 27.5.1993	ISSUE: A	DWG: ÄSPÖ rc litho.scdr	A 4	FINTACT

MEDUSA Full Feature Shader	HEADER: ÄSPÖ ROCK-CAD™ MODEL	TITLE: Fig. 4-15, Structural model view



DATE: 27.05.1993	ISSUE: A	DWG: ÄSPÖ rc structures.scrd	A 4	FINTACT

MEDUSA Full Feature Shader	HEADER: ÄSPÖ rc model	TITLE: Fig.4-16, "Certain" level structures



DATE: 27.05.1993	ISSUE: A	DWG: ÄSPÖ rc str_class0.scd	A 4	FINTACT

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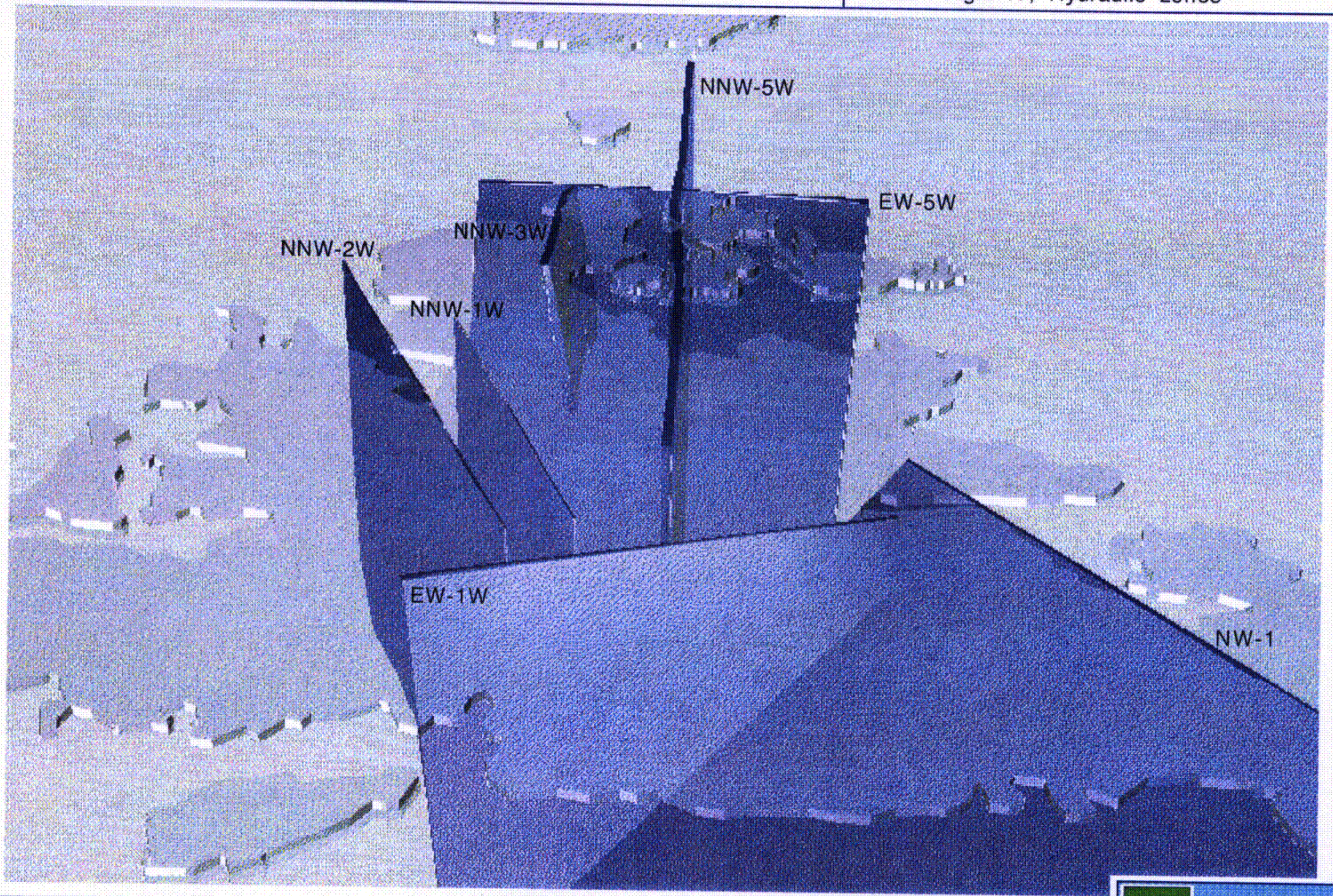

C10

DATE: 28.05.1993	ISSUE: A	DWG: ÄSPÖ rc hyd_zones.scd	A 4	FINTACT

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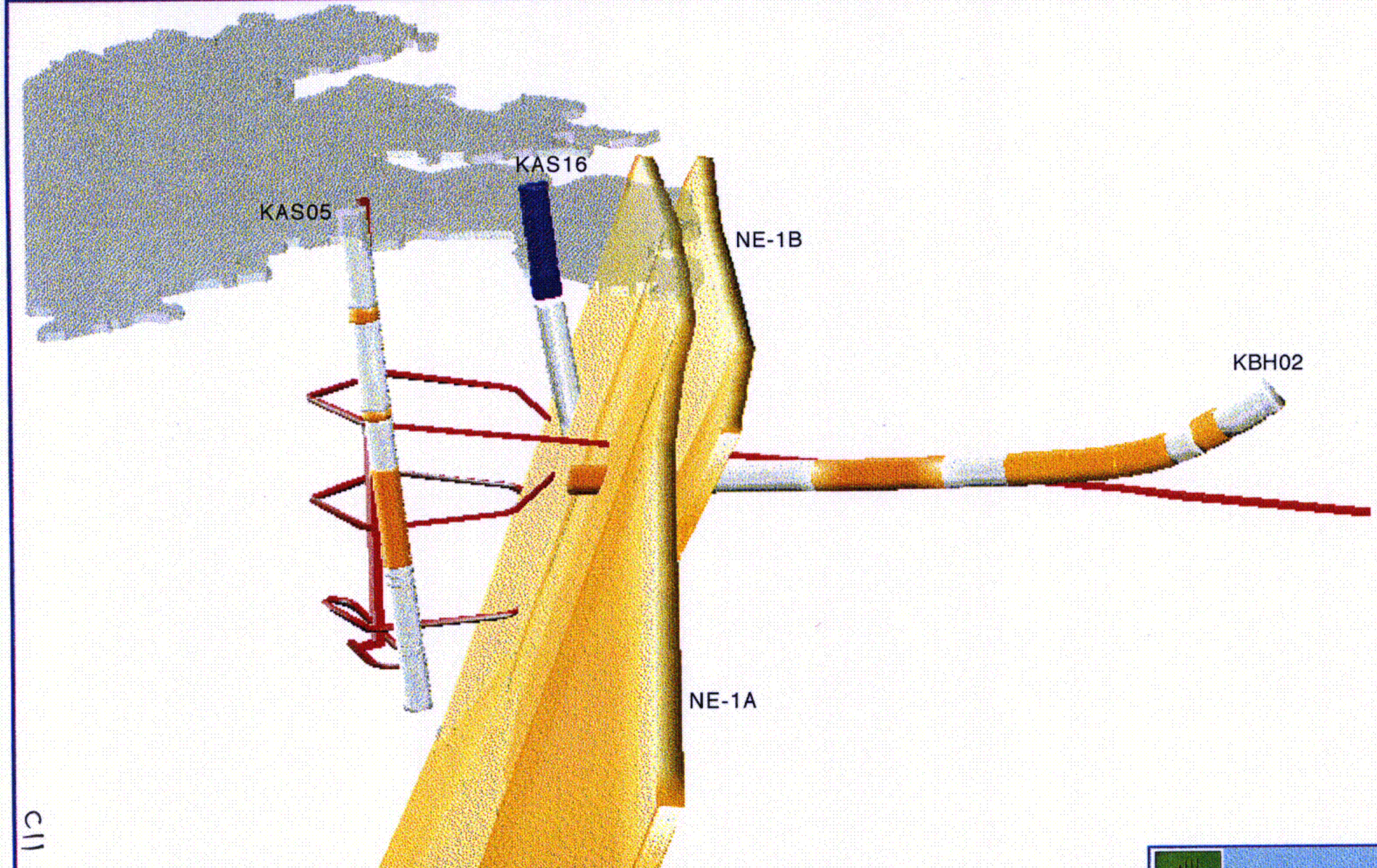
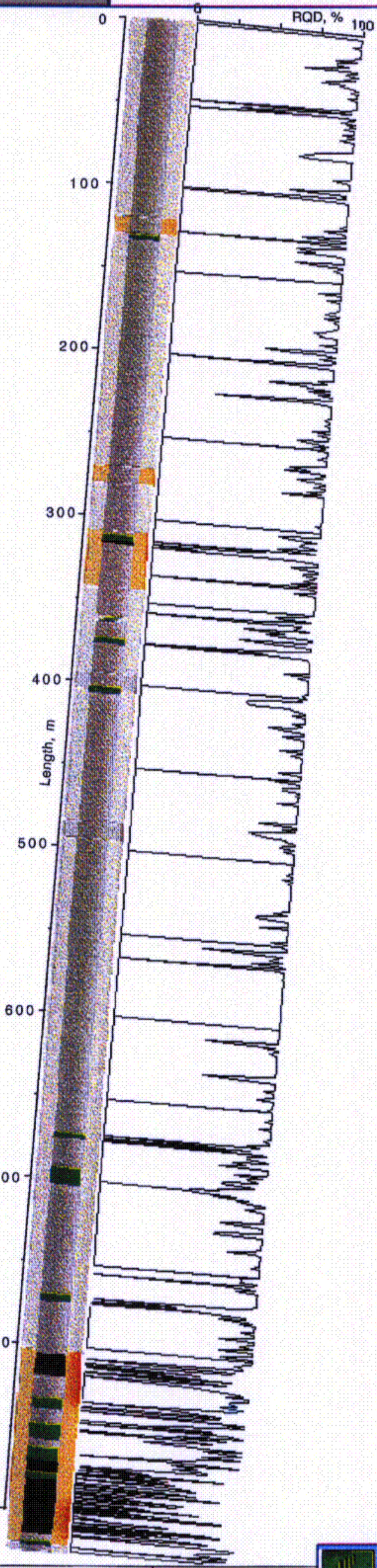


DATE: 02.06.1993	ISSUE: A	DWG: ÄSPÖ rc sub_assembly.scd	A 4	FINTACT

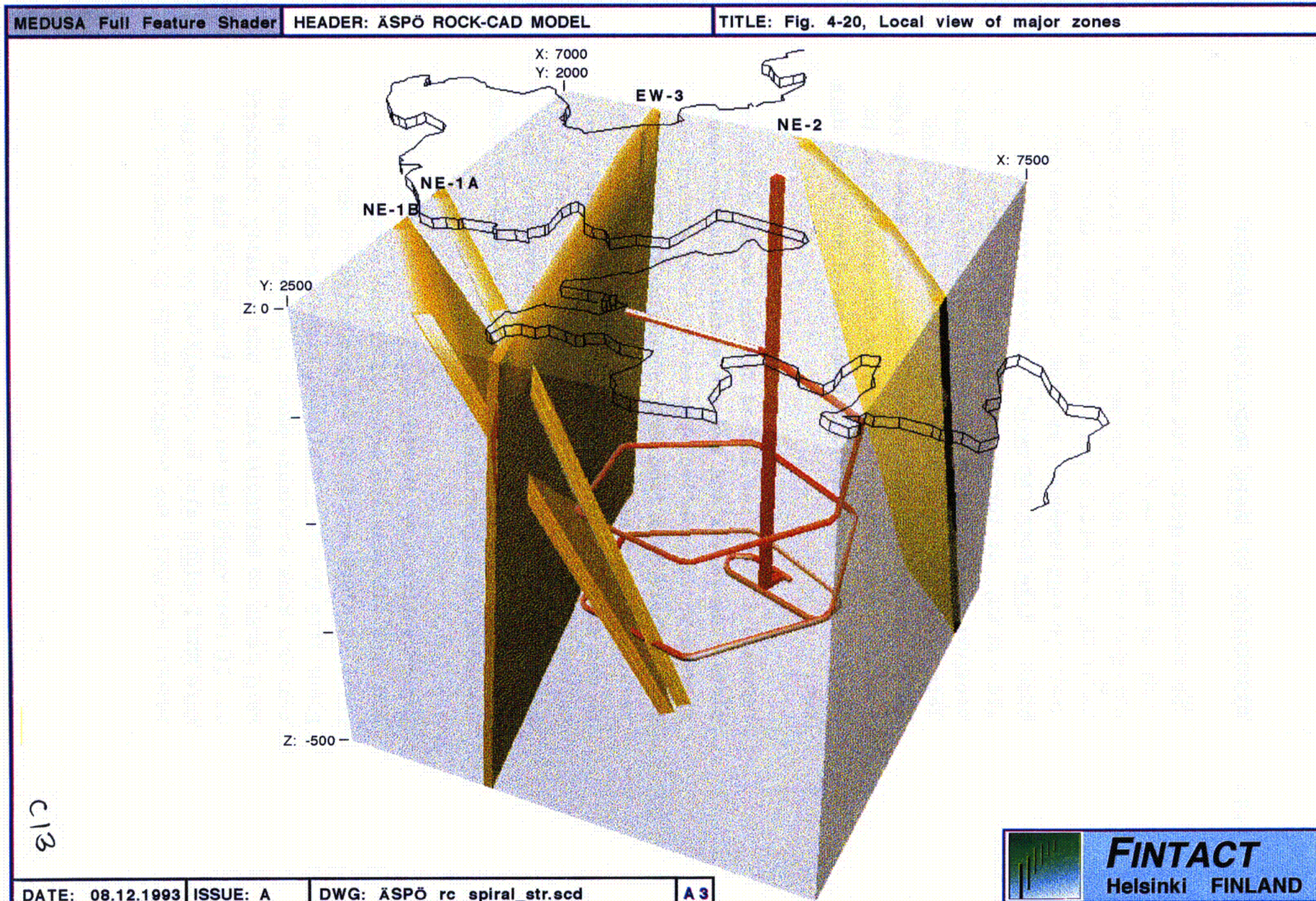
MEDUSA Full Feature Shader

TITLE: Fig. 4-19, KAS02 borehole logs



C12

DATE: 03.121993 | ISSUE: A | A4 | FINTACT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TITLE: Fig. 4-20, Local view of major zones
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Y: 2000
EW-3
NE-2
X: 7500
NE-1A
NE-1B
Y: 2500
Z: 0
Z: -500
C13
FINTACT
Helsinki FINLAND
DATE: 08.12.1993
ISSUE: A
DWG: ÄSPÖ rc spiral_str.scd
A 3

4.2. DISCUSSION OF ÄSPÖ MODELLING RESULTS

The conceptual geological and structural ROCK-CAD model of Äspö site follows and utilizes precisely the interpretations and observations made earlier. Some additional detailing work took account recent findings and supplementary studies. Computerized rock model - like ROCK-CAD model - is very revealing in its own way. It forces the user and the developer to consider parameters which are questionable and easily left open like structural depth extensions, strike length extensions, width variations etc. Expert judgment is needed to derive many of the geometrical parameters from geologically complicated and fuzzy data set.

Figure 4-1 shows the legend for the vector graphics plots. Figure 4-2 and 4-3 are standard surface maps showing whole modelled area and a local excerpt of it. Borehole data from four boreholes KBH02, KAS02, KAS05 and KAS16 has been used in further comparisons. We recognized from Fig. 4-3 that borehole KAS12 is marked with major zone EW-1 intersection (Table 3-2) but is located in conceptual model close to it but outside it. Naturally this implies the basic problem how to bound a fracture zone.

Cross-section A-A' in Fig. 4-4 is in E-W direction and runs via starting point of borehole KAS05. Other parts of KAS05 and KAS02 are projected to section plane from 0 - 90 m distance. Probable-type minor fracture zone structure NNW-2 is almost parallel and very close to borehole KAS05, and actually intersects it. If that could be verified from KAS05 the structure NNW-2 might also be classified as certain-type. Further analysis for borehole KAS05 is presented in connection with a local scale cut shown in Figure 4-12.

East-west striking possible-type zone EW-5 is almost in horizontal position in the plot 4-4. Zone EW-5 is gently (~30°) dipping towards the north. Hydraulic structure EW-5W associated with EW-5 has a interpreted dip of ~37°. Hence, it is located in the plot deeper and diverges from EW-5. Finally, Fig. 4-4 gives an idea that major zone parts NE-1A and NE-1B intersect borehole KAS02. However, this is not the case as will be seen later in local scale plot done along KAS02 (Fig. 4-11). KAS02 is here merely a projection. Northern part of zone NE-1A is interpreted to be more steeply dipping (~72°) than its southern part NE-1B (~67 - 68°) and they intersect each other. Sectioning of Äspö island outline is on the top in the figure.

Vertical cross-section B-B′ is presented in Figure 4-5. It runs close to trace line of borehole KBH02 in horizontal projection. Borehole KAS05 is located in reality some 50 - 60 m behind the sectioning plane. Cross-section cuts in steep angle most of the major NE-SW and ENE-WSW trending zones. Interpreted and differing dip angles for zones EW-1 & EW-1W and for EW-5 & EW-5W are clearly visible. Hydraulic zone NW-1 which outcrops in northwestern Äspö area intersects also the sectioning plane in Fig. 4-5 in the north.

A set of horizontal sections viewed from the south are presented in Figure 4-6. It gives an easily understandable, quick look for the depth extensions interpreted for the fracture and hydraulic zone structures.

Cross-section C-C′ with perspective view is presented in Figure 4-7. This visualizes dips and strikes of the major fracture zones. All the interpreted fracture zones are steeply (> 60°) dipping except EW-5 (and possible-type zone J). Borehole KAS04 intersects major fracture zone EW-1 and hydraulic structure EW-1W. Borehole KAS04 intervals are labelled according to structures interpreted there. Zones L and NE-2 are also met there. Borehole KAS02 depicts several intersection locations for zone EW-5 and meets NE-1 near the borehole end. KAS02 is projected from 35 - 65 m distance onto the cut plane. The sections marked with EWX in KAS02 represent subhorizontal fracturing features. In borehole KAS16 structure NNW-2W is met in its uppermost part. Structure NNW-2W (see Fig. 4-3) is situated actually in front of the section C-C′ plane and thus not present in the plot.

Figure 4-9 illustrates four CAD-objects which represent the planned rock rooms of the site. Laboratory rock room parts as modelled are listed in Table 3-3.

Figures 4-10 - 4-12 are local scale (1:4000) plots along the selected boreholes KBH02, KAS02 and KAS05. They allow better analysis and comparison with borehole data to be made.

In Fig. 4-10 a section along the borehole KBH02 is compiled. Major fracture zones NE-1, NE-3 and NE-4 intersect the borehole where modelled. However, subhorizontal borehole sections are much longer than thicknesses of conceptualized, geometrically defined zones. As an example, fracture zone NE-4 and NE-4B (conceptualized thickness ~10 - 20 m) occupy 150 m long borehole interval between 100 - 250 m in KBH02. Within that interval is also located probable-type structure EW-7. On the other hand, borehole interval 50 - 75 m is reported for the zone EW-7 which does not correlate in geometry with conceptualized zone EW-7. Gently dipping zone J (but possible-type) corresponds closer to EW7 borehole interval. Zone J is reported to be possible by certainty degree and that might be considered again if finding in the borehole is real.

According to the classified RQD data the fractured and highly fractured parts of the borehole correlate with structure locations. Generally, densely fractured intervals form clear grouping. If intervals are combined they seem to form shorter units than determined structure intervals in the borehole. Highly fractured borehole parts are mostly met within zones NE-4 and NE-4B.

In connection with major zone NE-1B and NE-1A relatively thin intervals of fractured rock has been met in the borehole except at the very end where a highly fractured borehole interval has been encountered.

The location of planned access tunnel (outline shown in the background in Fig. 4-10) is some tens of meters behind the borehole KBH02. Hydraulic structure NNW-3W oriented in N-S direction (if exists as modelled) could have been met in the borehole at distance 550 - 560 m along the hole.

Figure 4-11 presents local sectioned view into borehole KAS02. In the borehole three depth intervals belong to structure EW-5, two represent subhorizontal EWX fracturing features and at the bottom a long interval of structure NE-1 is reported. Classified, RQD-values based fracturing intensity bar is drawn here for comparison. Some fractured borehole intervals correlate with EW-5 and EW-X locations. Longer, highly fractured intervals are situated below the borehole length 800 m which belong to major zone NE-1. However, zone components NE-1B and NE-1A do not intersect the borehole according to the conceptualized model description. If the surface location is well determined, the dip can be slightly less steep than what established. Mutually intersecting zone components NE-1A and NE-1B may also need some consideration. Borehole KAS02 may end before it clearly penetrates zone NE-1.

Original RQD data profile is drawn in Figure 4-11. Note a small shift in axis starting point locations due to deviated borehole KAS02 trace line. Classification of RQD data has a cut-off character in some places: borehole interval 73.12 - 76.12 m is left out because interval 75.12 - 76.12 m has a value of 76 % (so just above used 75 % limit). On the other hand, similar outlooking interval 402.41 - 406.41 m having values in the range 63 - 72 % is preserved. Borehole intervals 200 - 250 m and 600 - 650 m contain several 1 - 2 m thick, anomalous RQD spikes that are screened out by classification. As a whole, RQD classification seems to yield a result explaining well the fracturing character of structural intersections.

Figure 4-12 depicts a local section view into borehole KAS05. Borehole penetrates several intervals which belong to structure EW-5. If so, EW-5 and its hydraulic associate EW-5W could also be modified to be as certain or possible-type. Within lower part of borehole KAS05 two intervals of gently dipping EWX fracturing is found. Conceptualized possible-type and minor fracture zone NNW-2 is almost parallel to the borehole and intersects it at about 400 m length. The borehole end point is at about 60 - 70 m distance from major zone NE-1.

Local sectioning through borehole KAS16 is in Figure 4-13. According to interference tests hydraulic zone NNW-2W has been interpreted there within length interval 0 - 120 m (Wikberg et al. 1991, Table 4.1). Borehole intersects according to geometrical modelling also major structures EW-3 and NE-1A & NE-1B between 240 - 330 m. Zones EW-3 and NE-1 are situated in the borehole almost at the same position, EW-3 being close to parallel to the hole. However, the conceptual modelling report (Wikberg et al. 1991) has no information and remarks of these zones in KAS16 to be considered more. RQD data bar is yet left blank and waiting measurement data to be processed.

Lithological submodel composition is shown with raster graphics print in Fig. 4-14. Small, embedded bodies of fine-grained and medium-grained granite, metavolcanite and greenstone are extruded vertically 50 meters downwards in 3-D. Only real lithological 3-D object is zone EW-5 conforming fine-grained, more fractured granitic body which is gently dipping to the north.

Figure 4-15 illustrates the whole structural model assembly from Äspö. Modelling volume 3000 · 2000 · 1000 m is visualized with translucent grey colour volume. Access tunnel comes from the south. Only certain-type structures is taken into more local view plot shown in Fig. 4-16. Access tunnel and spiral is visible in some places. Structure identification can be made with the help of Figures 4-2 and 4-3. Collection of hydraulic zone structures is given in Figure 4-17 as viewed from the approximate north.

Borehole structural and other classified bars can also be presented in 3-D with coloured pipelines. This is demonstrated in Fig. 4-18 that illustrates subassembly of zone NE-1 parts, planned rock rooms and borehole KBH02, KAS05 and KAS16 structural bar profiles. Boreholes KBH02 and KAS16 intersects zone NE-1 as discussed earlier and borehole KAS05 comes close to it. Planned spiral part of tunneling intersects NE-1 at several locations. Borehole intervals are coloured according to Table 3-7 (major zone = brown, minor zone = green, hydraulic zone = blue).

Figure 4-19 is an experimental plot of presenting log data profile as a surface model (in this case as a plane). Borehole bars are concentric solids modelled with coloured pipes in 3-D. Different spot lights and translucency for some objects have been applied to achieve shaded, see-through effects. The data is the same as in Figure 4-11. View direction is set to be perpendicular to the borehole and log profiles. If delineation of fracture zones is based on fracture density, the brown bar sections should include most of black and green coloured inner sections.

Figure 4-20 is a local scale, 500 · 500 · 500 m, block presentation of major fracture zones below southern Äspö island area. Planned tunnels intersect NE-1 three times, once along the access tunnel (outside the cube of this plot) and twice along the spiral part.

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