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THE GEOLOGY OF THE JOMA DEPOSIT: PROGRESS REPORT (DEC. 84) JOMA PROJECT

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A. Reinsbakken		1984	Grong Gruber AS

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A. Reinsbakken: Reporting on mine lithologies and ore types

N. Odling: The regional and local structures at Joma

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NTNF PROJECT: THE GEOLOGY OF THE JOMA DEPOSIT:
PROGRESS REPORT (Dec. 84) JOMA PROJECT, GEOL. INST.-NTH.

This is a progress report from the Geol. Inst.-NTH research group on the work completed for the Joma Deposit Geology Project in 1984. The report is divided into 2 parts, A. Reinsbakken reporting on mine lithologies and ore types and N. Odling authoring the second half of the report on the regional and local structures at Joma.

The hostrock lithologies and oretypes of the JOMA deposit. A preliminary report, December 1984.

A.Reinsbakken

Introduction.

At a 'steering committee' meeting in October 84 it was agreed that any future project reports will be written in English in order to facilitate our English speaking co-workers and to help in future communications with a research group from Clausthal Technical University, W. Germany, which is also working on certain aspects of the Joma deposit.

'SINTEF-forsker' A. Reinsbakken has been employed on the project from its start in May 1984, as the main executor and coordinator of project activities and mine mapping. He will also function as project-secretary throughout the life of the project.

Manpower.

Besides A. Reinsbakken, the project this year has also had two co-workers who have devoted a major part of their research on the

Joma project. Dr. Noelle E. Odling is in Norway on an NTNF post-doctoral research fellowship while stationed at the Geol. Inst., NTH, and has now applied for a year's extension in order to complete her studies here within the lifetime of the Joma project. Odling has a Ph.D. in the field of structural geology from Edinburgh University in Scotland, a country with long traditions in Caledonian structural geology. Her speciality is strain analysis, which she hopes to use in her work on the Joma deposit.

Dr. Brian Marshall was a guest researcher at Geologisk Institutt for a 5 months duration while on sabbatical leave from NSW Institute of Technology, Sydney, Australia. Marshall's main interests are in the fields of tectonics, structural deformation and metamorphism and their effects on the sulphide ores and the host rock silicates. He has therefore concentrated most of his efforts on the structures at Joma, with special emphasis on the tectonic fabrics and metamorphic textures and the mobilization and redistribution of the sulphide and silicate minerals during the main episodes of deformation and metamorphism.

Time disposition.

Reinsbakken spent a total of 16 weeks (4 months) at Joma this year. Two weeks were spent at the beginning of the project in May on a preliminary study of all previous work done on the Joma this year. One and a half weeks were spent on surface mapping and sampling around the open pit and on regional work with N. Odling, 9 1/2 weeks on underground mapping, sampling and drill core logging and ca. 3 1/2 weeks on the construction of 13 vertical geological profiles from previous mapping and drill core descriptions and from our detailed mapping.

N. Odling came to Joma on June 15, 1984 and spent a total of 12 weeks on project work at Joma - 6 weeks involved in regional mapping and structural interpretation and 6 weeks on detailed underground structural mapping. Dr. B.Marshall spent 6 weeks at Joma from his arrival around the middle of July - one week was used on surface mapping around the open pit and 5 weeks in underground structural mapping, interpretation and sampling.

Two groups of students (10 in all) from the Geol. Inst.-NTH spent one week each on an mine mapping course at Joma under the supervision of Professor F.M. Vokes. They were employed mapping areas adjacent to our own detailed study areas and their mapping and thin section descriptions have formed a basis for our further mapping and interpretations in the area.

Reinsbakken has been responsible for coordinating the mine mapping which was at times difficult when 4 geologists and 4 to 6 students were all involved in mapping within a limited area at the same time.

The choice of areas for detailed mapping was at first a problem in logistics, being limited to areas which had recently been mined and to areas where we would not hinder mining and transport activities. In such areas, the walls are still fresh (unoxidized) and water and hoses are still available to allow them to be easily washed down.

The mapping project was started at the 382s strosse area, as an earlier reconnaissance of the mine had shown this area to contain most of the geological aspects found at Joma, most of the mine lithologies and a good separation between the two major folding phases recognized in the area. This area was also large enough to accommodate the 3 co-workers through a preliminary mapping period, during which much time was spent confering with each other on the lithologies, the ore types and especially on the structures within the mine. This time was needed at the beginning of the mapping project as the two foreign co-workers had to adjust to the different rock types and structures found at Joma, all of which was quite different from that of their previous study areas.

The structures at Joma were found to be much more complex than first anticipated (much thrusting and imbrication structures, see Fig. 7 Odling). They caused considerable problems in interpretating the pre-deformational contact relationships; especially the zonation patterns expected in the original volcano-stratigraphy and the lateral zonation patterns found within the hydrothermal alteration 'feeder zone' beneath such a volcanogenic deposit as Joma.

Detailed geological mapping within the mine was carried out on most levels from the lowest present workings on the 362 m. level up to the surface level at 580 m above sea level. The following areas have been mapped in some detail by A. Reinsbakken, N.E. Odling and B. Marshall: 362öf+vf, 375vf+öf+öfsynk, 382s.stros., 385vf.s.stros., 402 (recon.), 416 b.s.6+7, 495 and the open pit (560 m a the pit floor) and the 580m surface level around the open pit.

The mine mapping was carried out on various scales depending on the degrees of detail needed. Reconnaissance mapping was carried out on 1:500 scale maps - the same scale as the mine plans and profiles. Detailed mapping was done on 1:100 and 1:200 scales and surface mapping in and around the open pit was done on a 1:500 scale. Regional surface mapping was performed using 1:5000 scale topographic maps.

The main aim of Reinsbakken's detailed mapping within the mine this year was to study the sulphide ores and host rock silicates and to divide these into mappable lithologies, thereby constructing a suitable volcano-stratigraphy and studying the effects of the pervassive hydrothermal alteration that has so strongly affected the lower volcanites which are the stratigraphic foot wall units to the massive sulphide ores. Both the silicate lithologies and sulphide ore types from the various mine levels have been closely sampled to facilitate detailed whole-rock chemical analyses and petrological study in order to characterize the mineralogical and chemical variations that occur across such hydrothermal alteration zones.

Odling and Marshall carried out complimentary structural studies from the same areas and an accompanying report on the mine and regional structures is given by N. Odling.

One of this year's major tasks has been the construction of 13 vertical geological profiles which are evenly distributed across the orebody and which will form the basis of all future studies on the mine (Fig.4). These profiles demonstrate the relationship between the host rock lithologies and the sulphide ores and their lateral distributions. The major structure are also well demonstrated.

Much of the data for these vertical profiles came from already existing drill-core descriptions and limited mine mapping and from our own detailed work on isolated areas spread throughout the mine. In connection with the interpretation of this vast number of drill-core descriptions, six(6) strategically placed drill holes from both the hanging wall (HW)and footwall (FW) areas of the ore zone were described in detail and sampled by Reinsbakken. The mine geologists were consulted at this time.

The 13 vertical mine profiles were constructed on a 1:500 scale A2 standard format and were reduced to A4 format and coloured for this report. The 1:500 scale profiles will be sent to Grong Gruber upon completion. These profiles must however be regarded as preliminary at this time as next year's mapping will change much of the details on them.

Regional geology.

The area surrounding the Joma deposit was studied by N. Odling this summer and a more detailed account of the regional geology and structures is given in her report (Odling p.1-4). A brief summary is presented here as an introduction to the following subdivision of the Joma volcanic lithologies.

The geology of the area surrounding the Joma orebody is dominated by two main lithologies, phyllites and greenstones. The phyllites are for the most part 'greyish' phyllite and quartz-rich phyllites, but graphitic phyllites and conspicuous quartzitic--phyllite or 'ribbon cherts' are common. These 'ribbon cherts' are composed of well-laminated thin quartzitic and dark graphitic phyllite components. They can be noticeably rusty - (po bearing). These quartzitic phyllites structurally overlie the 'outer' and 'middle' greenstones.

The Joma greenstones occur as three separate arcuate-shaped units, which from northeast to southwest are called the 'outer' (Orklumpen), the 'middle' and the 'inner' greenstones. The Joma deposit outcrops within the 'middle' greenstone unit. Of these three greenstones, the 'outer' and 'middle' greenstones show most similarities, having lithologies containing locally well preserved pillow structures, pillow-breccias and associated hyaloclastites, agglomerates and finely layered volcaniclastite or tuffs. The term 'pillows' is here used to describe close-packed pillows and isolated pillow structures - structures formed under the subaqueous extrusion of lava material, and 'pillow-breccias' as angular fragments of broken pillows set in a tuff-hyaloclastite matrix. The term 'hyaloclastite' (= 'aquagene tuff') can be freely translated as a rock composed wholly of glassy fragments. Hyaloclastite forms tuff-like deposits of small angular fragments generally found between the individual pillows and associated pillow-breccias and as individual beds closely associated these, and is formed by the scaling-off of glassy pillow rim material under the growth or expansion of individual pillows.

The distribution of these volcanic types in the 'outer' and 'middle' greenstones is similar, with a central core of dominantly pillowed lavas and minor pillow-breccias and hyaloclastites, flanked by dominantly volcaniclastic or tuffaceous layered lithologies (Fig. 1).

The 'inner' greenstone, in contrast, is quite monotonously homogeneous and massive in character. The occasional colour layering is interpreted as volcaniclastic in origin, with some of the coarser varieties showing a layered bimineralic gabbroid appearance. Several isolated, thick, homogeneous units may be intrusive.

Within the phyllites between the 'inner' and 'middle' greenstones, numerous thin greenstone bands or lenses are found paralleling the main lithologies and foliation in the phyllites. These are quite homogeneous and massive in appearance and generally have constant thicknesses of between 1-2 m, and could be interpreted as dykes. Some of these greenstone bands continue up into the irregular contact-zone on the west side of the 'middle' greenstone. One rather thick homogeneous unit has been interpreted as a sill unit. These greenstone 'dykes' may represent feeders to the 'middle' greenstone.

The phyllites may in part at least be older than the 'middle' greenstone and therefore be the base on to which the 'middle' greenstone lavas were deposited. These phyllites now structurally overlie the 'middle' greenstone and, therefore, the whole sequence has in part been inverted into its present position (Fig. 13, Odling).

The Joma orebody outcrops in the middle of a thick pillowed sequence that trends roughly through the central part of the 'middle' greenstone. This pillowed sequence thins notably in both directions away from the Joma deposit outcrop area.

To the southwest of the surface expression of the Joma orebody, several distinct rusty zones are found transgressing through the 'middle' greenstone, from the quartzitic phyllite and greenstone boundary (base of the 'middle' greenstone), northeast through the volcaniclastics and the pillowed+pillow-breccia and associated hyaloclastite sequences, directly into the western edges of the open pit area where it abuts against the massive ore zone within the hangingwall (HW) mine sequence (see Fig. 1+2 and profile X95200A and B1-3).

These rusty mineralized zones occur as discontinuous areas or patchy concentrations of disseminated po within a moderately greenish chlorite- and epidote-bearing altered greenstone assemblage. Within the vicinity of the open pit area, these rusty, pyrrhotite, disseminations appear to have a strong affinity to the more porous pillow-breccias and darker, chloritic hyaloclastite lithologies. Immediately west of the open pit (in the HW sequence), the po dissemination zones coalesce and grade rapidly into a marked zone of pyrite and quartz-pyrite veining and intense pyrite dissemination within a pale, dense, hard, albitic, and white mica-chlorite rich schistose assemblage which lies directly adjacent to the massive ore zone.

The mine lithologies.

Based on this year's detailed surface and underground mapping, the Joma orebody's immediate host rocks can roughly be divided into two major units: The Hanging wall (HW) sequence which occurs to the west of the open pit and is interpreted as being older than the massive ores; and the Footwall (FW) volcanite unit which lies to the east and beneath the massive ores and is interpreted as being younger than the ores (see Fig. 2+3 and profile B1-3).

Although intense isoclinal folding and associated thrusting has caused many imbrications, repetitions, inversions and has generally complicated the original geomorphological relationships, the whole mine sequence appears to be inverted, or, at least in part inverted, into its present position (see Fig. 7, Odling and profile B1-3).

FW volcanite unit.

The Joma orebody is structurally underlain to the east by a thick sequence of pillows, pillow-breccias and hyaloclastites which grade eastward sharply into well-layered volcaniclastites and tuffs - a similar volcanite series to that found in the HW to the west of the orebody.

These FW volcanites are, however, noticably paler in colour and richer in their free calcite and epidote contents, while being relatively free from any sulphide concentrations, compared to the HW volcanite series.

Thin carbonate benches are present within the pillowed greenstone and carbonate (calcite) often occurs concentrated between the individual pillows along with epidote knots. Some of the carbonate bands are tectonicly controlled.

A characteristic feature of this FW volcanite unit - immediately adjacent to the massive ores, is a 2-3 m thick zone of minor, fine-grained pyrrhotite dissemination associated with a dense, hard, almost flinty-like, very pale greenstone enriched in albite and actinolite. Numerous, large quartz-calcite-epidote filled veins occur in this zone as tension gashes, oriented axial planar to the large F_3 structures (see profile B2-11, lower ore horizon).

Another characteristic feature of the adjacent FW volcanites is the occurrence of numerous dark-grey to blackish, magnetite-bearing quartzitic lenses and bands, generally termed 'blåkvarts' at Joma. These are often found as individual lensoid units or as thin lenses stretched out along thin layers of darker-green chloritic schists, which sometimes carry minor pyrrhotite disseminations. The 'blåkvarts' lenses often grade into greyish quartzites which carry a minor pyrrhotite content as disseminations.

The mineralogy of the FW volcanite sequence appears to vary only slightly and contains <u>major</u> amounts of amphibole (act)+albite +chlorite (Mg-rich) and <u>minor</u> epidote+calcite, and <u>trace</u> amounts of pyrrhotite. There is, however, a noticeable increase in the albite+actinolite+white mica+pyrrhotite contents on approaching the ore zone, accompanied by an apparent decrease in the chlorite and calcite contents.

HW volcanite sequence.

The hanging wall (HW) volcanite sequence is overprinted by a large transgressing zone of intense hydrothermal alteration and accompanying sulfide veining and impregnation - immediately adjacent to the massive orebody. This is interpreted as being the 'feeder-zone' or root-zone to the massive sulphides at Joma. This overprinted zone of intense veining and alteration makes it very difficult, if at all possible, to define a clear volcanostratigraphy within the HW rocks adjacent to the ore zone.

In areas of high strain, tectonic shearing accompanying minor thrusting produces zones of intense schistosity within the rocks which often show metamorphic mineral layering which can appear quite different from their more massive, unsheared, counterparts.

More competent layers often break up and appear to float within a more schistose matrix, giving the rocks a volcaniclastic-pyroclastic appearance.

The following lithologies have been subdivided as distinct mappable rock units, but, one must bear in mind that there is a great deal of variability in the mineral contents and textures found within these units and they often show a complete gradation from one unit to the other. The units are described in order of their appearance upon moving from a more distal part of the HW down towards the massive ore zone.

1) moderate green, homogeneous greenstones:

This unit is generally massive to weakly schistose and noticeably darker greenish in colour than the FW volcanites, reflecting a somewhat higher chlorite content and only trace amounts of free calcite, epidote and disseminated po. This slightly altered greenstone variety is found covering a vast area outside the immediate mine area - several tens of meters from the orebody - and is best seen on the surface to the SW of the open pit (Fig.-1+2). Pillows, pillow-breccia and hyaloclastite structures are still recognizable.

The zones of pyrrhotite dissemination are noticeably concentrated in areas where pillow-breccias and hyaloclastites dominate. This greenstone variety is generally composed of varying amounts of chlorite (pale, Mg-rich) + amphibole (Act) + albite and <u>minor</u> amounts of white mica+epidote+calcite+pyrrhotite (po).

Near the orebody the zones of pyrrhotite dissemination coalesce into patchy areas and irregular zones of visibly harder pale albititic material with associated pyrite veining. This rock is enriched in albite+quartz+pyrite and depleted in free calcite and pyrrhotite.

2) pale greyish-green, massive albite+amphibole+pyrrhotite unit (Ab+Amf+po):

This is a very pale greyish-green, massive, hard, flinty-like unit rich in albite and carrying diagnostic pale amphibole needles and a marked pyrrhotite dissemination. Unit 2 grades from unit 1 by a marked increase in Ab+Amf+po at the expense of pale chlorite (Mg-rich) and free calcite.

This rock contains major amounts of albite+Fe-chlorite +amphibole (2 varieties) and minor contents of pyrrhotite +chalcopyrite+sphene. In zones of high shear, this unit occurs as well-layered, pale albitite and dark chlorite+amphibole-rich bands.

3) pale, greyish-green, albite+white mica+pyrite-rich schists.

This unit occurs as an irregular zone of inhomogeneous, pale, schists with varying contents of pale chlorite, white mica, albite and carbonate (calcite). It also shows varying amounts of pyrite dissemination and pyrite veining, which now often form tectonic layering. Patches of a denser, harder, albite-rich rock is found associated with the pyrite+quartz veining. XRD studies show that the following minerals are present: <u>major:</u> albite+chlorite+quartz +pyrite; <u>minor,</u> white mica and <u>trace</u> contents of calcite+amphibole +epidote+pyrrhotite±sphalerite.

This rock may well represent a more distal part of the hydrothermal alteration system and is within the mine often associated with areas where Zn-rich carbonate-bearing pyritic ores are most prominent. It also occurs often adjacent to the albitite and chlorite-schist units.

4) Albitite (albite+pyrite-rich rock - often called 'albittfels').

The albitite unit consists of a variety of very pale to almost cream-coloured, irregular to somewhat well-layered albitite and pyrite-rich units. It often has a laminated character with distinct creamy coloured, fine-grained albite, and darker, coarser-grained pyrite, bands. The pale albitite often contains greyish patches or bands which contain an extremely fine-grained dusting (dissemination) of pyrite. The coarser-grained pyrite bands and massive pyrite lenses (tectonic?) carry varying amounts of chlorite and biotite. Sphene occurs as a minor (2-5 %) mineral in the albitites. The following mineralogy is typical: major contents; albite+chlorite+pyrite; minor biotite+ sphene.

The albitites show sharp contact relationships to the dark chlorite+biotite schists (unit 5) and the albite+chlorite +amphibole unit (unit 2). The albitite horizons are generally quite thin and often occur as isolated lenses and bands within the massive ores and are here invariably in contact with associated chlorite schists.

5) Chlorite schists.

The term 'chlorite schist' is here used to encompass a variety of different dark green, chlorite-rich rocks, thereby being used as a kind of 'rag-bag' terminology. The chlorite-rich rocks vary greatly in their mineral contents, thicknesses and distributions throughout the mine, but, common to all are the chalcopyrite-pyrrhotite disseminations, veins and tectonic mobilizates which occur as bands and tension-gash fillings. The thicker concentrations of chloritic schists appear to be closely related to Cu-bearing fine-grained pyritic ores (i.e. bottom of 375 ö.f.synk; profile B2-15).

There are two major varieties of chlorite schists at Joma:

a) A dark-green, massive variety, rich in chalcopyrite-pyrrhotite disseminations and carrying varying amounts of biotite, magnetite, calcite, cherty bands and a minor porphyroblastic albite content.

b) A dark to moderate green, laminated chloritic schist having distinct interlayers of pale greenish albite-rich bands. This variety also carries thin pyrite bands besides the pyrrhotite-pyrite mineralization.

These two distinct chlorite schist varieties are in places (385v.f.s.strosse) separated by a discontinuous band of magnetite or pyrite. The chlorite schists show gradational and sharp contacts to the albite+chlorite+amphibole+pyrrhotite (unit 2) and the albitite units in the 382-385 s.strosse area.

The chlorite schists contain varying amounts of the following minerals; major chlorite (dark green Fe-rich variety (chamosite?)) +biotite+chalcopyrite+pyrrhotite; minor albite+sphene (up to 5 %) and trace pyrite.

The dark-green, Fe-rich chlorites show in places a marked alteration to pale-green chlorites (Mg-rich varieties) along S_3 cleavage planes. Biotite+albite+orthorhombic amphibole porphyroblasts are all late metamorphic minerals.

6) Quartz-chlorite-albite-biotite schists.

This unit is best developed in the newly worked 382 v.f.s. strosse area where it is found infolded within albitite banded chlorite schists and pale albitites and massive amphibole-phyric, albite-rich units, where they are separated by a thin discontinuous magnetite band. The max. thickness of this unit is here up to 2-3 meters.

The quartz-chlorite-biotite-rich unit often shows an irregular, lensoid, tectonic brecciated nature, and it is characterized by its numerous quartz-filled tension gashes and its high chalcopyrite to pyrrhotite content.

This unit has a very limited distribution within the mine and, besides the great thicknesses in the 385 v.f.s.strosse area, it occurs elsewhere only as thin slices and isolated bands or lenses along thrust zones within the massive ores (i.e. 375 ö.f. synk and 375 v.f. areas).

The albite-rich rocks (unit 4), the chlorite schist (unit 5) and the quartz-chlorite-biotite rich rocks (unit 6) all probably represent some form for zonal distribution related to an episode of extensive hydrothermal alteration. They are all intimately related with each other and often show gradational boundaries, although, the sharp contacts now found are the result of a complex imbricate thrusting structure found at Joma. The high sphene content in all three units (2-5 %) suggests that they are probably derived through hydrothermal alteration, from a common high-Ti Joma-type basalt, as Ti is generally regarded as a stable element under hydrothermal alteration processes. The Joma-type basaltic-greenstone usually contains ca. 2 % TiO_2.

Ore types.

This year's work has enabled the separation of the following ore types, which are based solely on field evidence and may well have to be revised after further detailed petrological and chemical investigations which are planned for 1985.

Massive to semi-massive sulphide facies:

1) fine-grained pyritic ore:

This ore type consists of a fine-grained, dense, almost flinty, pyritic facies, commonly carrying minor amounts of quartz as a matrix mineral. Besides being, for the most part, almost purely pyritic and devoid of Cu and Zn concentrations, Cu-rich and Zn-rich areas do occur. The chalcopyrite often occurs as fracture fillings and sphalerite occurs as irregular patches and bands within the fine-grained pyrite. This fine-grained pyritic ore facies often shows a characteristic brecciated texture (tectonic) with pyrrhotite, chalcopyrite and minor fibrous amphibole minerals forming the matrix to the angular fragments. The Cu-rich variety commonly occurs near and associated with the chloritic schists.

The thickest concentrations of this fine-grained pyritic ore occur on the east side and the south end of the open pit, and within the SW end of the 362 ö.f. level. Fragments of this fine grained pyritic ore facies are often found as isolated lenses within some of the other ore types (carbonate-bearing pyritic ore and cp-po breccia ore).

2) medium to coarse-grained, carbonate-bearing pyritic ore:

The conspicuously coarser grain size and the throughgoing tectonic layering and banded nature is a very characteristic feature of this pyritic ore facies. Carbonate (calcite) forms the dominant matrix mineral (ca. 5-20 %). In some areas, discrete patches and horizons containing conspicuous amphibole (actinolite?) needles are found within this ore type, often occurring at boundaries to other ore types (i.e. oxide facies) and between the silicate hostrocks and massive ores.

This carbonate-bearing pyritic facies is noticably more Zn-rich and less Cu-bearing than the fine-grained pyritic variety. The sphalerite often occurs as discrete bands and lenses parallelling the major tectonic layering in the ore. Thin bands of semi-massive pyrite and white carbonate, and isolated, isoclinal fold hinges of white limestone-marble occur in zones of high shear (thrusting) that cut through this ore type. These carbonate bands and isoclinal fold hinge remains are often found within or towards the FW (stratigraphic top?) of this unit. The limestone horizons can be up to 2 meters thick in fold hinge zones (see profile B2-7. 416 b.s.7 level) an they often contain thin pyrite and chlorite bands near their contacts with the massive ore.
Fragments of the fine-grained pyritic facies occur within this carbonate- and Zn-rich pyritic ore facies.

A conspicuous, 'grey-coloured', somewhat laminated to distinctly fragmental, pyritic facies occurs within the carbonate--rich pyritic ore facies, near the west side of the open pit (see Fig.3) and in the 382 s. strosse area. It occurs as layers of tightly-packed, angular to subangular pyritic fragments, set in a dolomitic (?) carbonate-rich matrix, which on weathering produces a characteristic buff to orange coloured surface. Thin white limestone (dolomitic?) and dark green amphibolitic bands are found associated with this 'slump-like' pyrite breccia ore occurring in the west side of the open pit.

Grey to whitish coloured quartzitic bands and isolated lenses are found within and adjacent to the carbonate-rich pyritic ore facies and as lateral extensions and thin pyritic bands in the 375 ö.f. area. These are spatially related to an area of intense pyrite+quartz veining within the pale albite-micaceous schists. The layering or banded nature of these ores and host rocks is probably tectonic in origin, although some original sedimentary layering can not be discounted.

3) chalcopyrite-pyrrhotite (cp-po) breccia ore:

This is a massive to semi-massive, Cu-rich sulphide ore facies which can form thick sections (2-3 m) containing up to 20 % Cu. It varies greatly in its nature, thickness, distribution and Cu-content. It characteristically contains numerous angular to well--rounded country rock fragments (chlorite-schists, amphibolites, carbonate and pale albite-micaceous schists) and fragments of glassy quartz and other sulphide and oxide-silicate ore facies (chert and magnetite-amphibole).

This cp-po ore facies shows a strong tectonic control in its occurrence and the type, shape and size distribution of included fragments. The occurrence of this ore facies appears for the most part to be controlled by F_2 axial planar thrust planes that transect the Cu-rich massive pyritic ores and the encompassing disseminated chlorite and albitic schists. (See Fig. 7 Odling.)

The types of country rock fragments found within this cp-po-breccia ore facies vary from place to place throughout the mine and appears to be locally derived. Angular fragments of locally derived ore types and adjacent host rocks often show isolated remnants of F_2 isoclinal fold hinges. Cp-po ore bands which project out into the silicate host rocks along thrust planes, thin noticeably away from the massive sulphide ores, and the fragments diminish markedly in size and become more rounded - showing the effects of milling during the process of tectonic mass transport ('durchbewegung').

In the 375 ö.f. synk + ö.f. areas, a cp-po breccia ore band extends for a distance of greater than 100 meters along such a S_2 thrust plane. Similar bands of cp-po breccia ores are found in thrust plane contacts along the base (FW contact) of the massive sulphide ore zone in the 382 and 385 v.f.s. stros. area (see Profil B_2-11).

Chalcopyrite and pyrrhotite-rich ores are also found in pressure shadow areas related to F_3 folded cuspate structures and upon the reworking of earlier F_2 structures (see Fig. 8, Odling).

4) massive pyrrhotite (po) ± sphalerite (sl):

Irregular bands and lenses of almost pure pyrrhotite occurs along contacts between the more schistose dark chloritic and pale amphibole-bearing micaceous rocks and the more massive competent albititic and quartz rich rocks. Pyrrhotite also occurs concentrated in F_3 piercement structures often associated with minor quartz and sphalerite (sl) (see Fig. 8, Odling).

5) semi-massive pyritic ore:

A medium-grained, semi-massive pyritic ore type has been found which contains a noticeable dark chlorite and minor carbonate rich matrix. It often shows a well-developed banding (original layering?) and, often, a distinct separation between its Cu and Zn-rich bands. Minor, thin bands of massive pyrite are also found. This ore type seems to occur in a zone separating the darker chlorite schists (cp-po bearing) from the paler, quartz-albite-biotite and albitite-banded chlorite schists which also often carry minor pyrite mineralizations. This semi-massive pyritic ore type is found best developed at the bottom of the 375 ö.f. synk area where it is associated with quartz-biotite-bearing chlorite schists and Cu-rich massive pyritic ores.

6) oxide and silicate rich ore facies:

This ore type occurs as discrete bands or zones containing isolated lenses of magnetite+chlorite-bearing dark quartzites (cherts?), magnetite+amphibole (cummingtonite?), dark chlorite and grey chert-rich bands, all floating in a well-banded cp-po-bearing pyritic groundmass (see Fig. 6, Odling).

Discrete bands rich in cp-po also occur interlayered within some of the magnetite and chlorite rich bands. This ore facies often occurs as a discrete zone marking the boundary area between the Cu-rich fine-grained pyritic facies and the coarser, carbonate-bearing Zn-rich pyritic ore facies.

A thick sequence of well-banded magnetite, amphibole, chlorite and greyish chert occurs as well-defined, isoclinal fold hinges in the 375 ö.f. synk area and as isolated fold hinge remains in the 382 s.strosse area (see Fig. 6, Odling). Angular fragments and isolated fold hinge remains of this more competent oxide-silicate facies often occurs as fragments within the cp-po breccia ore facies.

Disseminated ore types.

7) Chalcopyrite-pyrrhotite (cp-po) disseminations:

Chalcopyrite (cp) and pyrrhotite (po) occur as strongly varying disseminations, veins and as lensoid bands and tectonically concentrated layers within the dark green chlorite and quartz-albite-biotite-chlorite schists. Pyrrhotite also occurs as a very minor dissemination, with trace amounts of chalcopyrite, over a wide area in the slightly altered HW greenstones. The pyrrhotite content appears to have a close affinity to the darker, chlorite rich hyaloclastite zones.

8) pyrite disseminations:

Pyrite, as intense pyrite disseminations and pyrite - and pyrite-quartz veining (now as tectonic layers) occurs within a thin zone of pale albititic and pale chlorite+white mica bearing schists that occupy the immediate HW to the massive ores and the Cu-bearing chlorite schist units. Within the HW zone of the ore-body there appears to be a gradational zonal distribution between a more widespread pyrrhotite dissemination in the chlorite-rich altered greenstones to this more limited zone of pyrite disseminations and pyrite veining.

Free calcite is a conspicuous mineral within the pyrrhotite disseminated zone, but it appears to be absent within the zone of quartz-pyrite veining.

Zonal variations are also present in the Cu and Zn contents within the pyrite disseminations and pyrite veining. These zonal distributions are most likely the products of an episode of intense, pervasive hydrothermal alteration.

Both pyrite and pyrrhotite have been found as disseminations within 'greyish' quartzites (originally cherts?). The pyrite disseminated quartzites occur as bands and lenses within a zone adjacent to carbonate-bearing massive pyritic ores and within intensely pyrite-disseminated and pyrite-veined pale schists. Pyrrhotite (po)-disseminated grey quartzites, on the other hand, are for the most part limited to the FW volcanite sequence, where they show intimate and gradational relationships to the magnetite-bearing black to dark-grey cherty units (blåkvarts) that lie in thin darker chloritic bands within the paler FW volcanites. The pyrrhotite appears to be derived from a metamorphic breakdown of the magnetite.

Amphiboles.

Amphiboles occur as prominent minerals in several of the ore facies found in the Joma deposit. There is a noticable variation in their crystal forms, colouration and possible Fe-Mg compositions. The various amphibole types seem to be limited in their distribution to several or only one of the ore facies described earlier.

1) pale to moderate-green needles (actinolite?) within carbonate-bearing pyritic ores and close to pale albititic and micaceous schists.
2) moderate-green, fibrous-asbestiform needles as matrix minerals in very fine-grained pyritic ore breccias.
3) dark-green to blackish, thicker amphibole needles (hornblende?) within the cp-po breccia ore-types.
4) greyish-brown, short, interlocking clusters or bands of amphibole (cummingtonite?) within the magnetite-rich, oxide-silicate ore facies.

X-ray Diffraction study.

An extensive XRD investigation has been carried out on the 28 rock samples that have been sent in for whole-rock analyses from the various lithological units found at Joma. This XRD investigation was carried out as a preliminary rutine for the detailed petrological work that is to be done on these rocks and while awaiting the completion of thin sections from these rocks. Previous investigations on similar fine-grained greenstones have shown that it is often very difficult if not impossible to distinguish between quartz and albite, and pale coloured chlorite and actinolite in such rocks through the use of a microscope only.

From the diffractograms, limited thin section observations and from consultations with Dr. B. Marshall, the following minerals have been recorded in the host rocks at Joma:

Chlorite (Chl)	-	a dark green Fe-rich variety and a pale Mg+Ca-rich variety - possibly chamosite.
Amphibole (Amf)	-	several varieties are noted, actinolite, cummingtonite and hornblende?
Albite (Ab)		
Quartz (Q)		
White mica (wm)	-	probably paragonite
Biotite (B)	-	to phlogopite (very pale to colourless)
Calcite(Cc)		
Dolomite (Dol.)		
Epidote (Ep)	-	to clinozoicite
Sphene (Sp)		
Stilpnomelane (St)	-	as a minor content in the oxide-silicate ore-facies.

The common ore minerals found are pyrite (py), pyrrhotite (po), chalcopyrite (cp), sphalerite (sl) and magnetite (mt).

This mineralogy is typical of an upper greenschist facies paragenesis.

Whole-rock Lithochemistry.

Prior to the start of the 'Joma Deposit Geology' project in May '84, a total of 73 recorded whole-rock analyses had been performed on the Joma-type greenstones and host rock lithologies from Joma. Sixty-nine (69) analyses were done for J. Olsen during his earlier work at Joma. These are from several series and can be broken down as follows: 32 plus 7 greenstone samples from the mine area and immediate ore localities, 7 regional greenstone samples from the three main greenstone belts in the Joma synform, and 9 analyses on albitt-fels and 14 analyses on chlorite schists all from within the mine and near ore localities. J. Olsen's analyses are from two different series, consisting of major elements and 4 and 13 trace elements each.

With the exception of the 7 regionally located samples, the remainder of Olsen's samples are from the mine area and unfortunately have not been precisely located with regards to the mine coordinates - only the mine levels from which the sample have been taken are recorded. This presents a problem in interpreting what the sample really represents as far as classifying them within the host rock lithology scheme that has been presented here. It is very difficult, therefore, to say whether these samples represent massive lavas, pillows, pillow-breccia, hyaloclastic or volcaniclastic (tuffaceous) material, which is vital when carrying out a detailed study of chemical losses and gains during spilitization and intense hydrothermal alteration. The original starting material must be known. There are very few thin sections available from this earlier work by J. Olsen.

Reinsbakken has 2 analyses of Joma-type greenstones from south of Joma and 2 analyses of greenstones from within the mine obtained from G. Gale. These analyses have been performed at NGU.

Twenty-eight (28) samples, representing the various lithologies from the Joma mine have been delivered to the lab. at Geologisk Institutt, NTH, for major and trace element whole-rock analyses (28 elements in all). These analyses are expected to be completed by the end of this year (1984).

At this time a detailed literature study is planned on the fields of spilitization and hydrothermal alteration processes in basaltic rocks, a subject that has recently been receiving much attention, especially since the recent discovery of 'black smokers' and present-day deposition of sulphide mineralization on the sea-floor depressions of the East Pacific Rise (EPR).

A preliminary account on the available major and trace element contents of the Joma greenstones, their altered equivalents and the various host rock lithologies will be given at this time. This data will form the basis for further discussions regarding the future planned detailed chemical and mineralogical investigation of the hydrothermal alteration zone at Joma. This preliminary study should give some indication of the amounts of chemical variations that can be expected in these rocks and as to which elements that can be used to define a zonal hydrothermal alteration pattern.

Samples taken this year (1984) include 6 regional greenstone samples, 13 freshly blasted, surface samples, across the rusty alteration zone to the SW of the open pit, and numerous samples of the various host rock lithologies taken from various levels within the mine.

An extensive series of thin and polished sections are now being prepared for a detailed petrological study on the various host rock silicates and ore facies that have been sent in for chemical analysis.

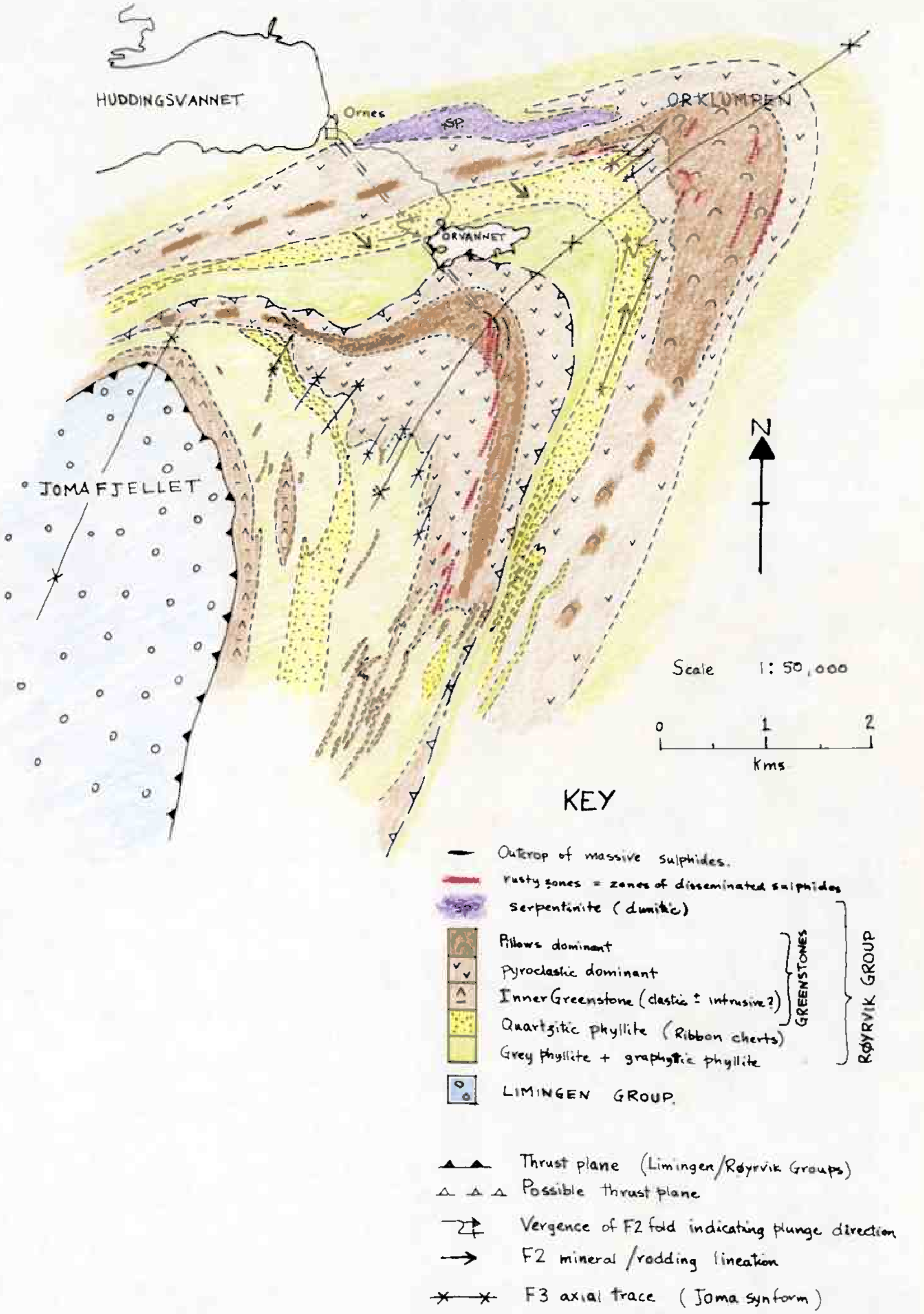

Fig. 1. Geological map of the Joma area showing major geological boundaries and distribution of greenstone (Modified after Kollung + Odling).

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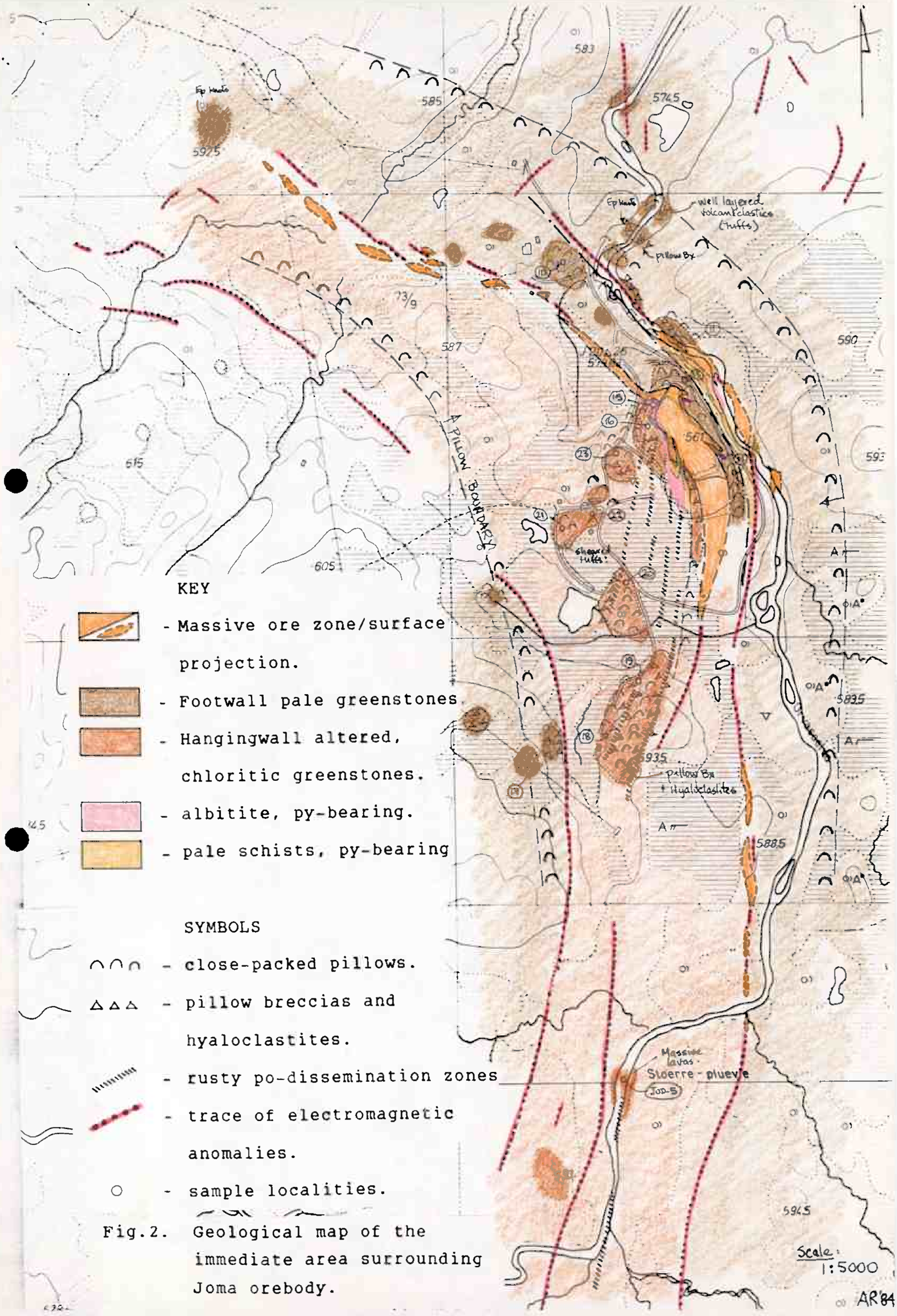
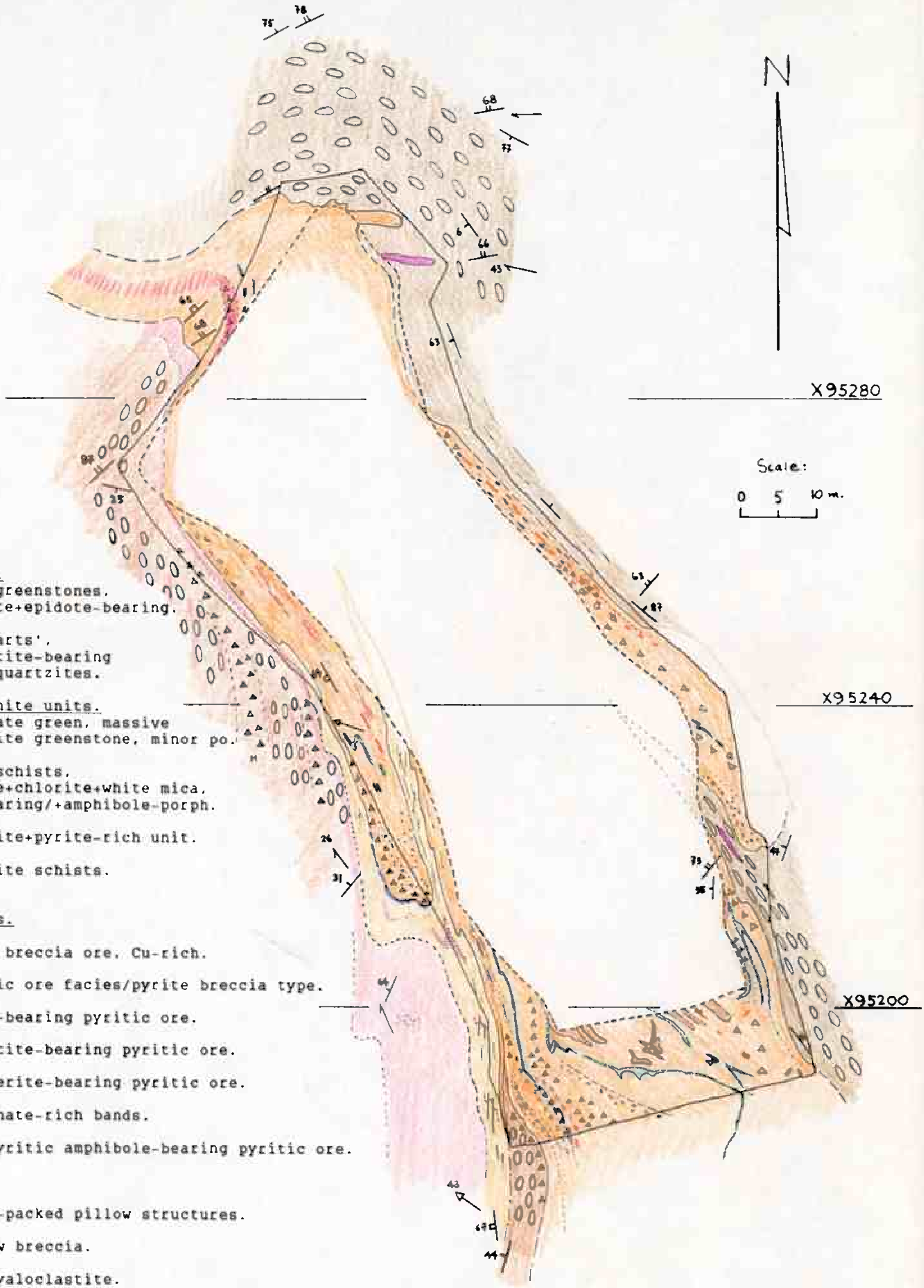


Fig.2. Geological map of the immediate area surrounding Joma orebody.



KEY

FW units.
- pale greenstones, calcite+epidote-bearing.
- 'blåkvarts', magnetite-bearing dark quartzites.

HW volcanite units.
- moderate green, massive chlorite greenstone, minor po.
- pale schists, albite+chlorite+white mica, py-bearing/+amphibole-porph.
- albitite+pyrite-rich unit.
- chlorite schists.

Ore types.
- cp-po breccia ore, Cu-rich.
- pyritic ore facies/pyrite breccia type.
- cp+po-bearing pyritic ore.
- magnetite-bearing pyritic ore.
- sphalerite-bearing pyritic ore.
- carbonate-rich bands.
- porphyritic amphibole-bearing pyritic ore.

Symbols.
- close-packed pillow structures.
- pillow breccia.
H H H - metahyaloclastite.
- strong schistosity, layering.
- lithological banding.
- S_2 schistosity.
- S_3 cleavage.
- L_2 mineral lineation.
- crenulation lineation.
- fold hinge (F_2)

Fig. 3. Geological map of the Joma open pit area.

AR+BM'84

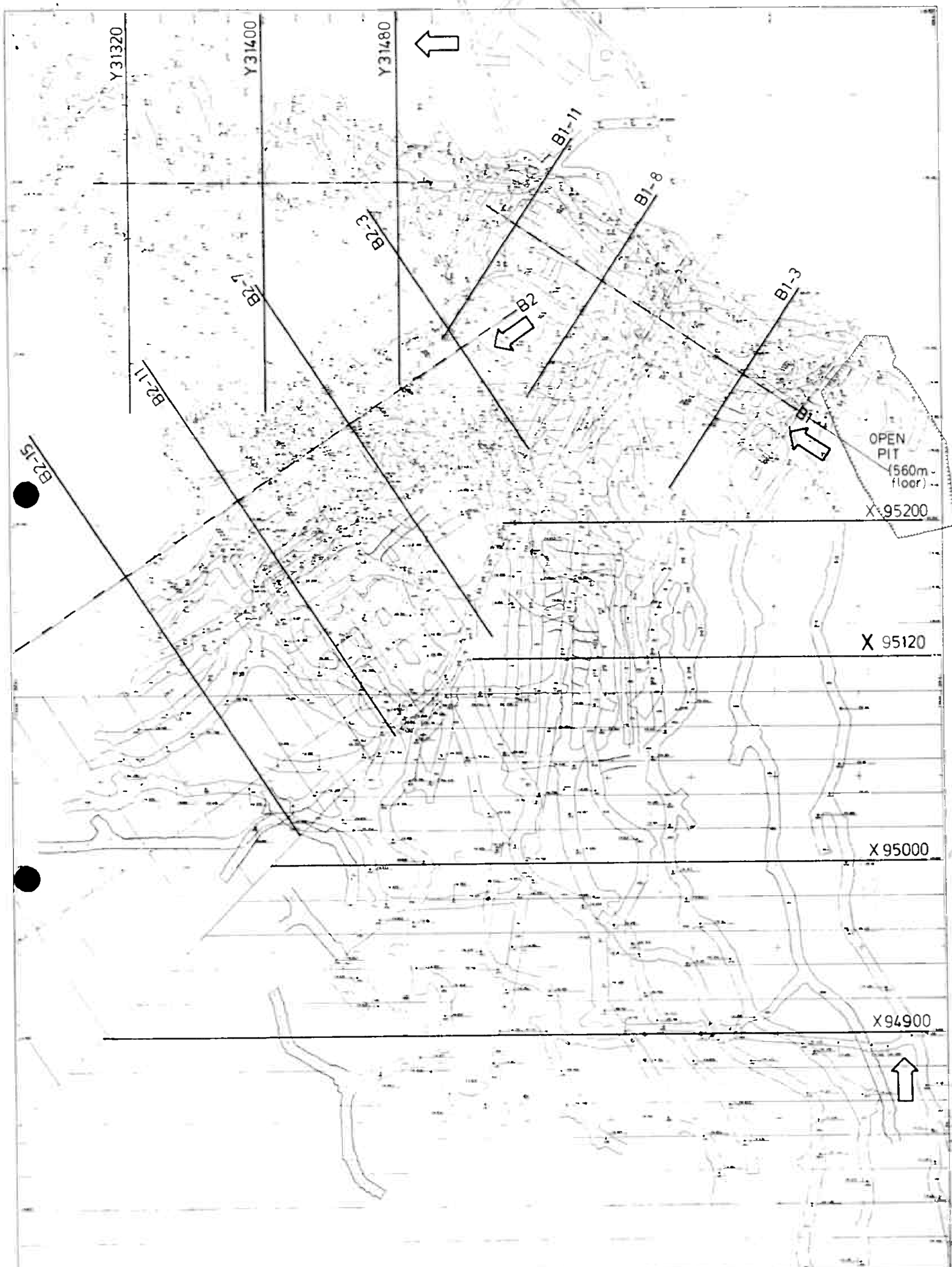


Fig. 4. Diagram showing distribution of the vertical profiles from the Joma mine. Arrows show viewing directions.

FIG. 5 KEY TO VERTICAL GEOLOGICAL PROFILES - JOMA

- Limestone marble and carbonates.
- 'Blåkvarts', magnetite-bearing dark quartzites.
- FW volcanite unit, pale, calcite+epidote bearing.

HW volcanite units.

- moderate green, massive, chloritic greenstones, minor po.
- pale, schists, albite+chlorite+white mica, py-bearing /+amphibole porph.
- albitite+pyrite unit.
- chlorite schists, cp-po bearing.
- chlorite schists with albite-rich banding, minor po+py.
- Q+B – quartz+albitite+chlorite+biotite rich unit, strong cp+po dissemination.

Ore types.

- chalcopyrite+pyrrhotite breccia ore, Cu-rich.
- pyritic ore facies/pyrite breccia type.
- cp po – cp+po rich pyritic ore.
- mt – magnetite-bearing pyritic ore.
- sl – sphalerite rich pyritic ore.
- cc – carbonate rich bands.
- porphyritic amphibole-bearing pyrite ore.

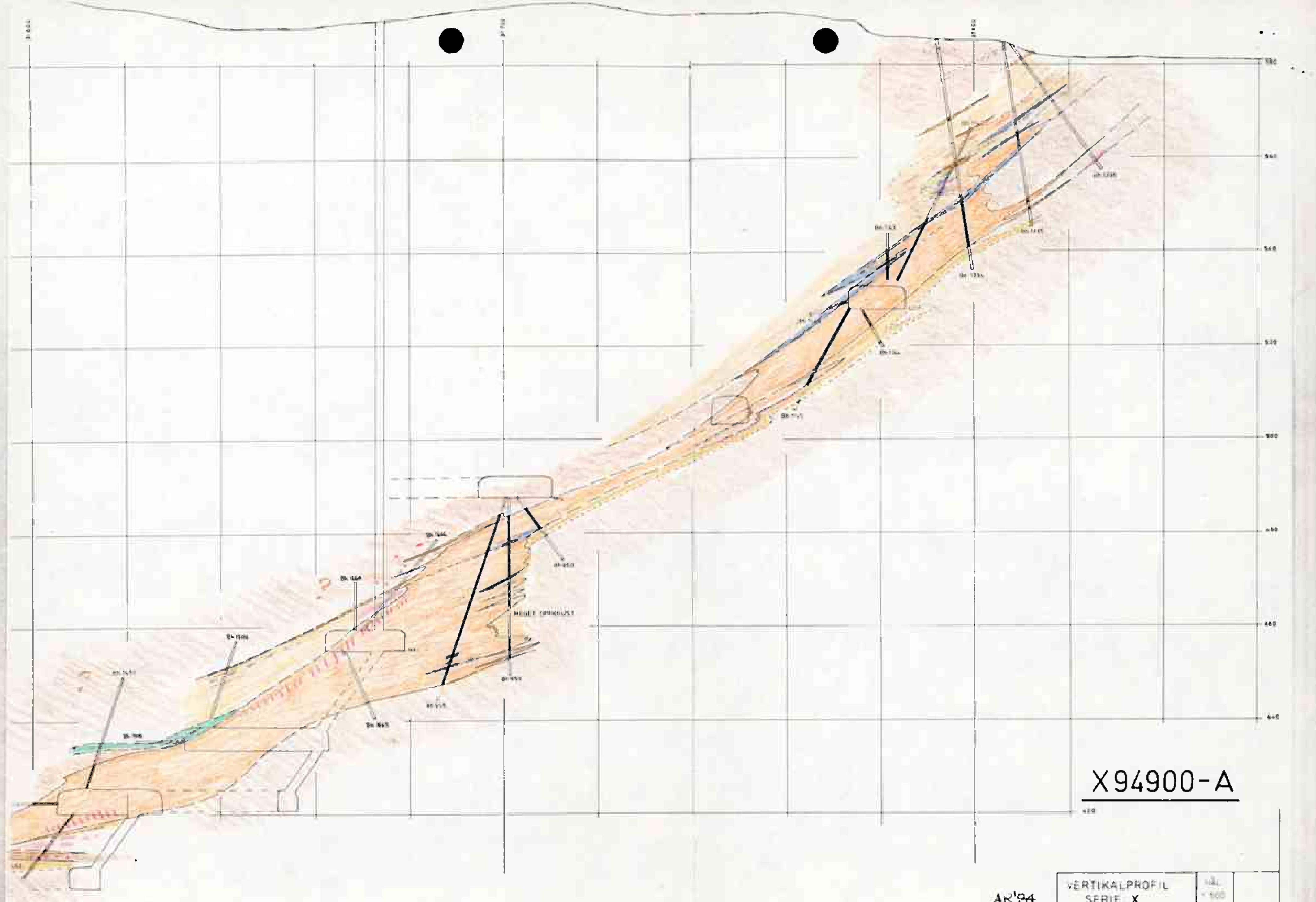
Symbols:

⌒⌒⌒ – close-packed pillows.

△ △ △ – pillow-breccia.

H H H – hyaloclastite.

—·—·— – Minor thrust zones.



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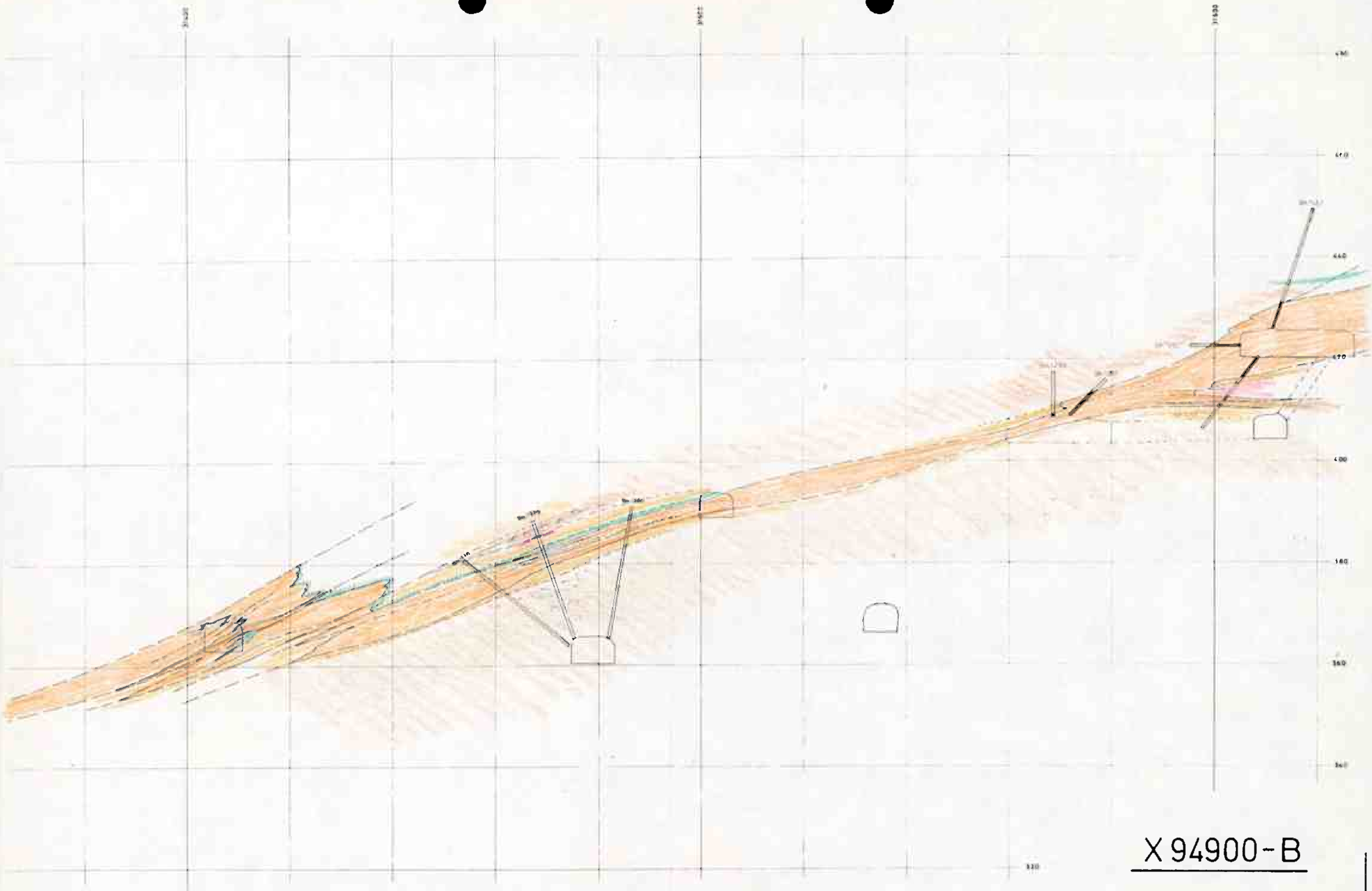
SERIE X

GRONG GRUBER A/S

Pr X 94900 A



X 94900-B

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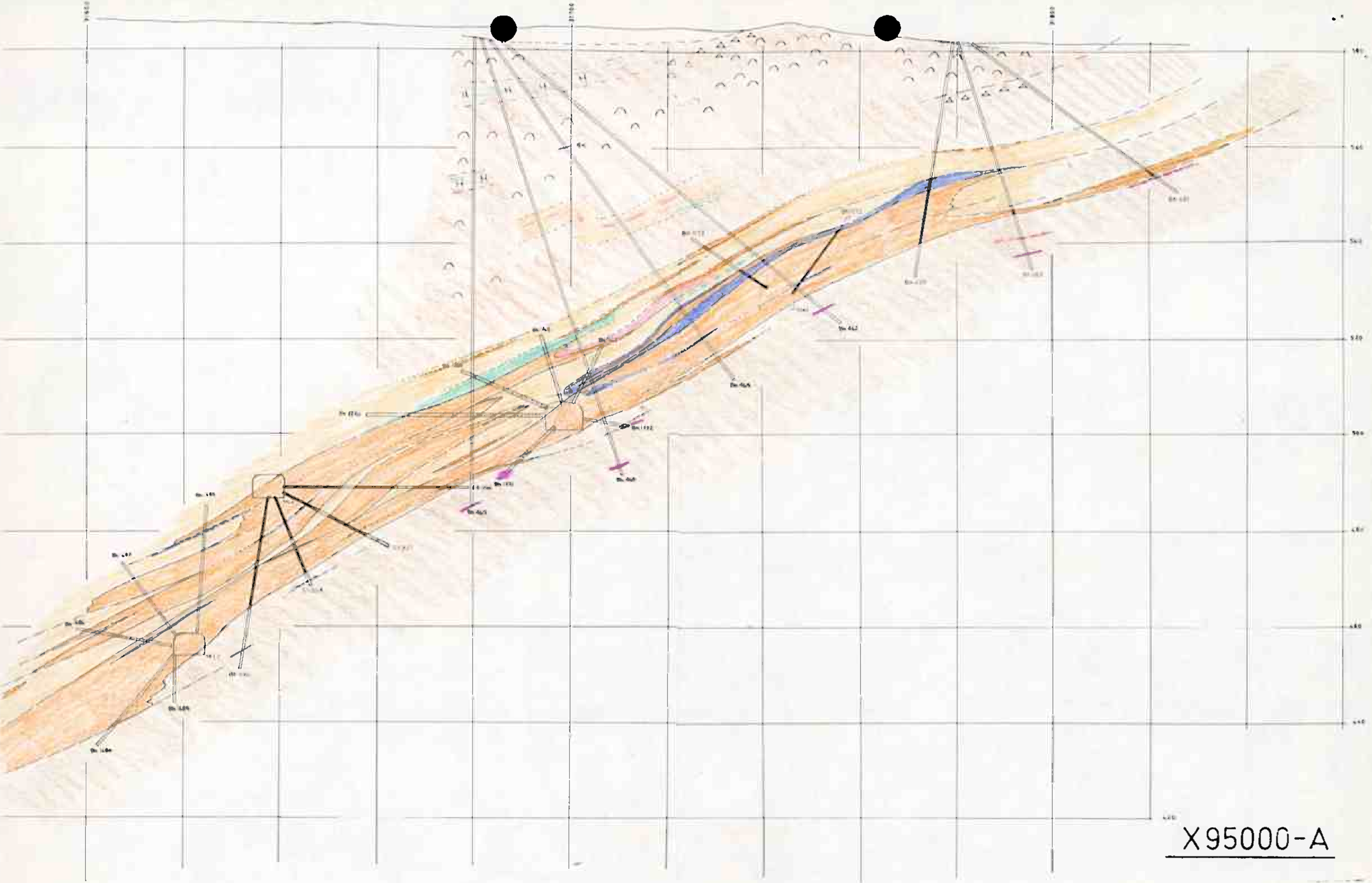

X95000-A

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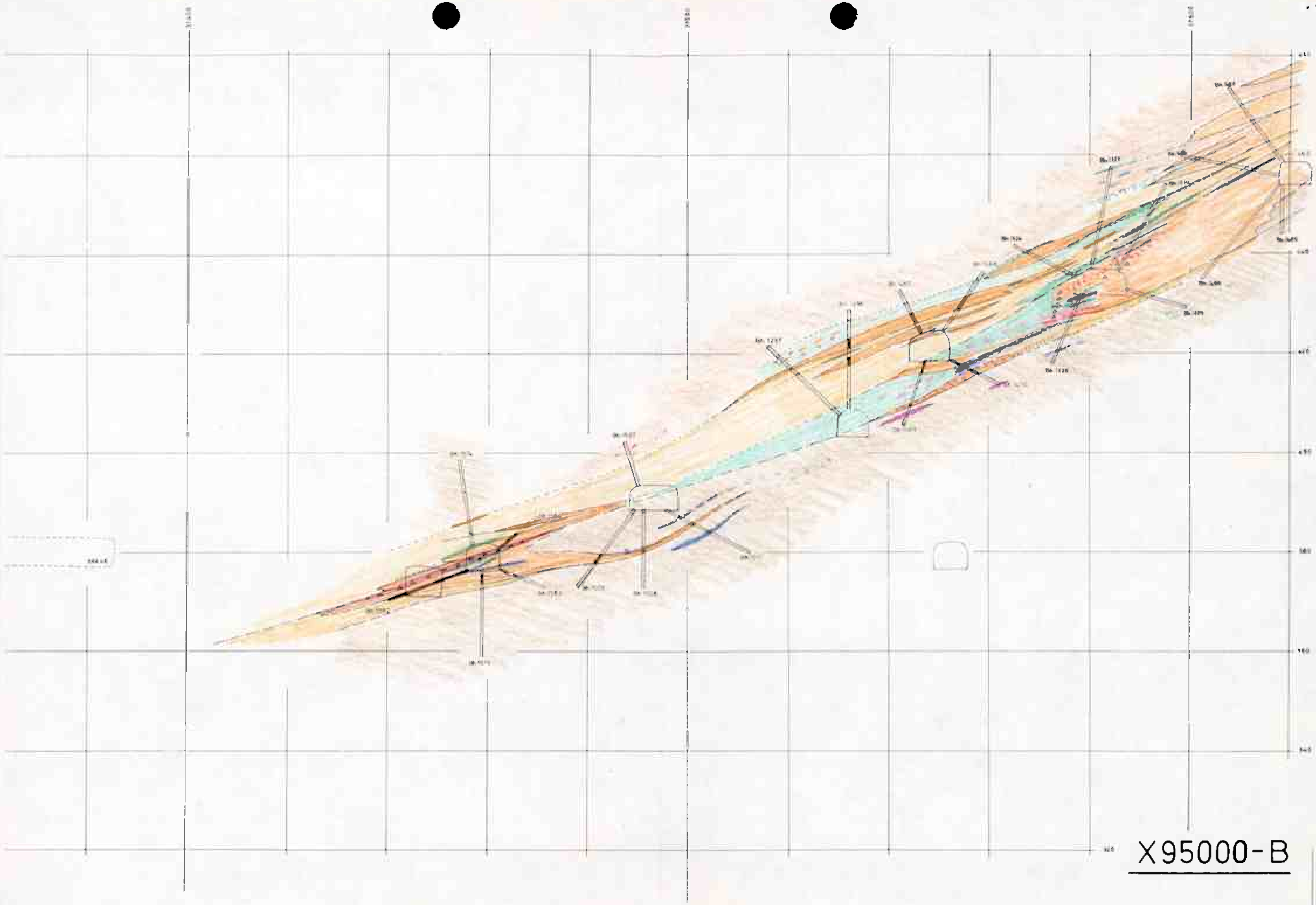
x

x 95000 A



X95000-B

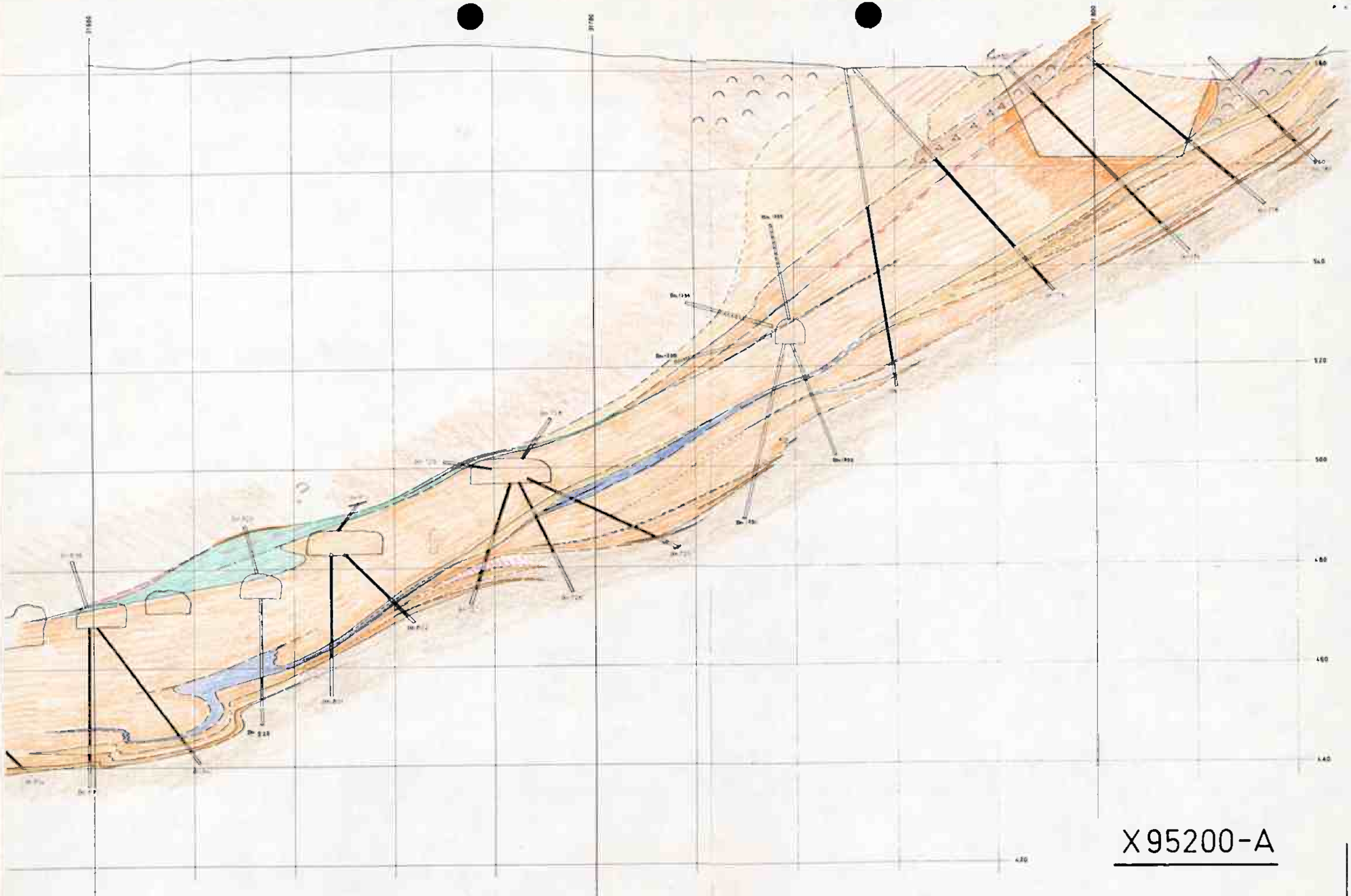
VERTIKALPROFIL
SERIE: X

MÅL 1:500

4R '81

GRONG GRUBER A/S

X 95000 B



X 95200-A

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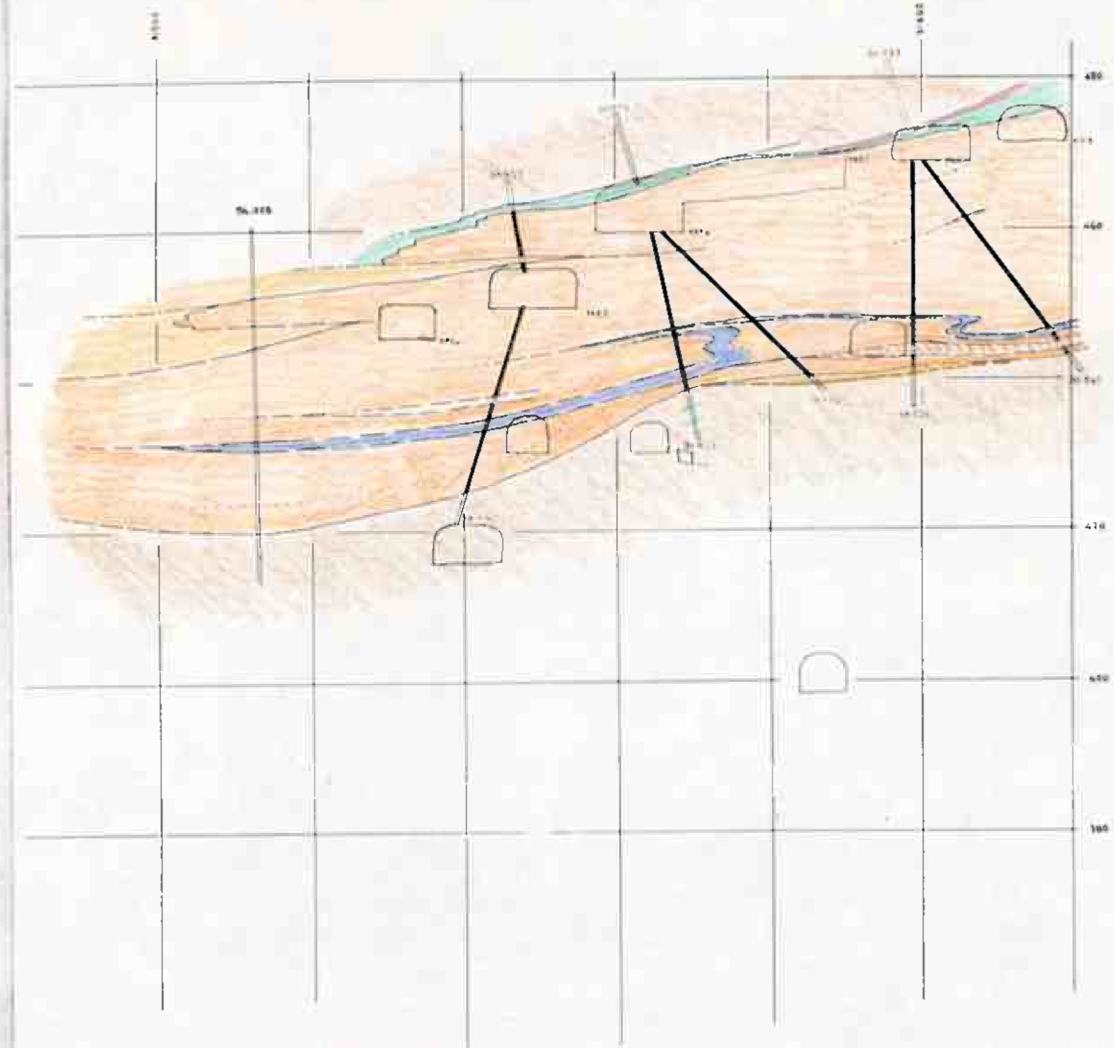

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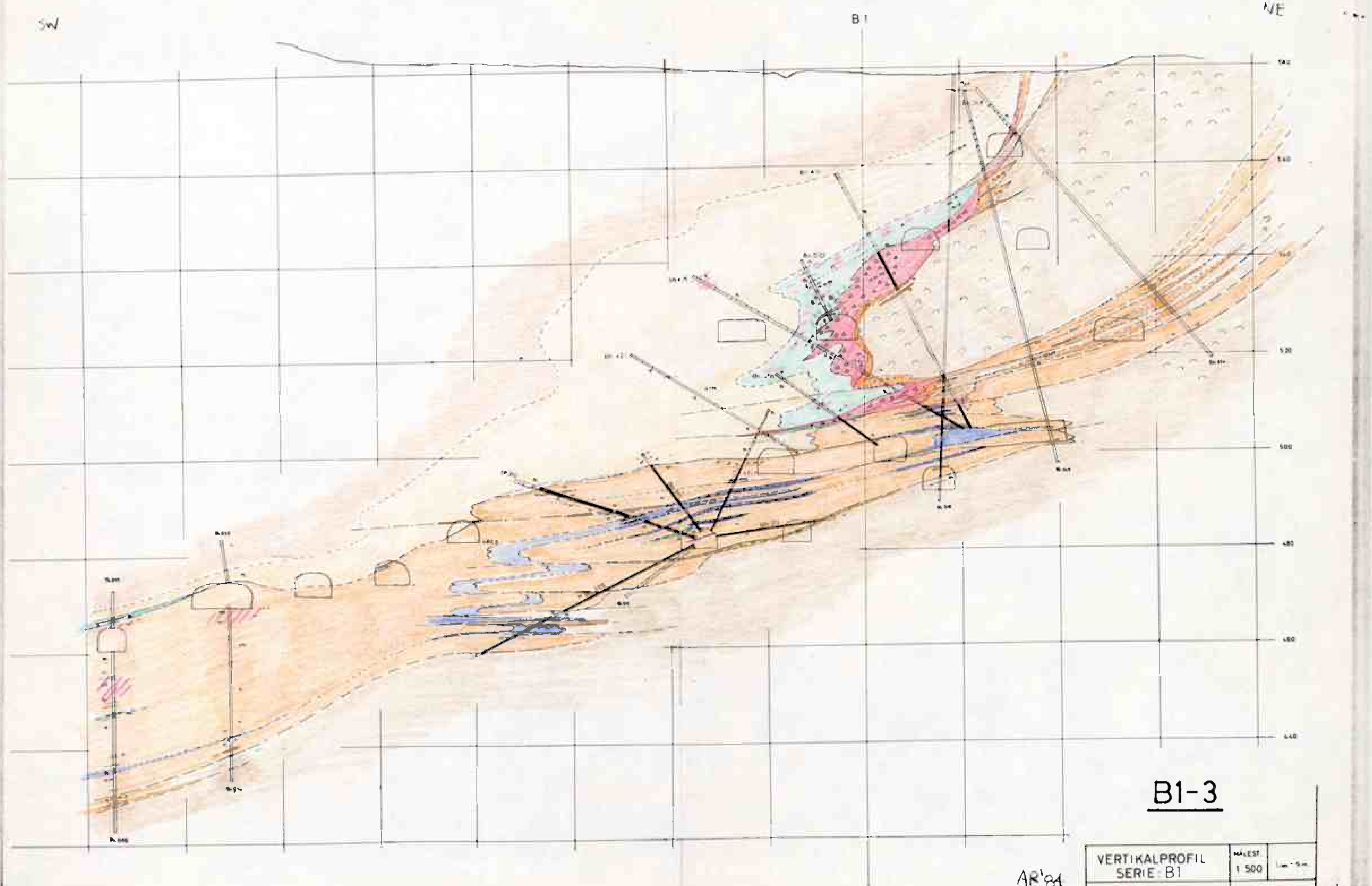

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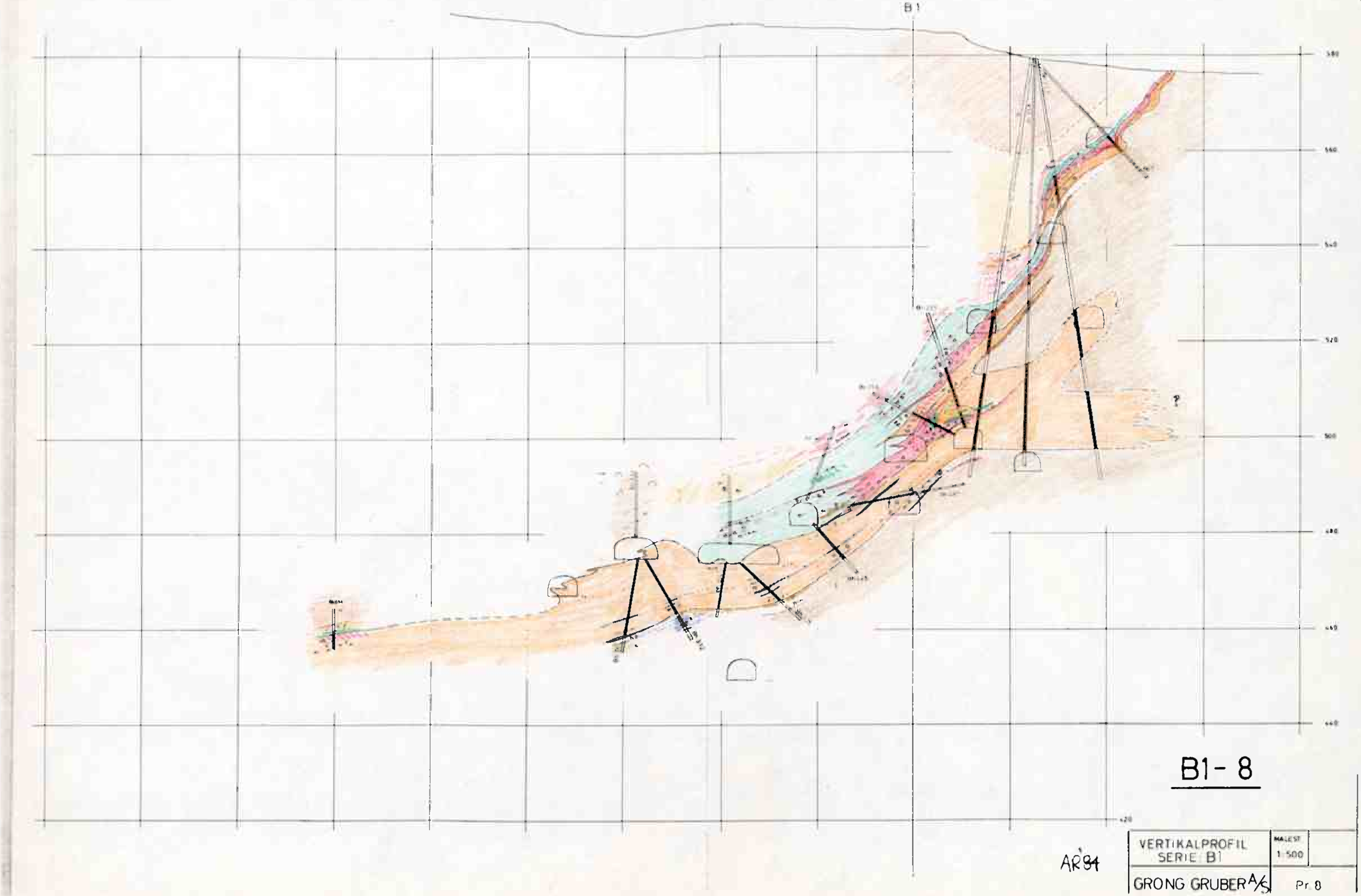
B1
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B1- 8
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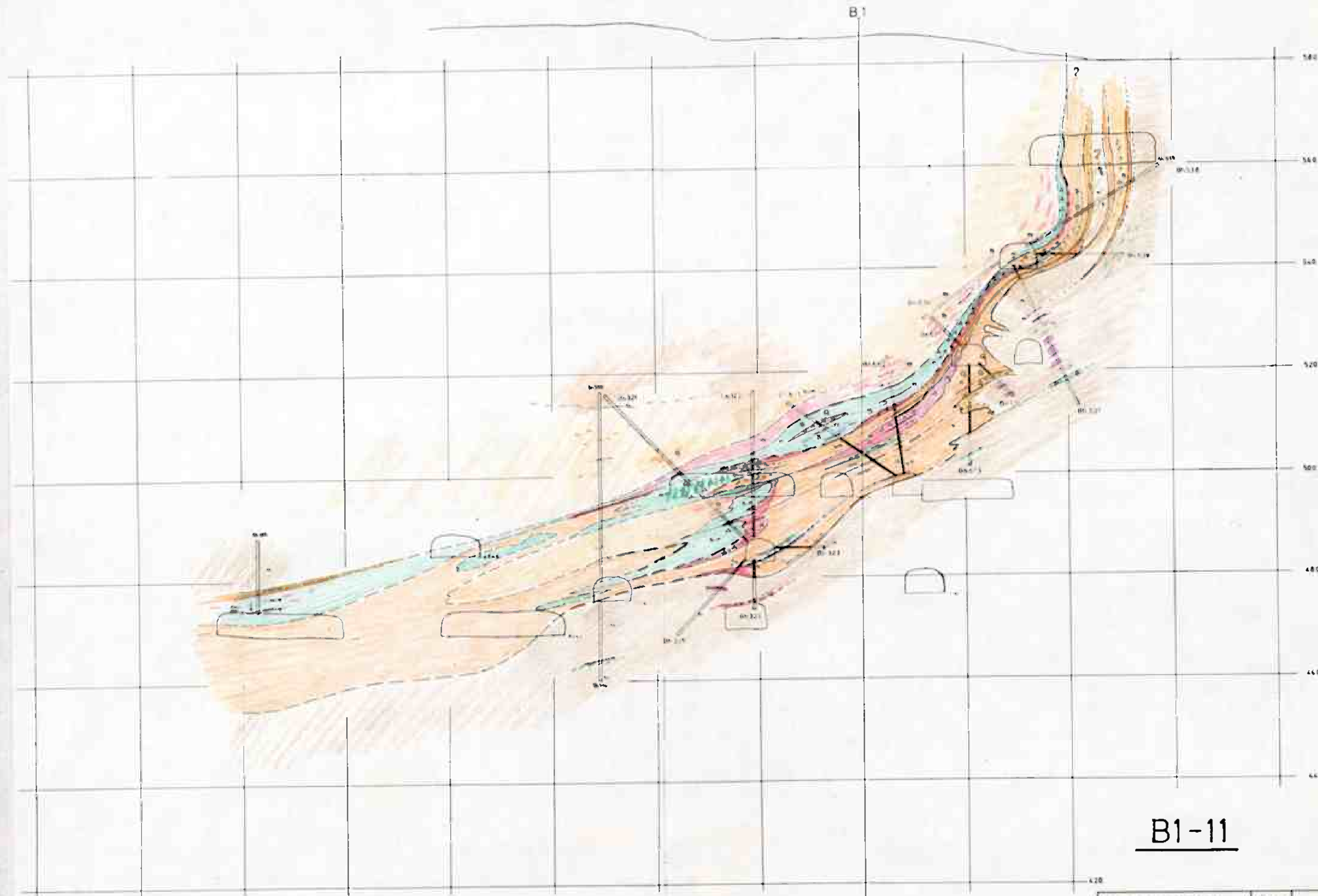
VERTIKALPROFIL
SERIE B1
MÅLEST.
1:500
GRONG GRUBER A/S
Pr. 8



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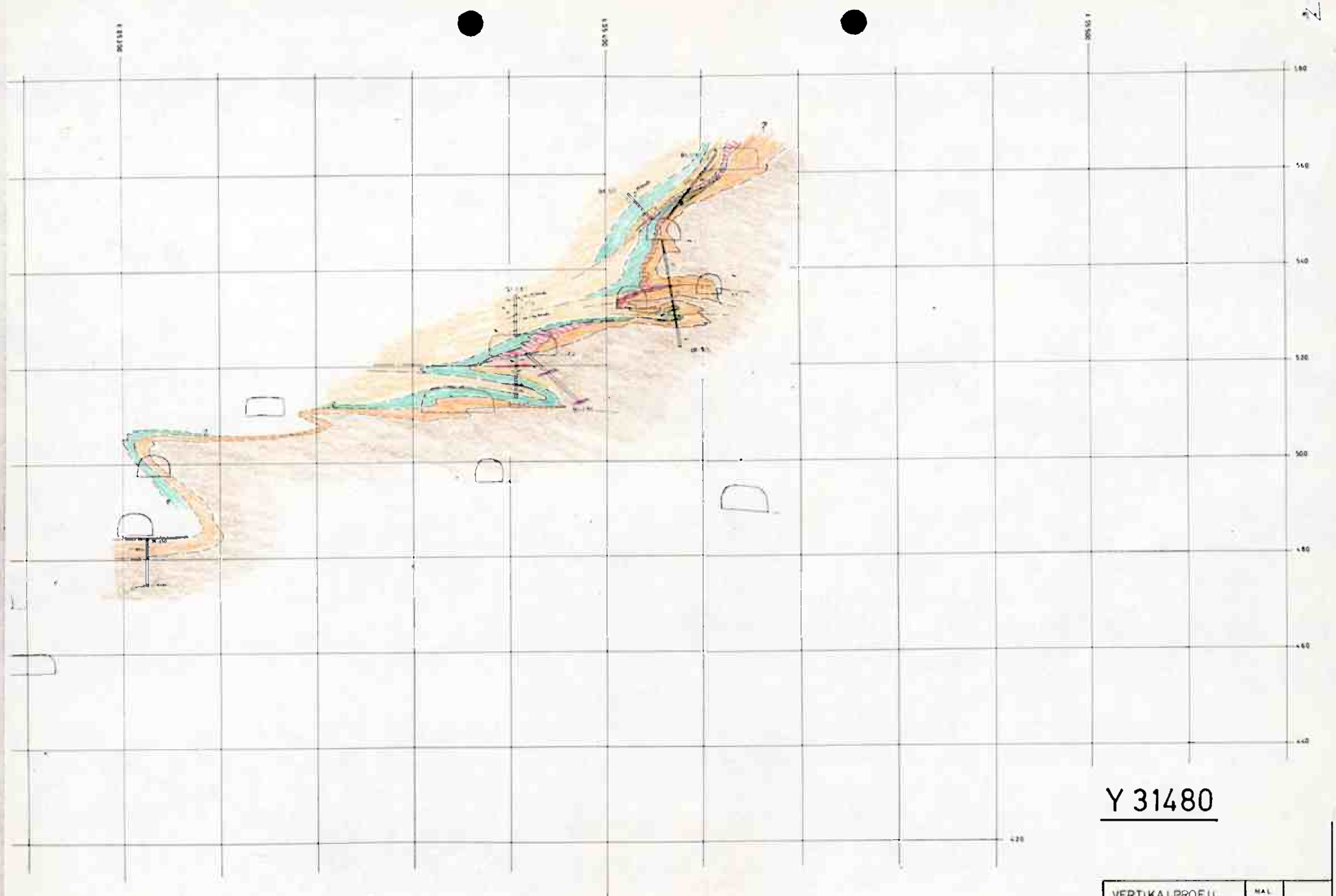
SERIE B1

1:500

GRONG GRUBER A/S

Pr.11



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AR'84

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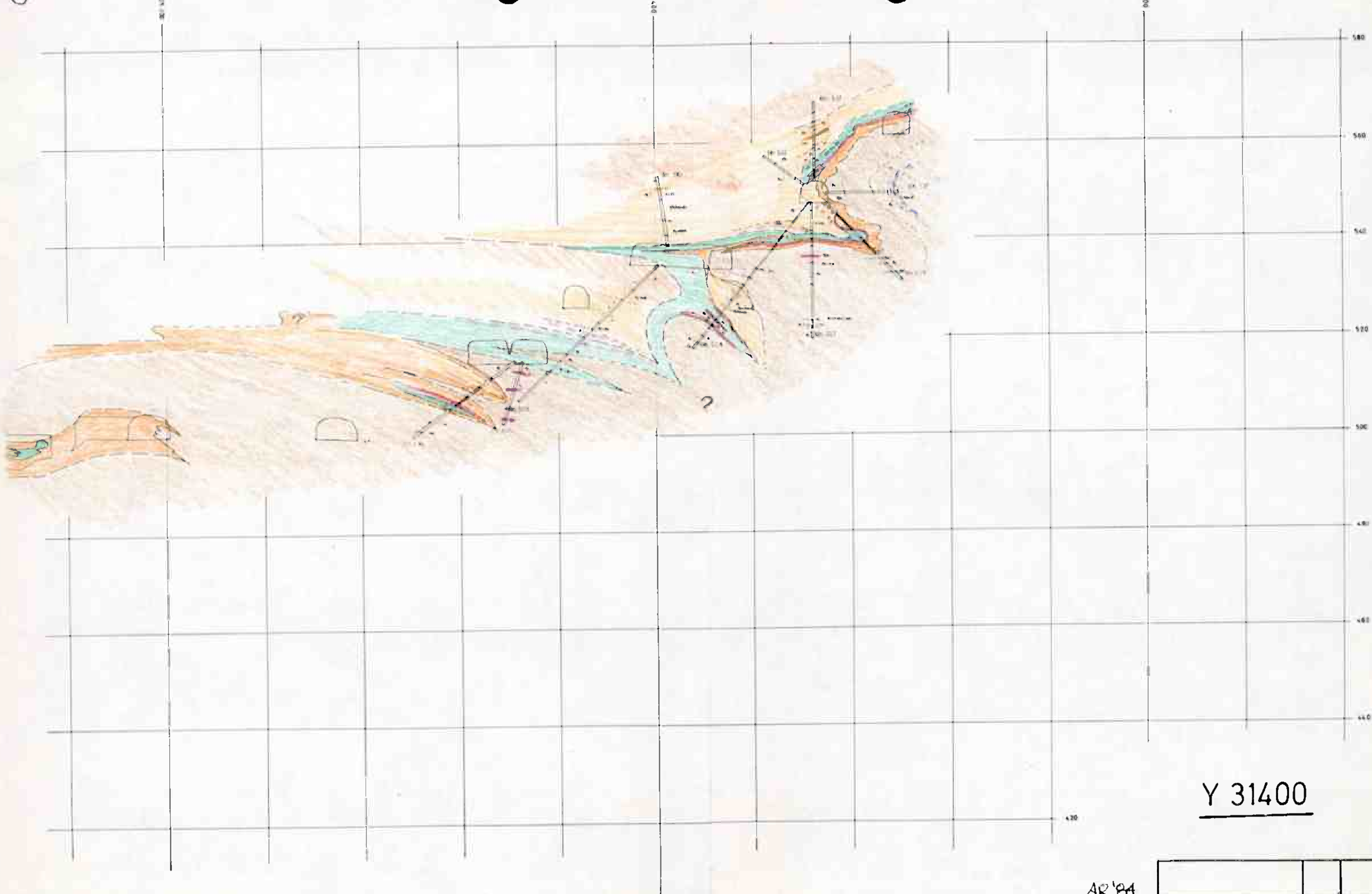
5



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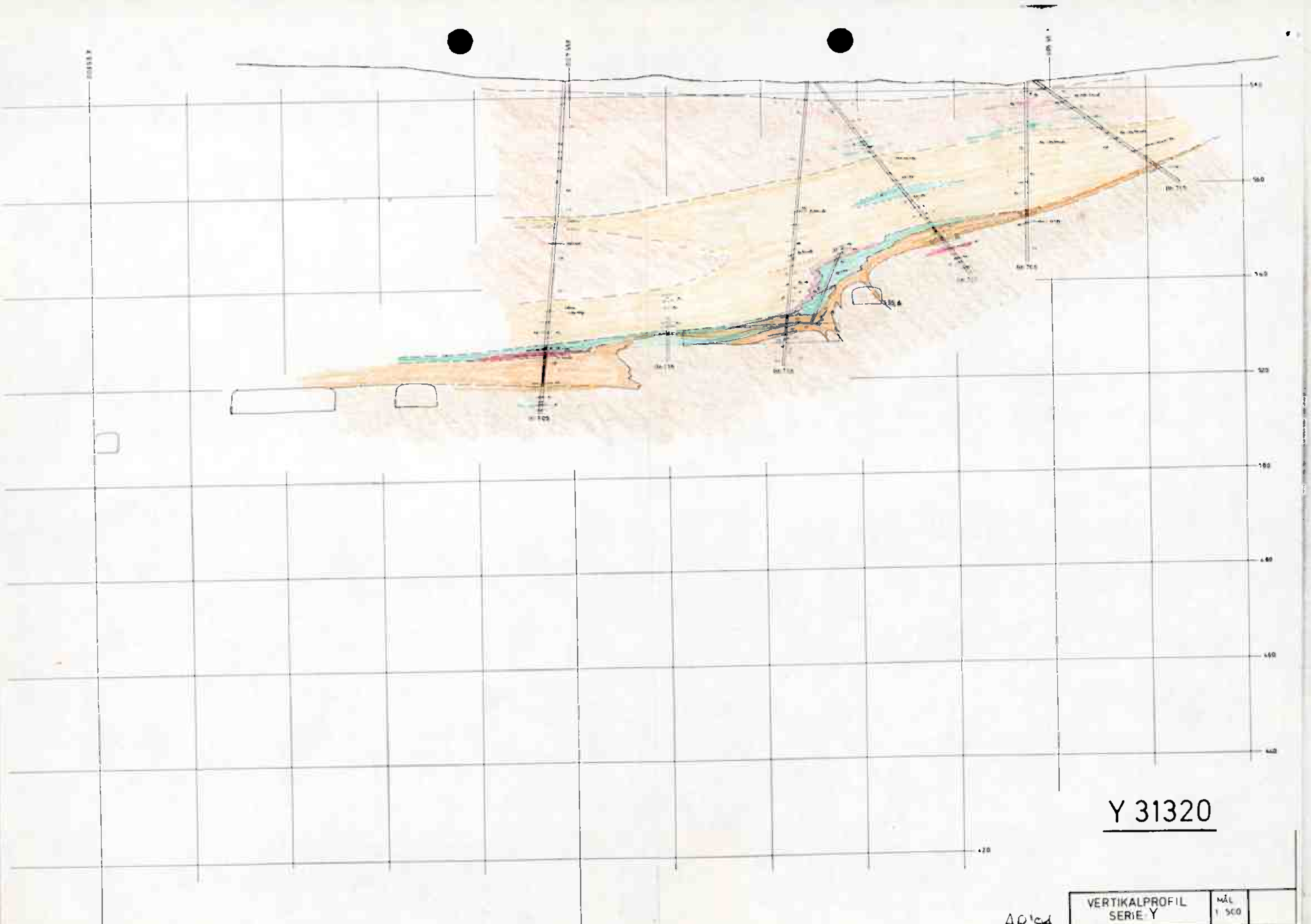
Pr Y 31 400



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AR'94

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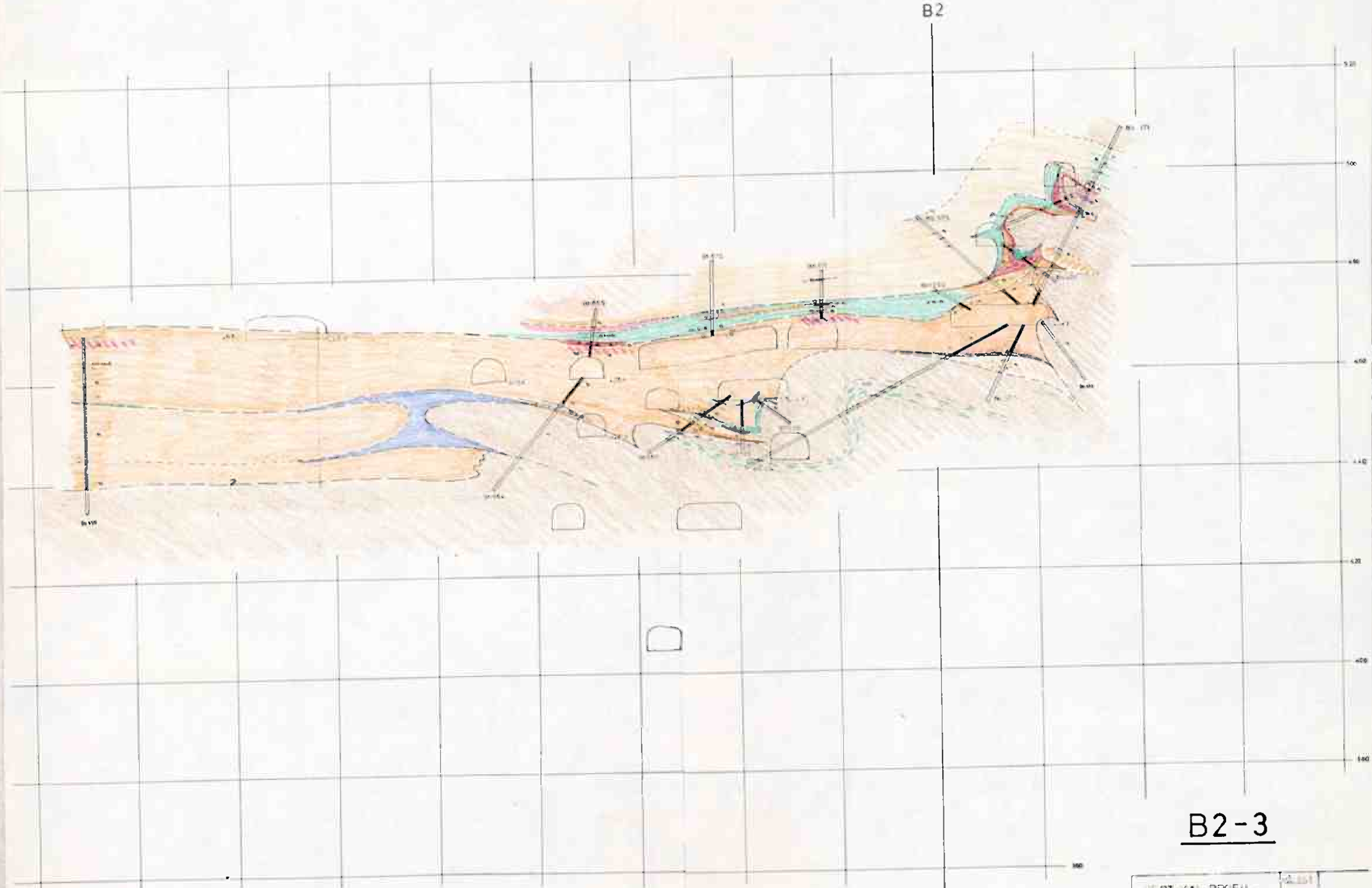


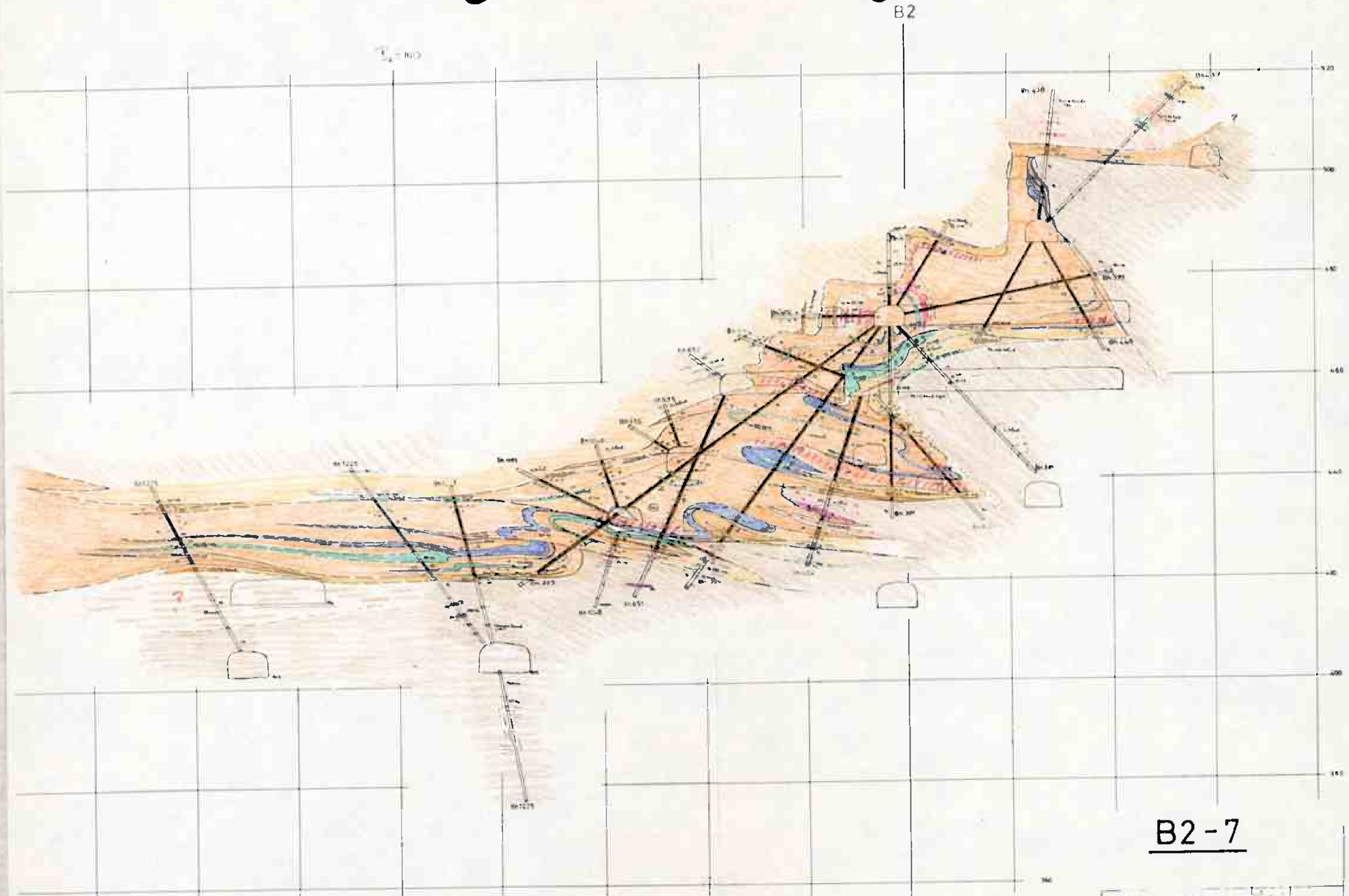
B2-3

AR'84

VERTIKAL PROFIL
SERIE B2

GRONG GRUBER A/S

Pr. 3



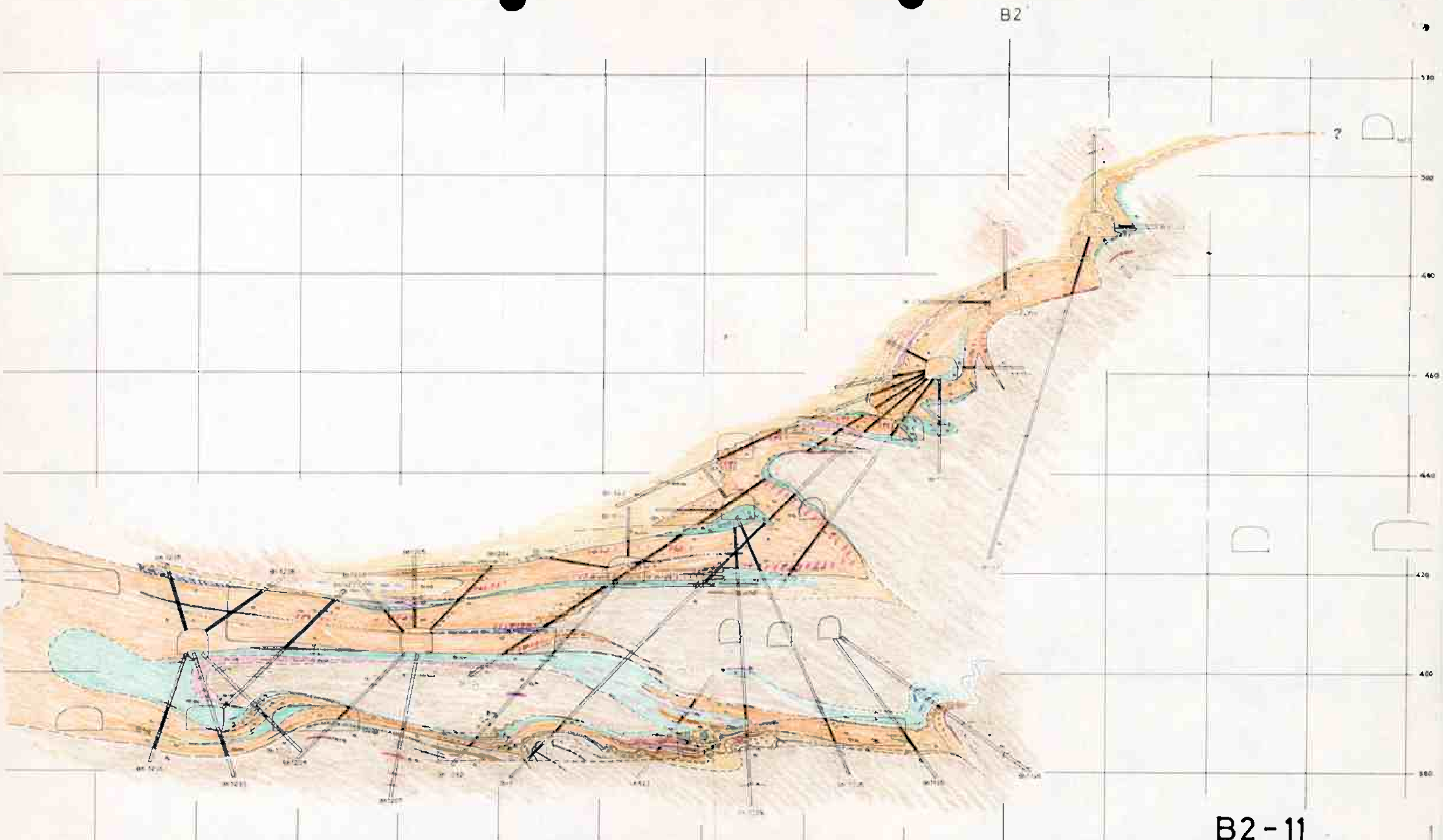
B2 - 7

AK 84

VERTIKAL PROFIL
SERIE B2

GRONG GRUBER A/S

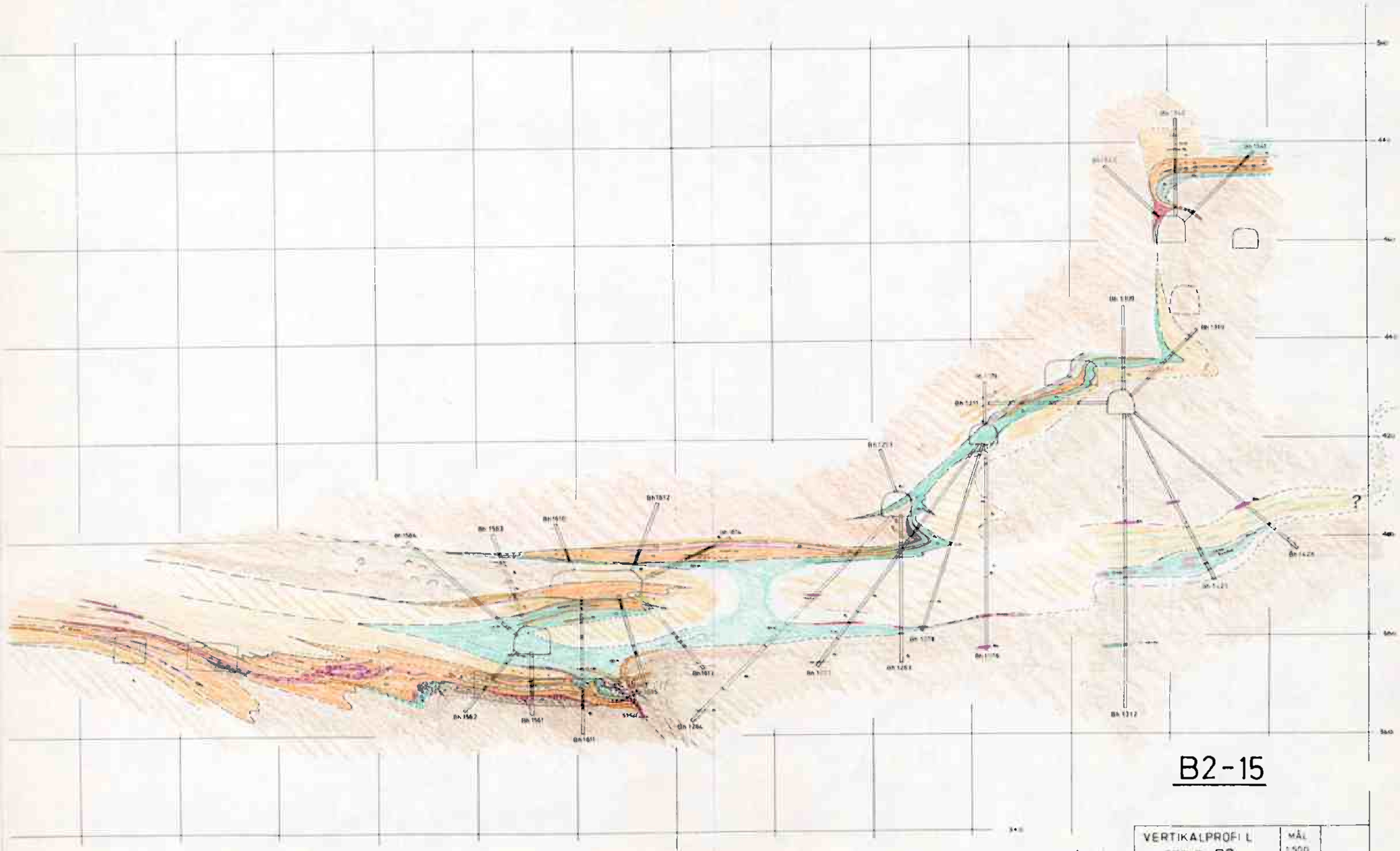
Pr 7



B2 - 11

AR'84

VERTIKAL PROFIL SERIE B2	
GRONG GRUBER A/S	Pr 11



B2-15

AR84

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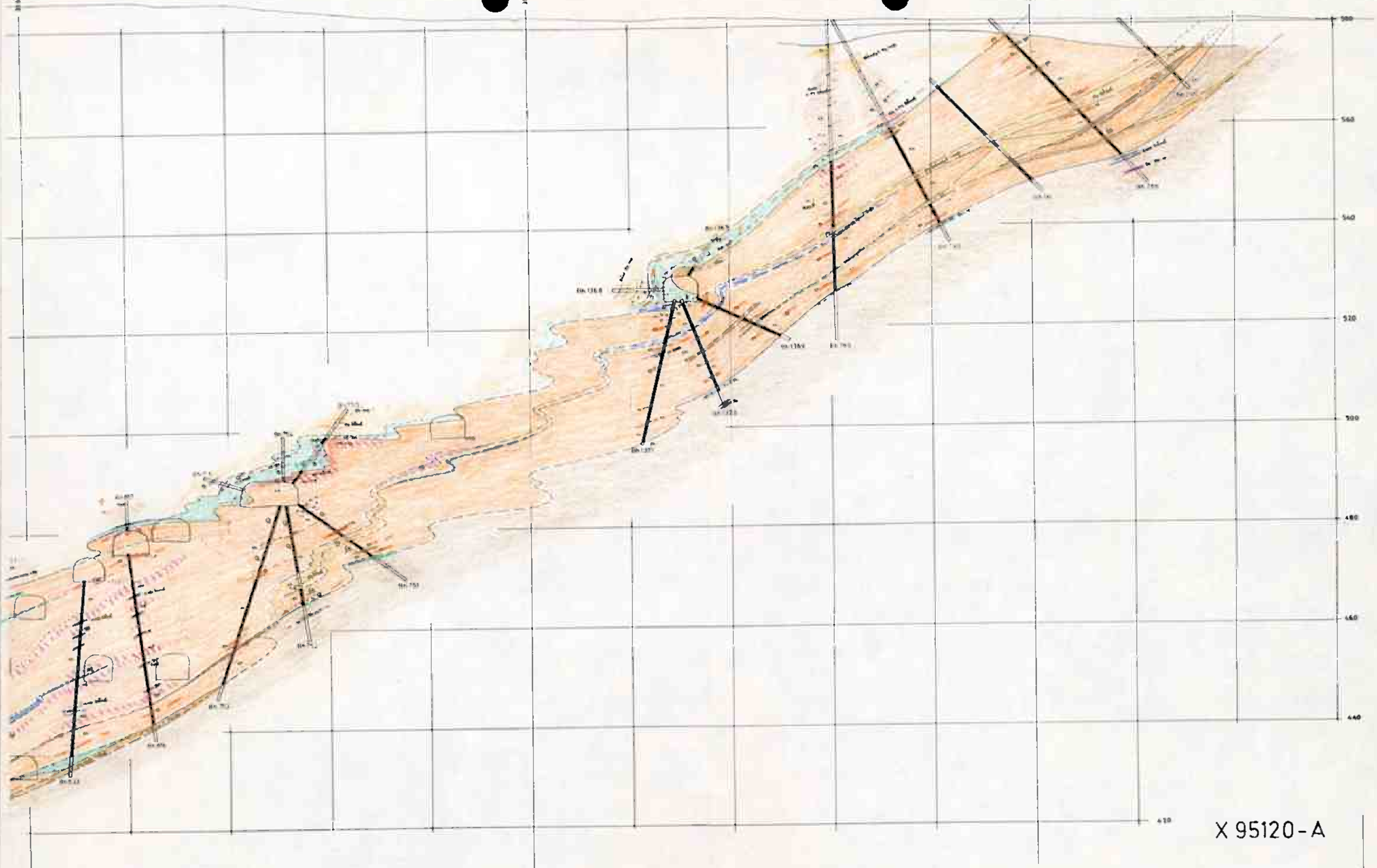

X 95120 - A

VERT. KALPROFIL SERIE X	1:500	
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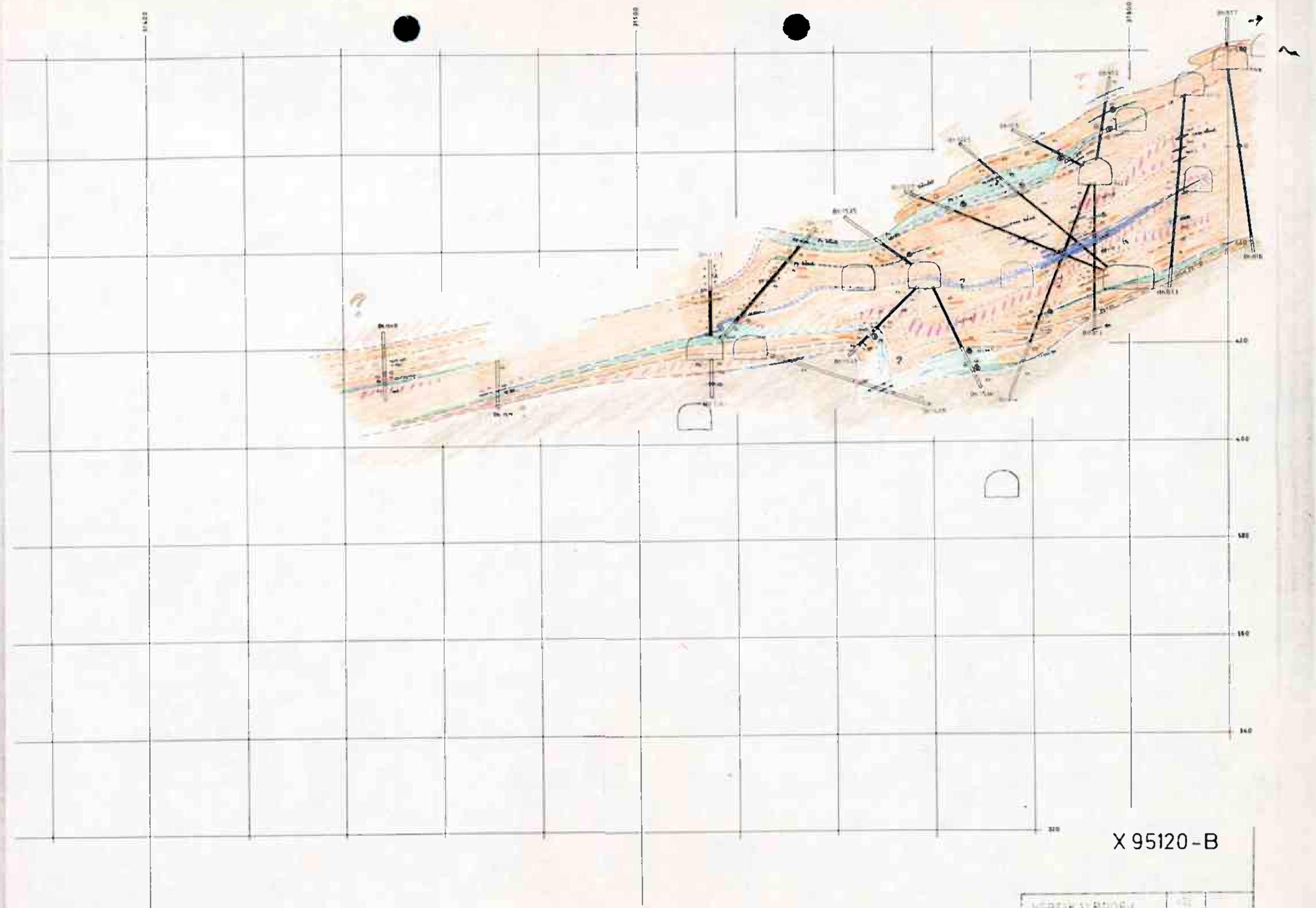

X 95120 - B

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