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INTERN RAPPORT.

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SAKSBEARBEIDER Ø. Logn

RAPPORT VEDRØRENDE:

REPPARFJORD KOBBERMALMFOREKOMST
SP-MÅLINGER I BORHULL. INNGÅR I BVLI-PROSJEKT "GEOLOGISK LOGGING AV BORHULL".

FORDELING

OSLO:

- [ ] Prospekteringsavd.

KIRKENES:

ANDRE:

- [ ] Folldal Verk A/S Repparfjord

RESYMÉ:

Kobberimpregnasjonene i Repparfjord frembringer selvpotensialer som synes å antyde at forekomsten danner en elektrisk dipol på liknende måte som de kompakte kislinealer gjør.

Selvpotensialene omkring Repparfjord er imidlertid meget mindre enn påvist ved de kompakte malmer, og målinger må utføres med stor nøyaktighet.

Potensialvariasjoner inne i forekomsten synes å følge kobbergehalten.

Potensialbilledet omkring forekomstens øvre del antyder at den kan ha stor utstrekning mot dypet elektrisk sett.

De orienterende målinger bør følges opp med mer detaljerte undersøkelser.

KOMMENTAR:

REPPARFJORD KOBBERMALMFOREKOMST

BVLI-prosjekt "Geofysisk logging av borhull"

SP-målinger

1. Innledning.

Geo-komiteen under BVLI satte i 1974 i gang prosjektet "Geofysisk logging av borhull", og oppnevnte et arbeidsutvalg for prosjektet bestående av Ø. Logn, A/S Sydvaranger og G. Grammeltvedt, Orkla Industrier. Prosjektet kom så smått i gang i 1974 med målinger i borhull boret fra Gruben på Løkken. Senere har utvalget besøkt flere gruber og forekomster av forskjellige typer, både kismalmer og jernmalmer. A/S Sydvaranger har dessuten foretatt borhullsmålinger i flere av sine gruber og malmfelter, og man regner med å benytte en del data fra disse målinger i den BVLI-rapport som arbeidsutvalget skal lage.

Arbeidsutvalget har konsentrert seg om oppgaven å beskrive forekommende selvpotensialer i borhull boret på forskjellige kjente forekomster. Det syntes naturlig å starte opp prosjektet med denne oppgave, der man hadde instrumenter og utstyr for hånden, og der man hadde et visst kjennskap til at selvpotensialene varierer betydelig ved en del malmgrenser. Senere kan man eventuelt ta stilling til om prosjektet bør utvides til å omfatte andre typer logginger.

Undersøkelsene i denne rapport kom i stand etter avtale med geolog Roar Hovland, og resultatene skal inngå i BVLI-rapporten.

2. Metode.

Selvpotensial-metoden er den eldste elektriske malmletingsmetode og tør være kjent av de fleste. Allerede omkring 1840 ble det påvist selvpotensialer i kisgruver i Cornwall, men det var først i 1913 metoden ble tatt i bruk for malmleting i Bor i Jugoslavia av de

franske brødrene C. & M. Schlumberger, og en teori for årsaken til potensialene stillet opp. Teorien, som knytter potensialene til oksydasjonsprosessene over grunnvannsnivået i en malmkropp, er ikke tilstrekkelig. I 1960 fremsatte Sato og Mooney en ny teori, der de antar at selvpotensialene omkring en malmkropp er forårsaket av forskjeller i redoks-potensialer mellom malmens øvre og nedre begrensning. Heller ikke denne teori synes tilstrekkelig, da den ikke forklarer potensialforskjeller som er større enn ca. 400 millivolt. Det er imidlertid et faktum at godt ledende kiskropper ofte forårsaker potensialforskjeller over utgående på størrelsesorden 800 mV, og over utgående godt ledende grafittskifre kan man påvise ennu høyere potensialdifferanser. Største potensialdifferans rapportert i litteraturen er vel 1800 mV, og differanser på 1200-1500 mV over grafittskifre er observert en rekke steder i vårt land, bl.a. i Grongfeltet.

For å søke å skaffe mer klarhet i opptreden og fordeling av selvpotensialer omkring en større, godt kjent kisforekomst ble det i 1969-71 foretatt målinger over Joma-forekomsten (se vedlagte avhandling av Logn & Bølviken, Geoexploration 1974). Målingene - som ble utført i NGU's regi - omfattet både overflate- og borhullsmålinger, og det ble også forsøksvis målt parametre som antas å ha betydning for potensialenes størrelse og opptreden, som redokspotensial, pH og elektrisk ledningsevne i borhullsvannet som hadde stått urørt i borhullene i minst 3-4 år.

Resultatene av disse undersøkelsene kan sammenfattes i følgende punkter:

1. Potensialene i og omkring forekomsten er sammensatt av to sannsynligvis uavhengige deler:
   a) Et potensial som skyldes de naturlige strømmer som passerer i gråberget utenom forekomsten.
   b) Et potensial knyttet til fenomener på grenseflaten mellom malm (elektronisk leder) og sidebergart (jonisk leder).

2. Det første potensial - som i artikkelen ble kalt jonepotensial - forårsaket jevne potensialgradienter av størrelsesorden 50-200 mV

i heng- og liggbergarten. Størrelsen er avhengig av i hvilken retning gradienten bestemmes.

3. Det annet potensial ble kalt elektronpotensial, fordi det ga seg til kjenne ved sterke potensialgradienter på grenseflaten mellom elektronisk og jonisk leder. Det kan antas å representere en kombinasjon av et elektrodepotensial og polarisasjonseffekter på elektrodene.

4. Jonepotensialet viste - etter eliminasjon av elektronpotensialer fra kisimpregnasjoner og malm - en tydelig dipolnatur med positiv pol ved malmens nedre del og negativ pol i utgåendet.

5. Det lave potensial på overflaten over malmens subutgående (maksimalt - 820 mV) ble oppfattet som bestående av et elektronpotensial på ca. -700 mV og et jonepotensial, som ga et potensialfall på ca. 120 mV inn mot utgåendet.

6. Elektronpotensialet er en næreffekt og avtar på overflaten hurtig med økende tykkelse av overdekket; jonepotensialet er imidlertid en fjernvirkning av malmkroppen, som i denne forbindelse blir å oppfatte som en elektrisk dipol.

7. Jonepotensialets fjernvirkning vil kunne benyttes direkte i malmletingsproblematikk. Målinger på overflaten kombinert med borhullsmålinger vil gi opplysninger om posisjonen av dipolens nedre pol, d.v.s. malmkroppens avslutning mot dypet.

8. Elektronpotensialet varierte i takt med gråbergsinnblanding i malmen og syntes å følge malmens svovelgehalt, d.v.s. malmens svovelkisinnhold (lite magnetkis), og det ble antatt at selvpotensialmålinger over malmgrensene og inne i malmkroppen utført i borhull og i orter skulle kunne benyttes som veiledning for gruvedrift, anvendt i kombinasjon med eller i stedet for diamantboringer.

For videre detaljer henvises til artikkelen som vedlegges som bilag.

Det er elektronpotensialets variasjoner ved malmgrenser, og inne i malmkropper som i første rekke er objekt for BVLI-prosjektet. Prosjektet har til hensikt å undersøke elektronpotensialets variasjoner i forekomster som er, eller kan bli satt i drift og se potensialvariasjonene fra et driftsteknisk synspunkt.

3. Forekomsten.

Geofysisk sett har Repparfjordforekomsten spesiell interesse. Forekomsten er (Bergverk 1975) knyttet til feltspatholdig kvartsitt innen det prekambriske Komagfjordvinduet. I et sterkt tektonisert område av kvartsitten har man her en impregnasjonssone av kobberkis, bornitt og kobberglans. Denne sone er i strøklengde fulgt sammenhengende 2 km med en maksimal mektighet på ca. 100 m i det sentrale området. Sonen som har et steilt, varierende fall er til nu påvist til et dyp av ca. 250 m under dagoverflaten. Mektigheten avtar mot dypet, mens kobbergehalten ser ut til å holde seg uendret. Hele sonens totale malmkvantum antas å være 12-15 mill. tonn med 0,6-0,7% Cu.

Man antok at den spesielle malmtype som finnes i Repparfjordforekomsten - fattig impregnasjon med bornitt og kobberkis som hovedmalmmineraler - ville være interessant som objekt for målinger av selvpotensialer i borhull. Fra NGU's undersøkelser i 60-årene kjente man til at selvpotensialer finnes i dagoverflaten over malmsonens utgående. Malmen har utvilsomt en dårlig elektrisk ledningsevne som sikkert ikke skiller seg spesielt ut fra sidebergartens ledningsevne. Man skulle a priori anta at en sådan malm burde forårsake relativt små selvpotensialdifferanser ved malmgrensene.

4. Utførelse.

Forsøkene i Repparfjord ble utført 12. juli 1976. Målinger ble foretatt i diamantborhullene 962 A og 962 B i profil 962 Y, samt i 970 A i profil 970 Y. Borhull 962 A var blokkert i 32 m dyp (omtrent i malmgrensen) og vi fikk således ikke potensial-kontakt med malmen. Borhull 962 B var blokkert i 88 m dyp; i dette hull fikk man målt seg gjennom mesteparten av malmmektigheten. Borhull

970 A var det eneste hull som var åpent helt ned i bunnen. Man har derfor bare en fullstendig passering av malmsonen, i de 2 andre hull har elektroden stoppet enten i malmsonen eller over denne.
Det ble forsøkt målinger i flere borhull, men disse var alle tette i påhugget.
I alle tre borhull ble potensialet bestemt med 2,5 m innbyrdes avstand mellom målepunktene. Potensialene i de enkelte borhull ble målt i forhold til et vilkårlig referansepotensial i Dagen nær borhullspåhugget. Det ble også søkt målt potensialprofiler i Dagen i de to borprofiler (962 Y og 970 Y); potensialene i overflaten varierte imidlertid relativt sterkt med overdekkets art og tykkelse, og målingene i Dagen er ikke direkte sammenliknbare med borhullsmålingene.
Ved målingene ble benyttet $Cu/CuSO_4$ upolariserbare potensialelektroder og et Data Precision digitalt multimeter. Repetisjoner av målingene tatt ved oppheising av elektroden i borhullet ga som regel resultater som ikke avvek mer enn 2-3 millivolt fra potensialene målt under nedheising av elektroden (K = kontrollmåling i pl. 1, 2 og 3).

5. Resultater.

Resultatene i de enkelte borhull er fremstillet som potensialkurver i pl. 1 og 2 (borprofil 962 Y), samt i pl. 3 (borprofil 970 Y). Borprofilene er tegnet i målestokk 1:500 og er stillet til disposisjon av geolog Hovland. Potensialvariasjonene i borhullene er fremstillet i relativt stor målestokk; 10 millivolt er lik 2,5 cm, og positivt potensial er til venstre på plansjene. Referansepotensialet ved påhuggene er vilkårlig satt lik null.

I pl. 4 har man forsøksvis laget en tydning av fremkomne jonepotensialer (se nedenfor) basert på en sammentegning av de tre målte borhull, idet det åpenbart var ønskelig å fremstille et ekvipotensialbillede av jonepotensialet omkring forekomsten. Sammentegningen er gjort, fordi man har så få måledata.

Av de tre borprofiler pl. 1, 2 og 3 fremgår at potensialene langs borhullene synes å være en sum av 2 potensialer:

a) Et potensial som avtar jevnt med dypet og danner en skrå "grunnlinje" i plansjene. Potensialet øker minst med dypet i det dypeste borhull 962 B.

b) Overlagret det jevne potensial ligger potensialer som varierer relativt sterkt langs borhullene (farvet orange i plansjene). De sterkeste variasjoner synes å følge kobberinnholdet i bornittmalmen.

Det jevne potensial svarer til det Logn og Bølviken i vedlagte artikkel av Jomaforekomsten kalte "jonepotensial"; det annet potensial representerer åpenbart potensialene som i Joma ble betegnet "elektronpotensial".

Resultatene i Repparfjord er således i utmerket overensstemmelse med resultatene i Joma bortsett fra ett forhold:

1. Jonepotensialdifferansene i malmliggen (skråningen av potensialkurvens grunnlinje) er av størrelse -2 mV (borhull 962 B, pl. 2) til -20 mV (borhull 962 A, pl. 1), regnet over borhullslengden fra påhugg til malmgrense. I tilsvarende posisjon på Jomaforekomsten er jonepotensialene av størrelsesorden -120 mV.

2. Elektronpotensialvariasjonene ved malmgrensene er av størrelse 4-32 mV; størrelsen synes til en viss grad å variere parallelt med kobbergehaltene. I Joma var tilsvarende potensialer av størrelse 400-600 mV for kompakt kis, og noe mindre for kisimpregnasjoner.

Det kan i denne forbindelse pekes på at potensialkurvene er basert på oppmåling av potensialene i borhullene med 2,5 m intervaller; man skulle formode at man hadde fått en mere variert kurve ved tettere målinger i borhullene. Dette kan være årsak til at potensialvariasjonene ikke i detalj følger kobbersøylene som i det vesentlige representerer prøvetaking av en meters borkjerner.
Mindre potensialvariasjoner fra 2 til 6 mV forekommer utenom malmsonen uten at disse kan direkte parallelliseres med borhullsdata. Man kan anta at noen variasjoner skyldes svakere kisimpregnasjoner (se f.eks. pl. 1); andre kan kanskje skyldes vann i forkastningssoner som er registrert både i ligg og i heng.

Det var nevnt at jonepotensialet hadde forskjellig størrelse i de tre borhull. For å skaffe rede på hva dette egentlig betyr, ble jonepotensialene avlest på plansjene 1, 2 og 3 (streket grunnlinje) og påført skissen pl. 4, der borhull 970 A er søkt projisert inn i snittet med borhullene 962 A og B. På basis av de på denne måte fremkomne jonepotensialer i borhullene er det tegnet ekvipotensiallinjer med ekvidistanse 2,5 og 5 mV. Linjene er tegnet med streket linje for å antyde deres hypotetiske karakter. Vinkelrett på ekvipotensiallinjene er anvist strømlinjer som viser jonestrømmenes omtrentlige retning i snittet.
Det går frem av skissen at malmen i prinsipp synes å representere et negativt sentrum nær utgående, og jonestrømmer som går i sidebergarten (sandstein), fører positive ladninger mot dette sentrum. Overensstemmende med teorien for selvpotensialene må man forutsette at forekomsten også har en positiv pol i dypet. Den tydelige konvergens av strømlinjene mot øvre pol tyder på at nedre pol befinner seg forholdsvis dypt sett i relasjon til de ca. 70 m vertikal høyde som pl. 4 representerer. Borhullsmålingene synes således å antyde at malmen elektrisk sett har en relativt stor utstrekning mot dypet. Forholdet er på ingen måte utfyllende undersøkt, og resultatet gis her med alle forbehold.

6. Konklusjon.

Som man hadde ventet synes ikke Repparfjordforekomsten å frembringe store selvpotensialer som de kompakte kisforekomster vanligvis gjør. Hva man ikke ventet, var at man skulle få påvist potensialvariasjoner som det visuelt var enkelt å spalte i 1) Jonepotensial og 2) Elektronpotensial, på liknende måte som Logn og Bølviken har vist for Jomaforekomstens kompakte kismalm. Elektronpotensialet syntes så langt det var mulig å kontrollere ved et kortvarig besøk, å følge parallelt med svovelgehaltene og ikke med kobber- eller sink-gehaltene. Denne forskjell må antas å bero på at det i Repparfjord hovedsakelig er bornitt - det kobbermineral som forekommer i størst mengde - som forårsaker de forekommende selvpotensialer (både elektron- og jonepotensialer).

Det skulle derfor være grunn til å følge opp de utførte orienterende målinger med mere detaljerte undersøkelser for å skaffe til veie et bredere erfaringsmateriale.

Lysaker, 20/12-1976

Ø. Logn

Etterfølgende bilag viser de diamantborhull som ble boret i år (1966), opptegnet i profiler. I noen av profilene har man fra tidligere av diamantborhull som også er inntegnet.

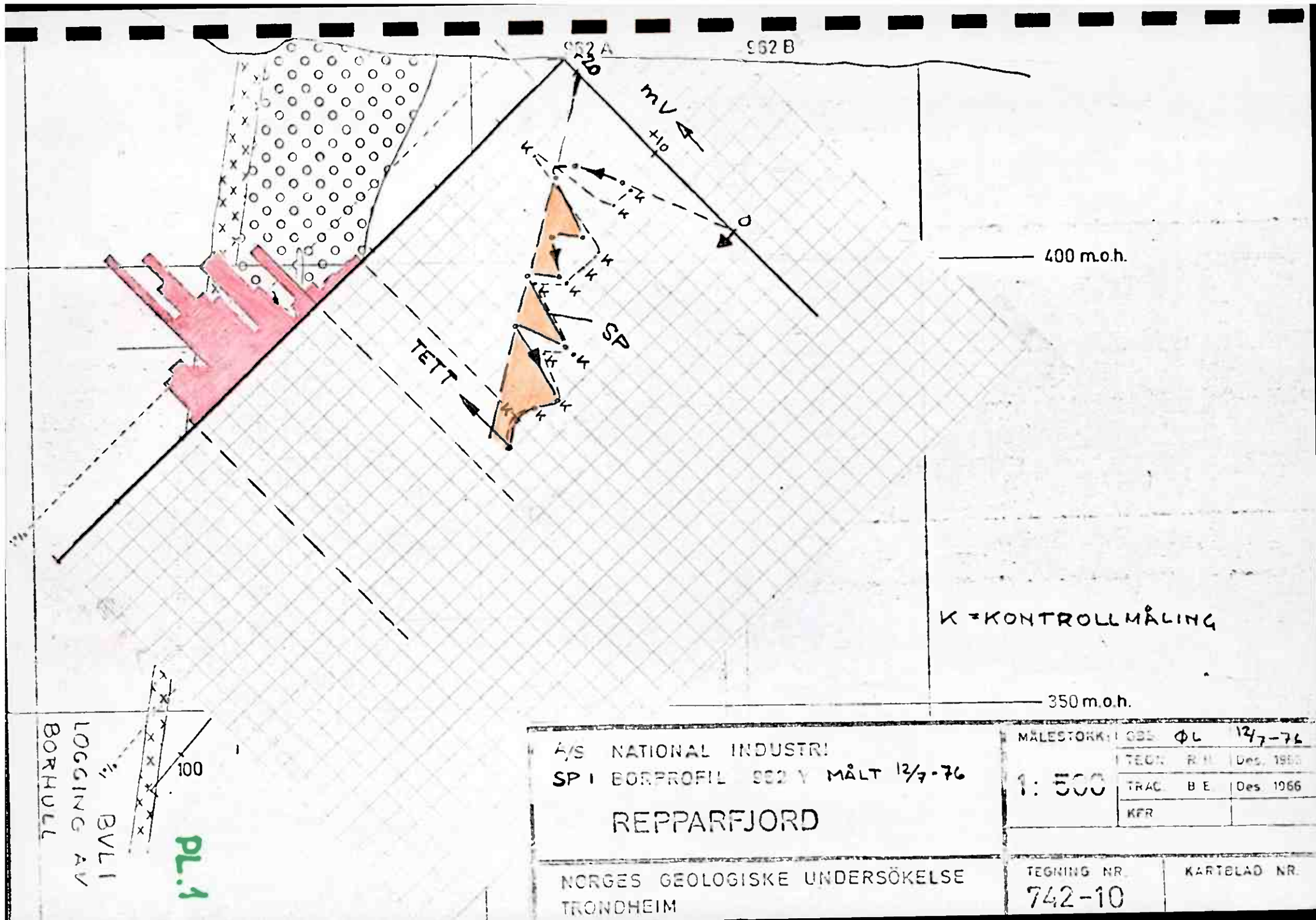
Profilene viser videre mineraliseringssonene samt type av mineralisering. I profilene fra Vestfeltet hvor mineraliseringen opptrer i nær kontakt med forkastningssoner, er disse også inntegnet. Analyseresultatene er dessuten avsatt grafisk langsetter borhullene.

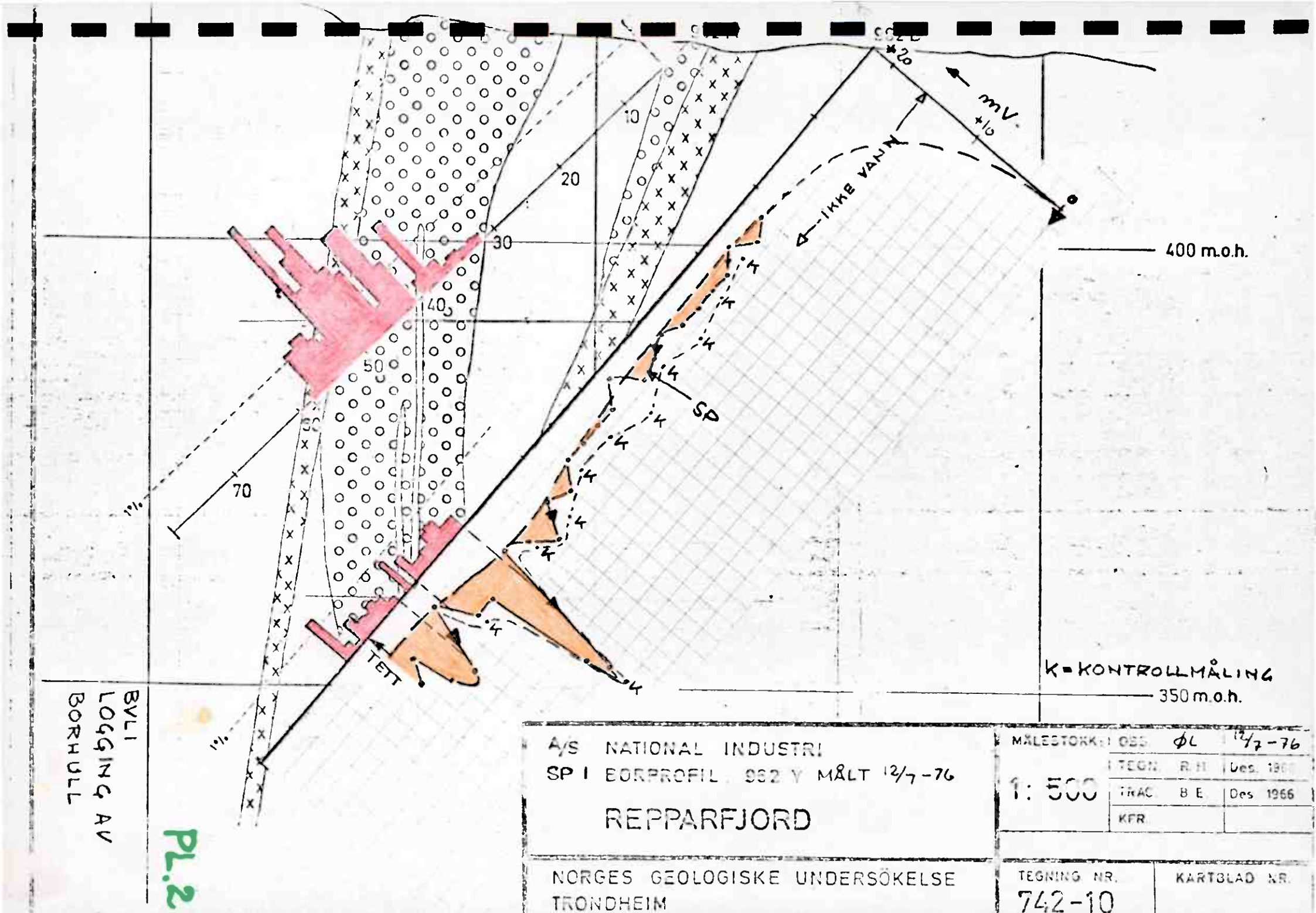
Trondheim, 20/1-67

Roar Hovland
Bergingeniør

Terrforklaring:

	kobberkisimpregnasjon
	svovelkisimpregnasjon.
	bornitt, kobberglansimpregnasjon.
	kobberkisholdig svovelkisimpregnasjon.
	bornitt, kobberkisimpregnasjon.
	forkastningssone.
	svovelkisimpregnert forkastningssone.
A.4 - A.6	anomalisoner funnet ved IP-målinger.
Borhull 1cm = 1% 2mm = 1m	grafisk framstilling av analyser.


962 A
962 B
MV
+10
0
400 m.o.h.
SP
TETT
K = KONTROLLMÅLING
350 m.o.h.
LOGGING AV BORHULL
100
PL.1
A/S NATIONAL INDUSTRI
SP 1 BORPROFIL 962 Y MÅLT 12/7-76
REPPARFJORD
MÅLESTOKK: 1:500
ØL 12/7-76
TEGN. R.H. Des. 1966
TRAC. B.E. Des. 1966
KFR
NORGES GEOLOGISKE UNDERSÖKELSE
TRONDHEIM
TEGNING NR. 742-10
KARTBLAD NR.



BVL I LOGGING AV BORHULL

PL. 2

A/S NATIONAL INDUSTRI

SP I BORPROFIL 982 Y MÅLT 12/7-76

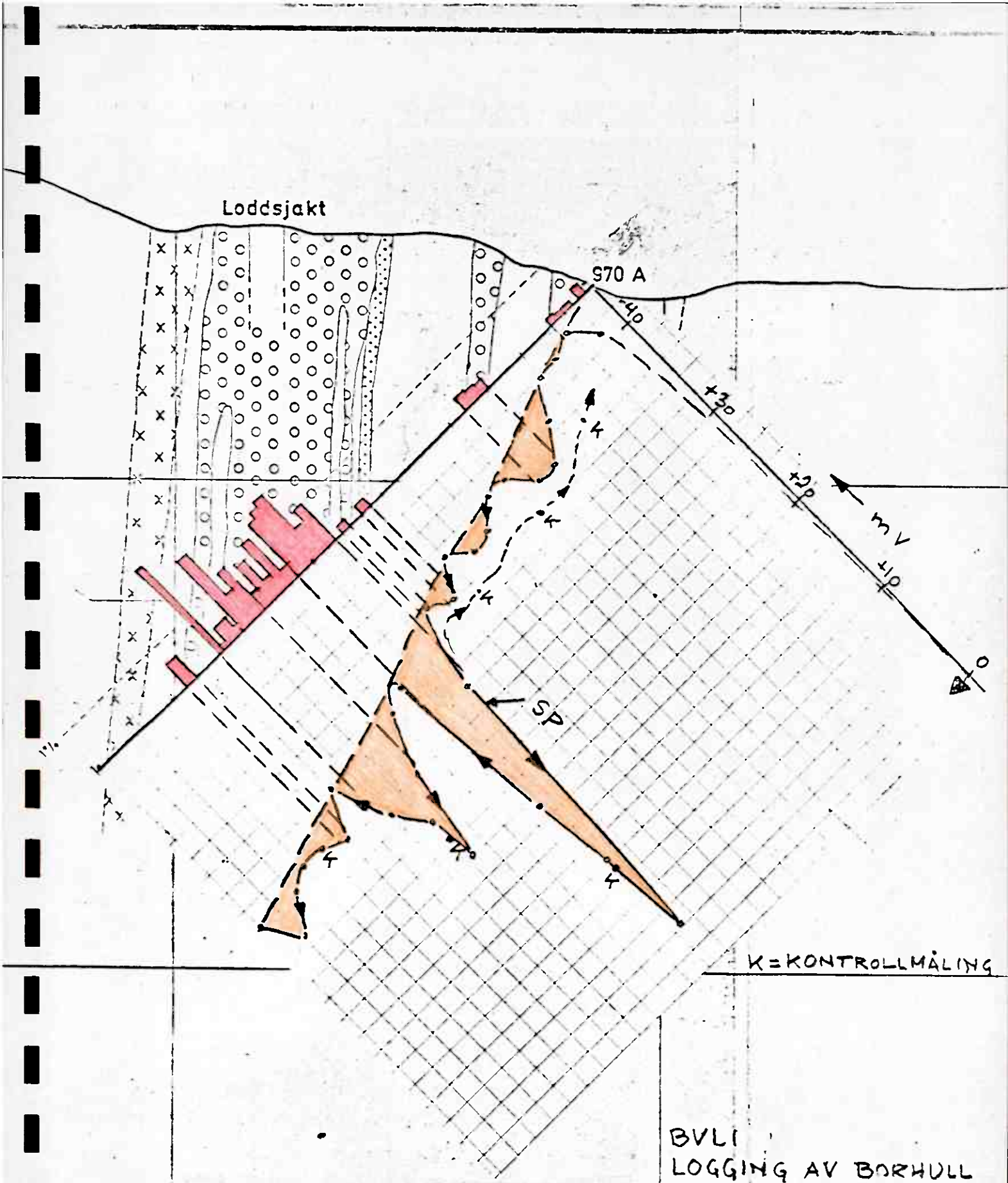
REPPARFJORD

MÅLESTOKK:	OSS	ØL	12/7-76
1: 500	TEGN.	R. H.	Des. 1966
	TRAC.	B E	Des 1966
	KFR.		

NORGES GEOLOGISKE UNDERSÖKELSE
TRONDHEIM

TEGNING NR. 742-10

KARTBLAD NR.



BVLI
LOGGING AV BORHULL

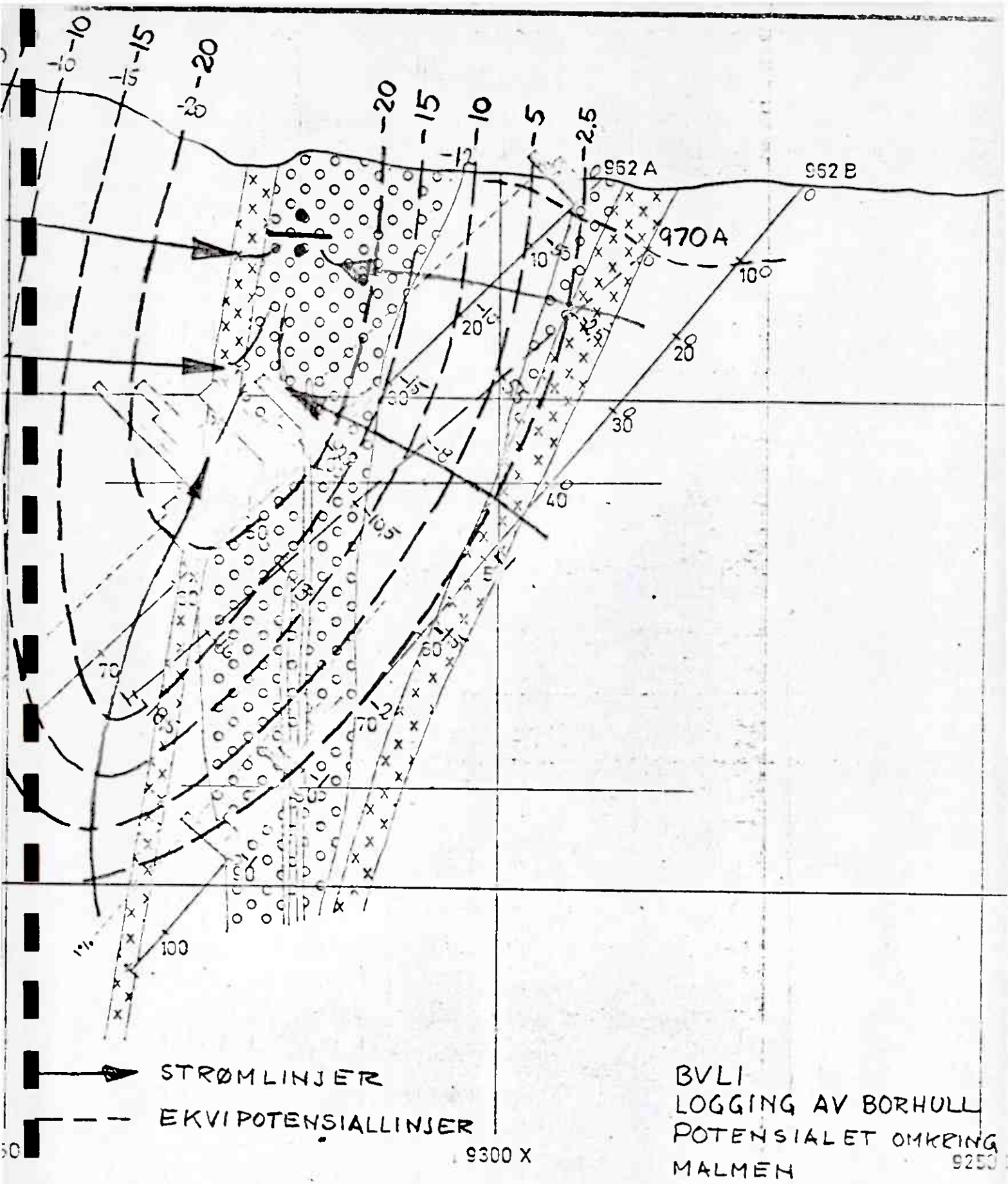
A/S NATIONAL INDUSTRI
SP 1 BORPROFIL S70 Y MÅLT 12/7-76

REPPARFJORD

MÅLESTOKK	DEL ØL	12/7-76
1 : 500	TEGN. [illegible]	Nov 76
	TRAC. B.E.	Nov 1976
	KFR.	

NORGES GEOLOGISKE UNDERSÖKELSE
TRONDHEIM

TEGNING NR.	KARTBLAD NR.
742 - 11	PL.3



STRØMLINJER

EKVIPOTENSIALLINJER

BVLI
LOGGING AV BORHULL
POTENSIALET OMKRING
MALMEN

9250

A/S NATIONAL INDUSTRI

BORPROFIL 962 Y OG 970 Y

REPPARFJORD

MÅLESTOKK: 1: 500	OBS: ØL	12/7 -70	
	TEGN: R.H.	Dec. 196	
	TRAC: B.E.	Des 1966	
	KFR:		

NORGES GEOLOGISKE UNDERSØKELSE
TRONDHEIM

TEGNING NR. 742-10

KARTBLAD NR. PL:4

SELF POTENTIALS AT THE JOMA PYRITE DEPOSIT NORWAY

By

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Abstract.

SP pattern both in drill holes and at the surface are separated into two parts:

(1) A general trend indicating the dipole pattern in the country rock around the deposit with maximum potential variations approximately 200 mV, and

(2) alternating potentials with minima down to -800 mV in the massive sulphides, the steep gradients of which indicate EMF's at the country rock/sulphide interfaces.

Sulphides and country rock are supposed to constitute galvanic cells of which the sulphides represent dipole electrodes and the pore water of the country rock the electrolyte. The redox potential of the pore water decreases with depth.

Separation of the SP potential pattern into two dipole systems offers possibilities for: (1) Locating possible extentions of ore bodies towards depth; (2) rough estimations of tonnage of total ore bodies if the tonnage of upper parts are known; (3) estimations of sulphide contents of ore sections without analysing drill cores or drilling cuts. The concept of galvanic cell indicates that electro-chemical prossesses to some extent control the dispersion of chemical elements around ore deposits.

INTRODUCTION

The existence of natural self potentials (SP) was first reported by Fox (1830). SP-anomalies in connection with ore bodies have later been demonstrated in a great number of cases, after Schlumberger (1922) introduced the use of unpolarizable electrodes. The application of the SP-method is to some extent based on empirical experience; the origin of these natural potentials is not completely understood, although many explanations have been proposed. An exellent survey of the theories are given by Sato and Mooney (1960) in "The electrochemical mechanism of sulphide self potentials", where they relate the SP to natural differences in redox potentials existing in the upper lithosphere. Sato and Mooney do not, however, explain potentials lower than approximately -400 mV in connection with sulphide ores while practical experiences has shown that negative potentials lower than 1000 mV are often encountered in the field. The incomplete knowledge about the nature of the self potentials seems to impede an exhaustive interpretation of SP results. This could be the main reason why SP measurements are not very much used in nowadays mining exploration even though such measurements can be both simple and reliable. More knowledge about the nature of self potentials could be gained through studies of their distribution at known ore deposits. Earlier work of this kind deals mostly with two-dimensional potential distributions at the surface above sulphide ore bodies. In ore prospecting only few reports have been published about measurements of self potentials in drill holes or vertical sections even though the SP drill hole technique is well established in oil exploration (Lynch 1962, Schlumberger 1972).

Recently Parasnis (1970) and Malmquist and Parasnis (1972) have reported interesting results from both surface and drill hole SP measurements. They find that: (1) Both massive and disseminated sulphides may give distinct SP-anomalies; (2) self potentials are stable in time amplitudes of SP variations being within 20 - 30 mV, which would not seriously disturb the much stronger potentials occurring around ore bodies; and (3) SP in drill holes may be as low as -600 mV at a depth of 100 m which Parasnis (1970) considers contra-

dictory to the earlier theory of sulphide oxidation as the main mechanism responsible for sulphide self potentials.

The present paper is a report of the distribution of SP in drill holes and at the surface at the Joma pyrite deposit, Trøndelag Central Norway. Joma was selected for this type of measurements because at the time when the measurements were carried out the deposit (1) was known to produce nice SP-anomalies, and (2) was well known through trenching a lot of diamond drill holes and some underground work, and (3) was not put into production. Selected SP results from Joma have been published earlier (Bølviken et al. 1973). The investigation seems to corroborate the theory of electrochemical mechanisms as being the origin of self potentials, and indicates that an improved interpretation of SP results may have practical consequences in prospecting.

GENERAL DESCRIPTION

Location and history.

The Joma deposit is situated in North Trøndelag, Norway, near the Swedish border (Fig. 1), 580 m above sea level in a terrain of relatively gentle topography. The maximum height difference within the area of the ore body is about 30 m (Fig. 6). Mean annual temperature is approximately +1°C, average summer temperature is approximately +7°C. The overburden above the deposit is frozen approximately 9 months per year, the frozen ground penetrating 1.5-2 m under the surface.

The ore was found some 70 years ago. From 1910 to 1915 the outcrop of the ore was located by trenching, and some diamond drilling. A second exploration epoch, during the last world war, included different geophysical investigations and diamond drilling. A third epoch which started in 1958 comprised further geophysical prospecting, exploratory underground work and extensive diamond drilling from the surface. These investigations resulted in an evaluation of 17 mill. tons of cuperiferous pyrite ore with 1.3% Cu, 1.7% Zn and 35% S which places Joma among the largest pyrite deposits in Norway.

In 1972 the deposit was opened for mining operation. Planned production is about 250 000 tons of ore per year.

Geology.

The geology of the Joma deposit is described by Foslie (1926), Foslie and Strand (1956) and Oftedahl (1958). During the period 1964 - 68 a detailed geological map was prepared by R. Kvien (personal communication 1972). Fig. 1 is a reproduction of a part of his map. The deposit is situated in a greenstone bed belonging to a series of alternating supracrustal sediments and volcanics. The sedimentary rocks which dip under the greenstone formation consist of phyllitic schists and quartzites with varying content of graphite. The series are strongly folded during the Caledonian orogeny. Different folding phases have been observed, the main fold-axis direction being approximately SW. The deposit lies in a fold where the greenstone bed is thick.

The ore consists of compact pyrite with varying amounts of chalcopyrite and sphalerite, chalcopyrite being abundant in zones both in the hanging- and footwall. Accessory galena occurs locally. In the greenstone of the hanging wall a horizon of disseminated pyrrhotite and pyrite occurs about 50 - 100 m above the massive sulphides.

The ore body is shaped like a saucer gently dipping towards SW in the folding axis direction, being thickest in the central parts (maximum ca. 35 m) and thinning out at the flanks. The country rock and the ore are rich in carbonates, a property which together with the cold climate of the area, prevents any extensive oxidation of the ore.

Overburden and ground water.

The ore body is covered except at the socalled "Elvegang", which is exposed in the river Orvasselv on the eastern side of the deposit. The overburden consists of till partly also of bogs and weathered material. The thickness of the overburden varies from 0.5 m to a few metres, being 0.5 - 1.2 m above the suboutcrop of the ore. The conditions are

exellent for surface potential measurements in the summer season. Since the overburden is moist there are small contact resistances at the potential electrodes, and the reproducibility of single measurements was normally within 10 mV.

All diamond drill holes held stagnant ground water, except for one hole (DDH 12 S), which had water flowing out at the top. In holes started on dry ground the water level was found at a depth of 5 - 8 m. The pH of ground water was measured to be 6.0 - 9.5 and the water temperature was 4 - 10°C.

ELECTRIC RESISTIVITY OF GROUND WATER ORE AND COUNTRY ROCKS

Specific resistivity of the drill hole waters measured on samples taken at different depths was as an average 5 000 ohm cm, single values varying between 4 000 and 5 900 ohm cm. This relatively good conductivity yields low contact resistances at the electrode, and the SP measurements in the drill holes were reproducible within 1 - 2 millivolt.

The resistivity of (1) compact ore, (2) sulphide disseminations and (3) country rocks were measured on drill cores, cut by a diamond saw to cylinders with height approximately equal to the diameter (32 mm). The results are indicated in Fig. 2.

The specimens were carefully moistened under pressure to obtain conditions similar to those in situ, before the resistivity was measured by a four point method. In cores with disseminated sulphides the mean angle between pyrrhotite bands and drill core axis was estimated, since the average resistivity would depend on this angle. Specific gravity of the moist cores was supposed to be a useful parameter indicating content of sulphide minerals. Results of specific gravity measurements are plotted along the ordinate of Fig. 2. For comparison the resistivity (Parasnis 1966) and corresponding specific gravity (Hurlbut 1955) of pure minerals are included in the figure. The compact pyrite ore has resistivities between 0.25 - 1.5 ohm cm (area A in Fig. 2), central values being 0.75 ohm cm, which agree well with the resistivity of pure pyrite given by Parasnis (op.cit.).

As the Joma ore contains some chalcopyrite, pyrrhotite and sphalerite, the specific gravity of the samples of the ore are lower than that of pure pyrite. The two samples at the left hand side in area A contain pyrrhotite, and those at the right chalcopyrite, sphalerite and some quartz and calcite in addition to pyrite. Chalcopyrite - pyrite ore (F, Fig. 2) is less conducting than the pyrite ore, resistivity being approximately 4 ohm cm, which is in correspondence with the data for pure chalcopyrite given by Parasnis (op.cit.).

The pyrrhotite disseminations from the country rock of the hanging wall cover a larger area of variation (B, Fig. 2) than the compact ore types. The resistivity of the samples of pyrrhotite disseminations is 0.02 - 30 ohm cm, the central value being 0.58 ohm cm. The lower resistivities of the group represent pyrrhotite banding along the core axis.

The greenstone of the hanging wall is represented by the area D in Fig. 2. The resisitivity varies between 10^5 and 10^6 ohm cm, the central values in area D ($3.1 \cdot 10^5$ ohm cm) is supposed to be a fair estimate of the average values in the greenstones surrounding the Joma deposit. The following average resistivity contrasts can be estimated:

$\rho_{ore} / \rho_{greenstone} \approx \underline{1/430\,000}$

$\rho_{ore} / \rho_{drill\text{-}hole\ waters} \approx \underline{1/6700}$

$\rho_{greenstone} / \rho_{drill\text{-}hole\ waters} \approx \underline{60}$

Resistivity of three graphitic phyllites are indicated (area C, Fig. 2), central values being 850 ohm cm. The resistivity of phyllite depends on the content of graphitic material. The graphitefree phyllite (Fig. 2, area E) has the highest resistivity of all rock types investigated, central value being $7.7 \cdot 10^6$ ohm cm. Average resistivity contrast between graphitic phyllite and graphitefree phyllite is 1/9 000.

SP-MEASUREMENTS

SP was measured (1) in diamond drill holes and (2) at the surface. In diamond drill holes the potential differences were recorded at depth intervals of 1 - 10 m between a stationary reference electrode placed at the surface beside the hole and a mobile electrode lowered into the hole. In addition the potential differences between the stationary electrodes of the different drill holes were measured to obtain a common reference for all SP measurements. Altogether SP were measured in 14 holes distributed over the central parts of the deposit. The hole lengths varied between 30 and 360 m. The last drilling operations were finished 3 years before the SP measurements. At the surface the potential differences were recorded every 50 m along 5 selected profiles, in areas of high potential gradients also at intermediate stations along the profiles. The potential of the background field at some distance from the deposit was chosen as a common reference (zero).

The electrodes used consisted of Cu-wire immersed in a saturated solution of $CuSO_4$, separated from the exterior by a wooden plug. The instrument was a potentiometer with 1 M ohm input resistance.

Drill-hole self potentials

SP results of (1) four typical drill holes through ore (3 V, 49, 10 M and 5 N) and (2) one hole through the country rock at about 200 m distance from the ore (1A) are shown in Fig. 3. Results from eight holes projected into section AA are presented in Fig. 4 (see Figs. 9 and 11 for location of profile and ore respectively). Two potential patterns can be distinguished:

(1) An abruptly alternating potential with several minima of varying magnitude.

(2) A general potential trend that seems to constitute some sort of a basis for the abrupt potential variations.

It is possible to separate these two patterns visually by drawing a continuous line through the most positive values of the SP curves as shown in Fig. 3 and Fig. 7.

The steep potential gradients occur at the boundaries of (1) the compact ore and (2) the sulphide disseminations, their SP minima within the mineralization being of the order 400 - 800 mV and 100 - 300 mV respectively regardless of depth (Figs. 3 and 4). The - 400 mV contour follows the boundary of the massive ore closely (Figs. 4 and 8).

The general potential trend, which was reproduced by repeated measurements the next year, is of the order 0 - 50 mV within drill holes and maximum 200 mV along the ore. The sign depends on the position relative to the ore body; in the holes 3 V and 49, which intersect the deeper part of the ore body (Fig. 3), the potentials of the general trend increase with increasing depth, and in the holes 10 M and 5 N, which intersect the upper half of the ore body, the SP potentials decrease with increasing depth. In the "background" hole 1 A, which is drilled through the footwall rocks, the general potential trend is nearly constant through the greenstone in the upper part of the hole, and decreases with increasing depth through the graphitic phyllites in the lower part.

Surface self potentials.

The potential distribution at the earth surface over the central part of the ore is shown in Fig. 5, and that of a profile BB which crosses the greatest thicknesses of the deposit in Fig. 6. The SP-variations along this profile, which should be quite representative for the potential distribution along a geometric symmetry plane of the deposit, is described below. When one approaches the deposit from a reference point on the footwall side, the SP decreases gradually about 100 mV. At Elvegangen which crops out in the river, the potential suddenly drops (the minimum value could not be measured in the profile due to high water level in the stream). Between Elvegangen and the main ore outcrop the potentials again raise to approximately - 100 mV, followed by an abrupt drop to a minimum of - 800 mV above the sub-outcrop of the ore. On the hanging wall side the potential increases to ca. +150 mV above the deeper parts of the body some 200 m from the outcrop. Then a decrease follows until the potential reaches an approximately normal value about 500 m from the outcrop.

On both sides of the strong anomaly caused by the main ore, there are local minima, of which those in the hanging wall rocks, being approximately - 300 m V, are supposed to be caused by pyrrhotite disseminations.

As in the drill holes there seem to be two potential distribution patterns, which can be separated graphically: (1) An abruptly alternating potential occurring in close connection with the sulphide mineralizations and (2) a more smooth general potential trend, in some way connected with currents in the country rock. The positive maximum belong to this trend.

INTERPRETATION OF SP RESULTS

The two types of potential distribution patterns distinguished in the preceeding section are interpreted in the following way:

(1) The abruptly alternating pattern is a consequence of the presense of electromotive forces at the interfaces of country rock and sulphides, and indicates indirectly that electronic currents pass <u>within</u> the sulphides.

(2) The general trend pattern indicates that ionic currents pass through the pore water of the silicious country rock <u>outside</u> the ore body.

In the following these two types of potentials are called "electronic current potential" and "ionic current potential", respectively. As indicated above (Fig. 3) it is in most cases easy to separate the two potential patterns in drill holes by a simple graphical estimation as illustrated in Fig. 7. This procedure can also be used for surface data, see Fig. 6.

Electronic current potential.

The potential distribution within the ore was measured relative to the point of lowest potential found in the ore (hole 10 M, in the central part of the deposit).

Fig. 8 shows a horizontal projection of the distribution of the minimum potentials recorded in each drill hole within the deposit. From both flanks of the ore body the minimum potentials decrease towards the central part, where a low potential channel passes along the ore between the upper and lower ends, indicating the thickest, best conducting parts of the ore body where the electric currents are concentrated.

Fig. 9 shows the distribution of SP within the ore in a vertical section along the low potential channel. The equi-potential lines follow the boundaries of the ore body very closely, except at a few zones of low conductivity within the body. The maximum potential drop along the path of strongest current density in this section is found to be of the order of 20 mV, the lowest potential being at depth and the highest near the surface. The real minimum potential drop along the path may possibly be even smaller, since it is difficult to find the exact best position of the electrodes. This potential drop shows that currents must be running downwards through the ore. The resistivity of the compact ore is approximately 0.75 ohm cm (Fig. 2). Using this value, the maximum current density through the ore is calculated to approximately 5 milliamperes pr m^2. At depth the position of the maximum current density path seems to pass NW of the drill holes 49 and 3 V indicating an interesting possibility for finding depth extensions of the thicker parts of the ore body.

The electric currents within the ore deposit must be distributed according to the laws of Kirchhoff. Pyrite, is the best conductor (see page 5), of the main ore minerals. A close connection between SP and pyrite content of the ore should therefore be expected. In Fig. 10 SP is compared with sulphide content of drill cores, which is a good indication of the pyrite content of this type of ore. It is seen that high S^{2-} generally corresponds to low SP readings. Occasional exception from this rule may apparently be due to the fact that S^{2-} is given an average per metre drill core, while SP is recorded more continously.

Any possible effects from Cu and Zn minerals seem to be overshadowed by the effect of the pyrite.

Ionic current potential.

The distribution pattern of ionic potentials (Fig. 11) can be more easily interpreted than the pattern of the original data (Fig. 4) from which they are estimated. The pattern of ionic current potentials is similar to that caused by a dipole with some modifications which are probably due to the irregular shape of the ore body. The two negative centers which occur at the surface are very likely caused by the two sulphide bodies, the main ore and Elvegangen respectively.
The highest potential observed in the profile in Fig. 11 is about 120 mV, indicating a positive centre situated near the lower end of the ore body. This is in agreement with the results given in Fig. 6, where it is seen from fig. 8 that the drill holes 5N, 4M, 10 M and 11 M lie on the NW side of the potential maximum as fig. 6. The position of the centre in relation to the ore cannot be determined exactly due to lack of drill holes, and a maximum exceeding 120 mV migh exist nearer to a possible thicker part of the lower end of the ore somewhere outside section AA. The ionic currents above the ore body can be visualized by the average vertical current density, J_v, along drill hole given by:

$$J_v = \frac{1}{\rho} \cdot \frac{\Delta V}{\Delta z}$$

where ρ is the resistivity of the surrounding country rock and $\frac{\Delta V}{\Delta z}$ is the average vertical ionic potential gradient between the earth surface and the hanging-wall boundary of the ore estimated from SP-logs. The resulting vertical current densities are given in table 1, using $3.1 \cdot 10^5$ ohm cm as resistivity of the country rock.

The horizontal projection of the distribution of the vertical ionic current density, which is shown in Fig. 12, agrees well with the picture in section AA in Fig. 11. The direction of the current is mainly upwards above the ore at depth (around the holes 3 V and 49),

downwards above the central parts of the ore body, and upwards above the upper parts of the body.

From the data in Fig. 11 the average horizontal current densities J_h above the ore body have been estimated by computing the potential gradient between drill holes, and multiplying with the average conductivity ρ. The total current densities are estimated as the vector sum of J_v and J_h, see table 2, which shows the ionic current densities vary between 0.1 and 0.3 microampere per m^2 in the country rock above the ore body.

It should be remembered that the vertical current densities calculated above presuppose the same potential in the pore water of the bedrock as in the drill hole water. This will not necessarily be the case since the water filled drill-hole is a much better electric conductor than the country rock (see page 6). The calculated vertical current densities for country rock, therefore, most probably are too low. The calculated horizontal current densities, however, would possibly be closer to the true values.

SP MODEL

Based on the described distribution of SP at Joma a simplified schematic model is shown in Fig. 13. If one approaches the ore from a reference point A the self potential decreases evenly until a point B near the upper end of the ore. At the country rock/ore interface the potential drops abruptly at point C from where it decreases slowly with depth inside the ore. At the ore/country-rock interface between D and E the potential increases suddenly, and from E on through F to A the SP decreases regularily back to the reference zero potential.

The potential pattern seems to fit well into the model of a galvanic cell in which the pore water of the country rock constitutes the electrolyte and the massive ore the electrode, the upper end being the cathode and the lower end being the anode. The electrolyte varies in composition between cathode and anode having higher

oxidation potential around the shallower part than around the deep part. The electromotive force of the cell is situated at the interface between ore and country rock, its theoretical magnitude being the Eh difference of the pore water in the country rock at the upper end and that at the lower end. A current will run through the cell driven by a voltage which is equal to the EMF minus potential drops caused by polarization and ohmic resistance of electrolyte and electrode. In the ore body, which represents the outer conductor of the cell, electrones will flow from anode to cathode, i.e. upwards. In the country rock which represents the inner electrolyte of the cell, cations will move upwards and anions downwards, the cations (mainly H^+) being discharged at the surface of the upper end of ore, producing H_2, and the anions (mainly OH^-) being discharged at the lower end of the ore producing O_2 and H_2O. The H_2 produced at the upper end will most probably react with oxidizing species of the atmosphere or waters, and might for example, reduce O_2 to H_2O. The O_2 produced at depth will analogously react with reducing species, and, for example, oxidize Fe^{2+}.

This model is consistent with the mechanism proposed by Sato and Mooney (op. cit.), as far as the distribution of self potentials in the silicious country rock surrounding the ore body is concerned. We have called these potentials ionic current potentials; in the case of Joma they show a maximum variation of approximately 200 mV, which is well within the theoretical maximum limit (400 mV) estimated by Sato and Mooney (op. cit.).

As refered by Sato and Mooney, SP of the order of minus 1 - 1.5 V are frequently found in connection with graphite or sulphides. This is in agreement with our experiences from Norway. We believe that self potentials of this order can be demonstrated only when one of the electrodes is located in the country rock and the other is in direct electric contact with a sulphide body or other good conducting mineralization. At Joma potential minima of the order of - 300 mV were found under such conditions. These high potential differences should not be confused with the more smooth ionic current potentials within the country rock. Because of the electromotive force

postulated at the sulphide/country rock interface the Laplace continuity equation can not be applied across the ore boundaries. The potentials within and outside sulphide bodies must consequently be treated separately. The potentials within sulphides need some explanation in addition to the theory proposed by Sato and Mooney, a matter which will be dealt with in a forthcoming publication. (Bølviken and Logn, in preparation.)

PRACTICAL CONSEQUENCES

The self potential method has a particular position among the electric ore-prospecting methods, since the energy supply might be interpreted as a dipole with two current electrodes. When regarding the potentials of the country rock outside the ore body the negative pole will be positioned in the upper end and the positive in the lower end of the ore body. When regarding the potentials within the ore body, the positive pole will be positioned at the interface of the country rock and the upper end of the ore body and the negative analogously at the lower end. We do not know of any other geo-electrical method where such a position of current electrodes are possible without knowing the position of the lower and upper end of the ore in beforehand.
With this natural electrode configuration measurements of self potentials in the country rock outside the ore may produce

(1) potential distribution patterns at the earth surface which may be easily interpreted.

(2) potential distribution patterns in drill holes which may give information about extension towards the depth of an ore body, in particular assist in location of the lower positive pole, and provide data for an estimation of volume or tonnage of the lower part of an ore body if the upper part is known through diamond drilling.

The distribution of self potential within the ore body may be used as a corrective guide in a drilling programme by

(1) indicating the direction of the thickest compact part connecting the upper and the lower part of an ore body.

(2) being an alternative to chemical analyses of drill cores or drill cuts.

Beside having these possible practical consequences in geophysics, the concept of sulphide ore and country rock pore water forming a galvanic concentration cell, may also have important implications in geochemical exploration as recently pointed out by Govett (1973). It is not unlikely that the concept might lead to a better understanding of the principles - in particular the electrochemical mechanisms - behind the dispersion of chemical elements around ore deposits.

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REFERENCES

Bølviken, B. and Logn, Ø. A contribution to the understanding of natural self potentials. In preparation.

Bølviken, B., Logn, Ø., Breen, A. and Uddu, O., 1973. Instrument for in situ measurements of Eh, pH and self potentials in diamond drill holes. In M. J. Jones (Editor) Geochemical exploration 1972. Proceedings of the fourth International Geochemical Exploration Symposium. London 1972. Inst. Mining. Metal., pp. 415 - 420.

Foslie, S., 1926. Norges svovelkisforekomster. (in Norwegian with an English abstract). Norges geol. Unders., 127: 1 - 122.

Foslie, S. and Strand, T., 1956. Namsvatnet med endel av Frøyningsfjell. (in Norwegian with an English abstract). Norges geol. Unders., 196: 1 - 82.

Fox, R. W., 1830. On the electromagnetic properties of metalliferous vein in the mines of Cornwall. Phil. Trans. R. Soc. 120: 399 - 414.

Govett, G. J. S., 1973. Differential secondary dispersion in transported soils and post-mineralization rocks: an electrochemical interpretation. In: M. J. Jones (Editor) Geochemical exploration 1972. Proceedings of the fourth International Geochemical Exploration Symposium. London 1972. Inst. Mining. Metal., pp. 81 - 91.

Hurlbut, C. S. jr., 1955. Dana's Manual of Mineralogy. John Willey, New York, 529 pp.

Lynch, E. J., 1962. Formation Evaluation. Harper & Row. New York, 422.

Malmqvist, D. and Parasnis, D. S., 1972. Aitik: Geophysical documentation of a thirdgeneration copper deposit in North Sweden. Geoexploration. 10: 149 - 200.

Oftedahl, C., 1958. Oversikt over Grongfeltets skjerp og malmforekomster. (in Norwegian with an English abstract). Norges geol. Unders., 202: 1 - 75.

Parasnis, D. S., 1966. Mining Geophysics. Elsevier, Amsterdam, 356 pp.

Parasnis, D. S., 1970. Some recent geoelectrical measurements in the Swedish sulphide ore fields illustrating scope and limitations of the methods concerned. Min. Groundwater Geophys. /1967 (Ottawa), pp. 290 - 301.

Sato, M. and Mooney, H. M., 1960. The electrochemical mechanism of sulfide self potentials. Geophysics. 25: 226 - 249.

Schlumberger, 1972. Log Interpretation. Volume I - Principles. Schlumberger Limited, New York, 113 pp.

Schlumberger, C. and Schlumberger, M., 1922. Phénomènes électriques produits par les gîsements métalliques. Comptes Rendus. 174: 477 - 480.

Svinndal, S., 1968. Diamant-boring med hullavviksmåling og geologisk bearbeidelse av kjernematerialet ved Joma-malmen/ Røyrvik. Unpubl. Rep. Norges geol. Unders. 665. 9 pp.

Table 1 Average vertical current density J_v in the hanging wall country rock (greenstone), Joma pyrite deposit, central Norway. Resistivity of greenstone $3.1 \cdot 10^5$ ohm cm. Positive current is upwards.

Drill hole	J_v ($\mu A/m^2$)	Drill hole	J_v ($\mu A/m^2$)
3 V	+ 0.033	4 M	- 0.233
16 M	+ 0.065	5 N	- 0.151
16 M	- 0.133	119	- 0.366
10 M	- 0.018	117	+ 0.667
11 M	- 0.083	116	+ 0.306
12 S	- 0.167	2 H	+ 0.234
33 N	- 0.0394	1 A	- 0.024

Table 2 Average horizontal, J_h and total, J_t current density between drill holes through the hanging wall country rock (greenstone), Joma pyrite deposit, central Norway. J_v is taken from table 1. Resistivity of greenstone = $3.1 \cdot 10^5$ ohm cm.

Drill holes	depth (m)	J_v ($\mu A/m^2$)	J_h ($\mu A/m^2$)	J_t ($\mu A/m^2$)
3 V - 49	120	+ 0.049	0.104	0.114
49 - 10 M	90	+ 0.024	0.094	0.097
10 M - 11 M	70	- 0.051	0.214	0.220
11 M - 4 M	60	- 0.158	0	0.158
4 M - 5 N	55	- 0.192	0.095	0.214
5 N - 116	40	+ 0.078	0.278	0.298

FIGURES

Fig. 1. Geological map of the area surrounding the Joma pyrite deposit, central Norway. After R. Kvien (personal communication 1972).

Fig. 2. Resistivity of pure minerals (Parasnis 1966) and massive sulphide ore, sulphide disseminations and country rock of drill core samples from Joma pyrite deposit central Norway.
Abscissae: Resistivity, Ordinate: Specific gravity.
M: Magnetite; Py: Pyrite; Po: Pyrrhotite; Cpy: Chalcopyrite.
A: Massive sulphide ore
B: Sulphide disseminations
C: Graphitic phyllite
D: Greenstone
E: Phyllite
F: Chalcopyrite - pyrite ore

Fig. 3. Self potentials and geological observations in diamond drill holes 3 V, 49, 10 M and 1 A at Joma pyrite deposit central Norway. SP variations are separated graphically into two parts (1) an abruptly alternating potential (black) and (2) a general potential trend (bottom inclined line) see Fig. 7.

Fig. 4. Self potential in drill holes projected into section AA' Joma pyrite deposit, central Norway.
Location of section AA' is shown in Fig. 8.

Fig. 5. Surface distribution of self potentials at Joma pyrite deposit, central Norway. Potentials are measured along the indicated profiles.

Fig. 6. Self potentials along profile B-B, Joma pyrite deposit, central Norway. Location of profile is shown in Fig. 5. SP variations are separated graphically into two parts (1) an abruptly alternating potential (black) and (2) a general potential trend (bottom line), see Fig. 7.

Fig. 7. Graphical separation of self potential log into ionic current potentials of country rock and electronic current potentials of sulphides.

Fig. 8. Horizontal projection of distribution of minimum self potentials within the ore body, Joma pyrite deposit, central Norway.

Fig. 9. Distribution of self potentials within massive sulphides at Joma pyrite deposit, central Norway (lower half). The position of the ore is indicated in the upper half of the figure.

Fig. 10. Correspondence between self potentials and percentages of S and Cu + Zn in diamond drill holes 117 and 119 crossing the ore body, Joma pyrite deposit, central Norway. Geological and chemical data after Svinndal (1968).

Fig. 11. Distribution of ionic current potentials in drill holes estimated from data in Fig. 4 projected into section AA', Joma pyrite deposit, central Norway. For location of section AA' see Fig. 5. Principle for separation of self potentials into ionic and electronic current potential is shown in Fig. 7.

Fig. 12. Horizontal projection of vertical ionic current potential in the country rock, Joma pyrite deposit, central Norway. Unit on contours: $10^{-2}\mu A/m^2$.

Fig. 13. Simplified SP model based on the distribution of self potentials in vertical sections through country rock and ore, Joma pyrite deposit, central Norway.

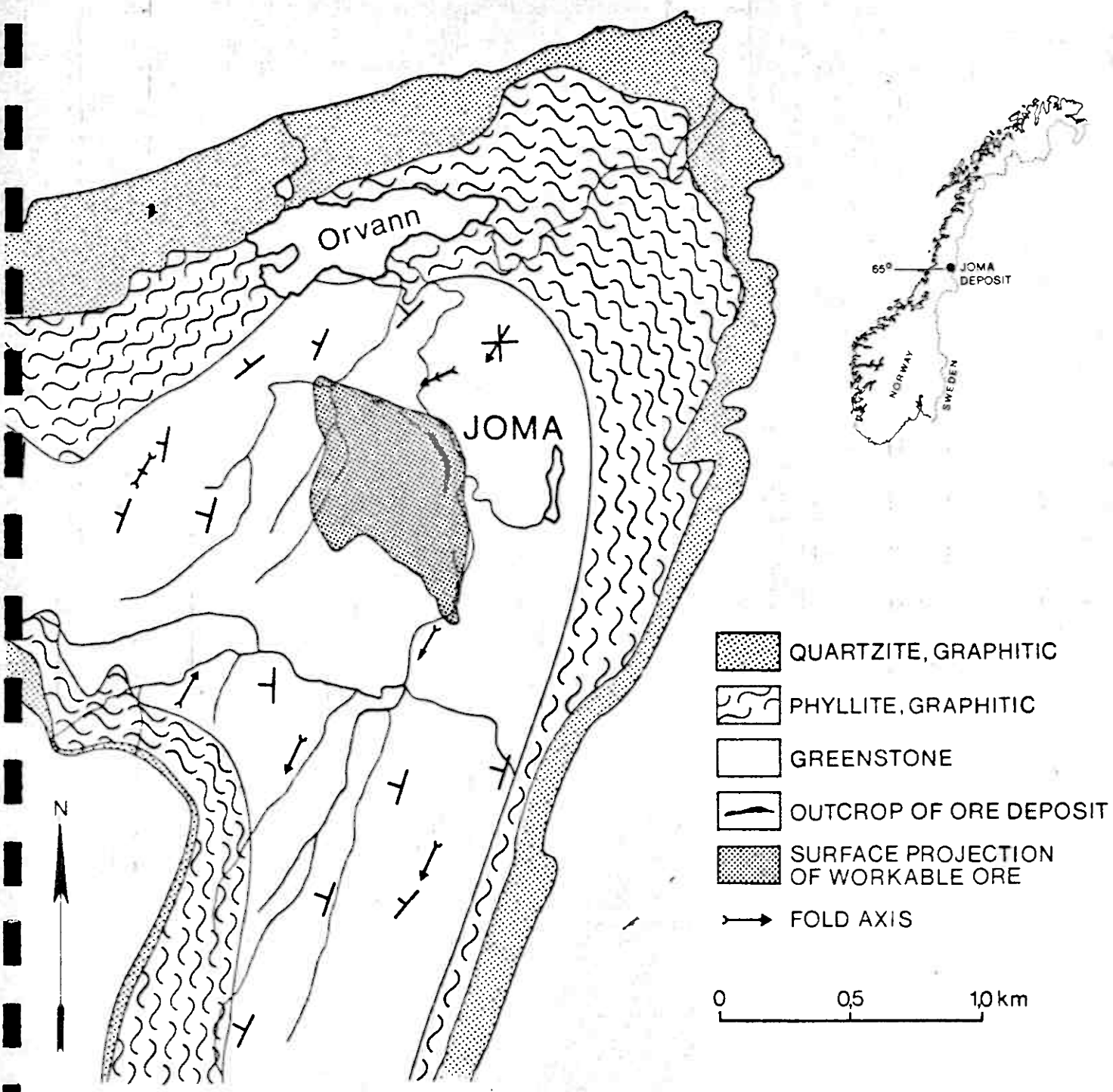

Orvann
JOMA
N
65°
JOMA DEPOSIT
NORWAY
SWEDEN
QUARTZITE, GRAPHITIC
PHYLLITE, GRAPHITIC
GREENSTONE
OUTCROP OF ORE DEPOSIT
SURFACE PROJECTION OF WORKABLE ORE
FOLD AXIS
0
0,5
1,0 km

FIG. 1

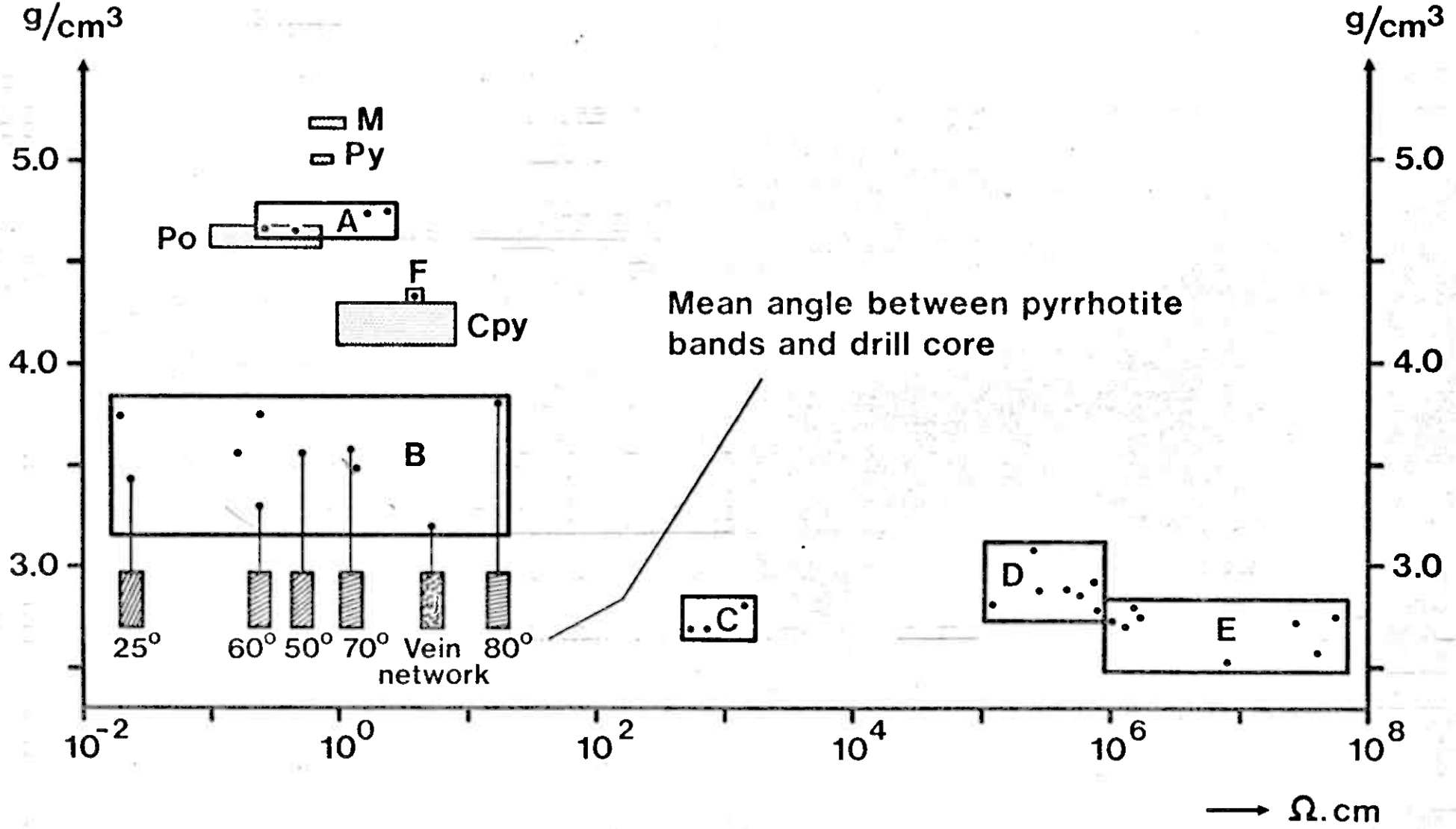

g/cm3
g/cm3
5.0
4.0
3.0
M
Py
Po
A
F
Cpy
Mean angle between pyrrhotite bands and drill core
B
C
D
E
25°
60°
50°
70°
Vein network
80°
10-2
100
102
104
106
108
Ω.cm

FIG.2

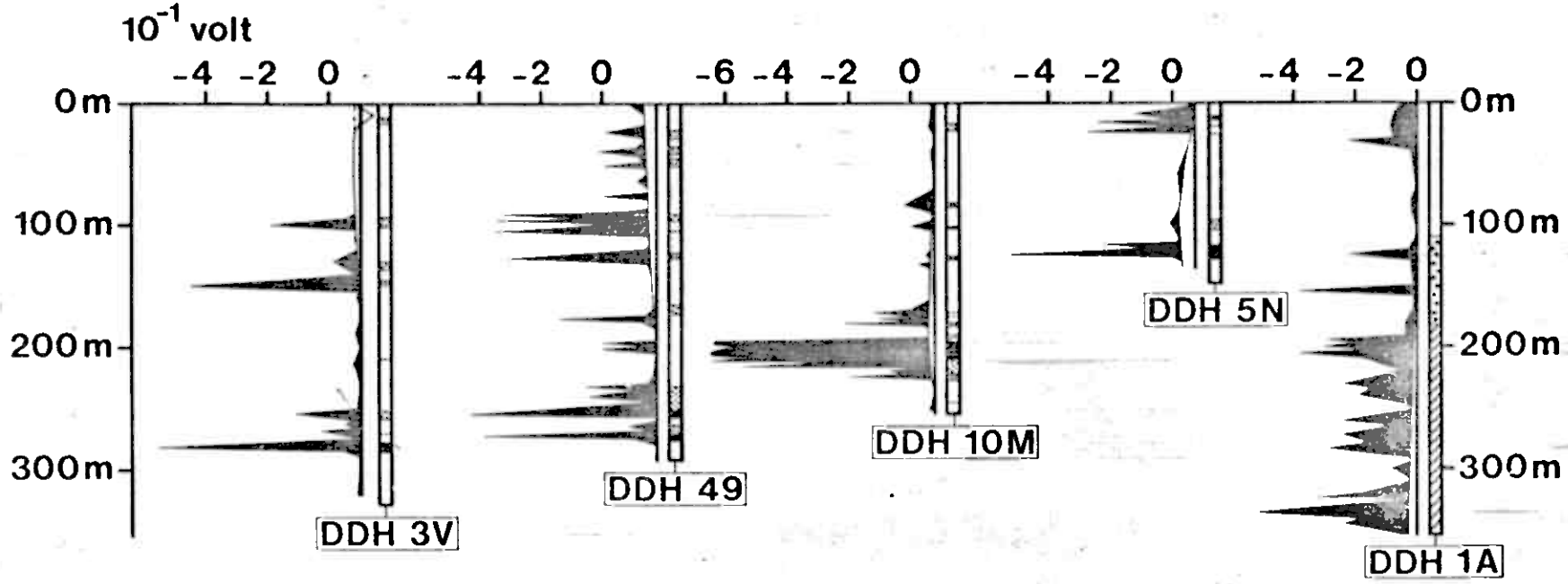

10^{-1} volt
-4 -2 0
-4 -2 0
-6 -4 -2 0
-4 -2 0
-4 -2 0
0m
100m
200m
300m
DDH 3V
DDH 49
DDH 10M
DDH 5N
DDH 1A
Sulphide disseminations
Massive sulphide ore
Greenstone
Interbanded phyllite and greenstone
Phyllite (graphitic)

FIG.3

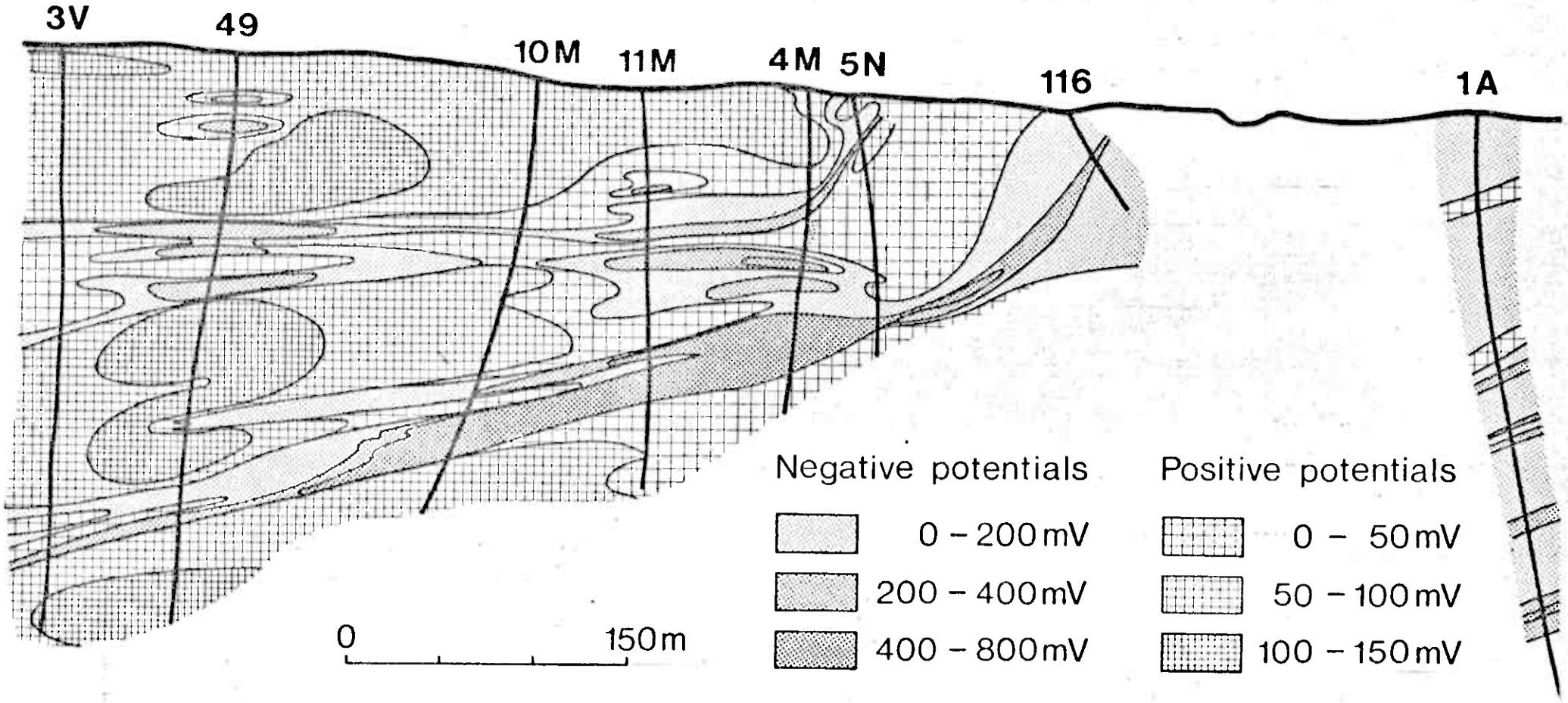

3V
49
10M
11M
4M
5N
116
1A
Negative potentials
0 – 200 mV
200 – 400 mV
400 – 800 mV
Positive potentials
0 – 50 mV
50 – 100 mV
100 – 150 mV
0
150 m

FIG. 4

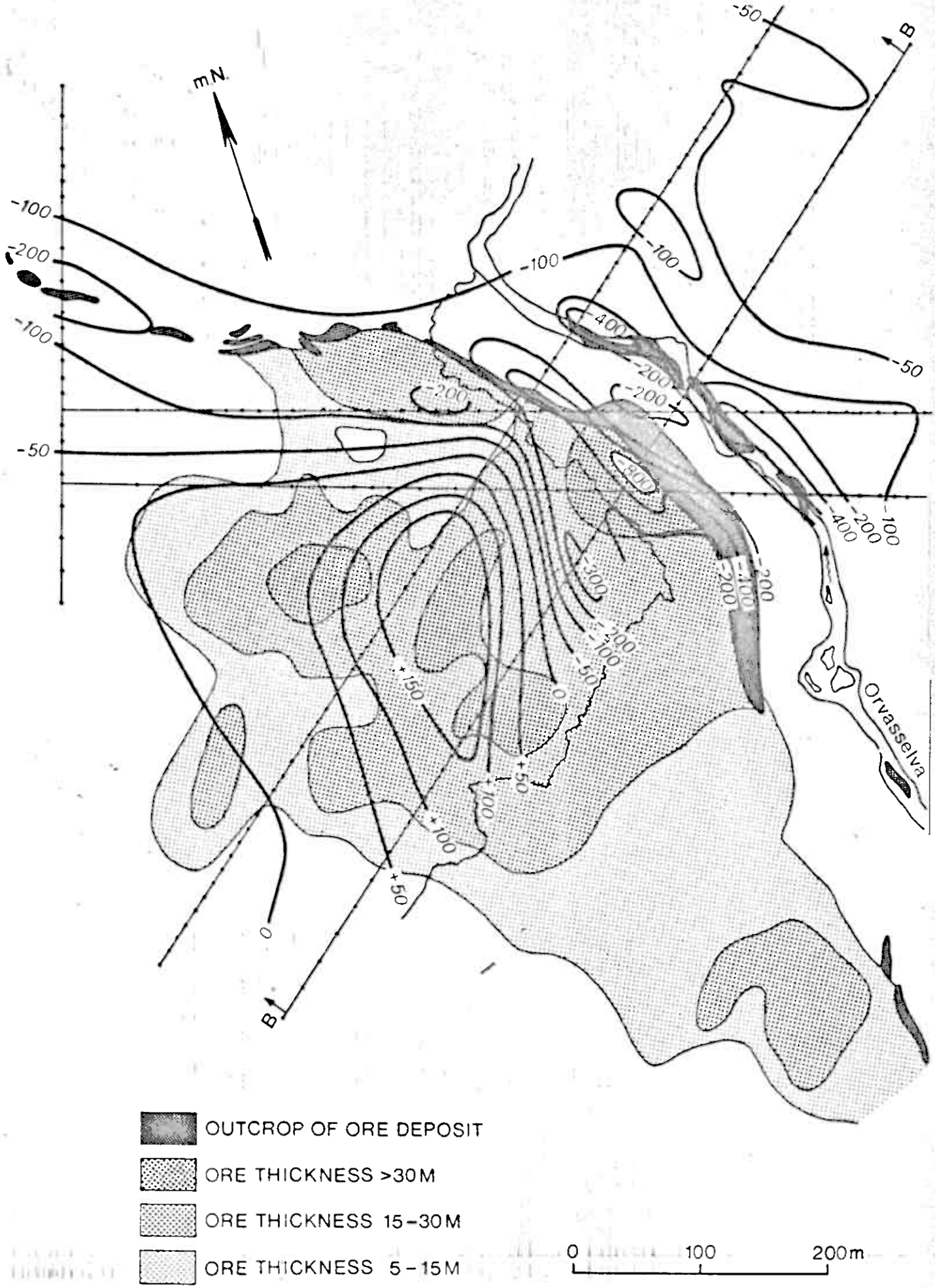

mN
B
B'
-50
-100
-200
-400
-300
+150
+100
+50
0
Orvasselva
OUTCROP OF ORE DEPOSIT
ORE THICKNESS >30M
ORE THICKNESS 15-30M
ORE THICKNESS 5-15M
0
100
200m

FIG. 5

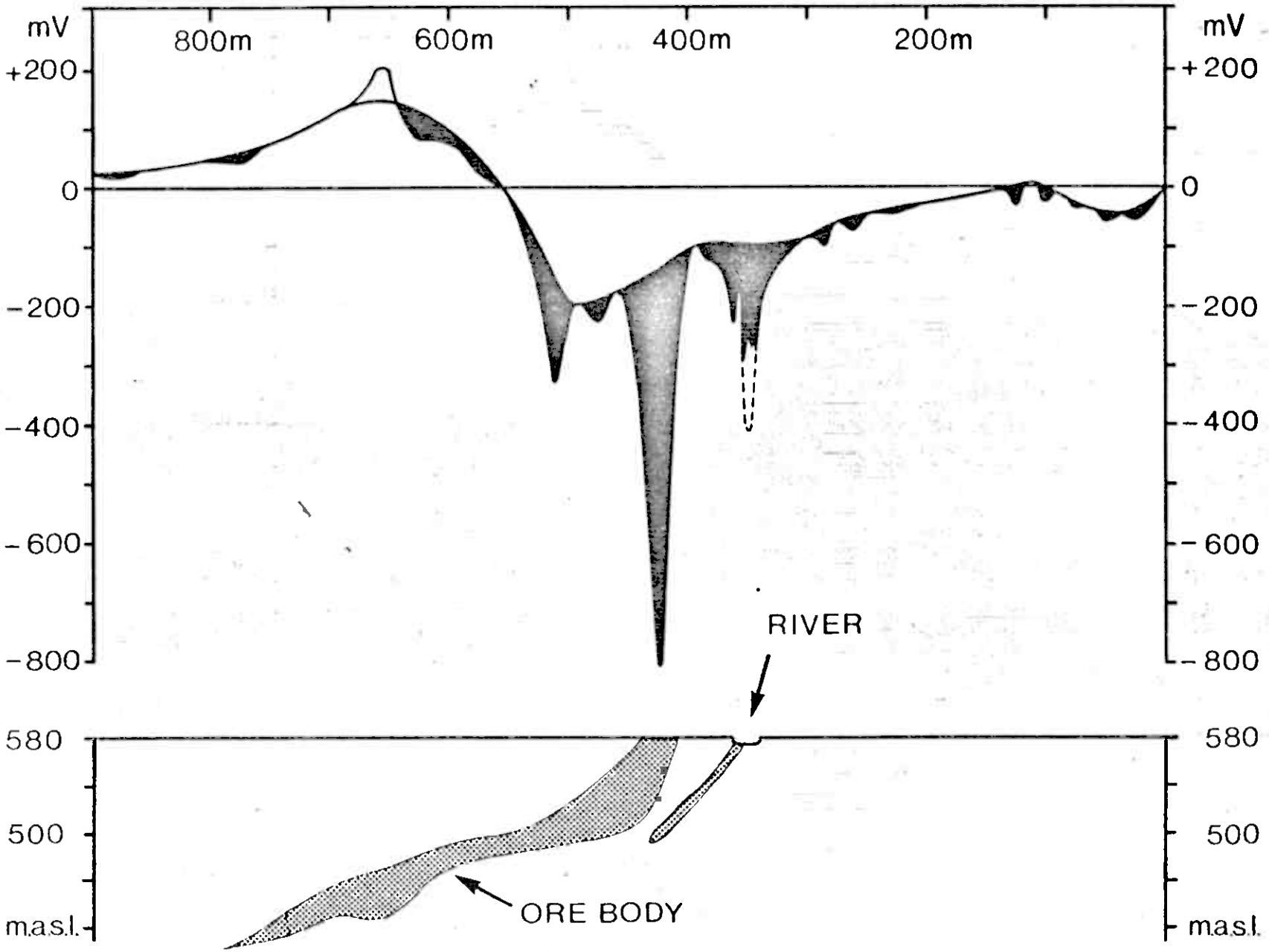

mV
800m
600m
400m
200m
mV
+200
0
-200
-400
-600
-800
+200
0
-200
-400
-600
-800
RIVER
580
500
m.a.s.l.
ORE BODY
580
500
m.a.s.l.

FIG. 6

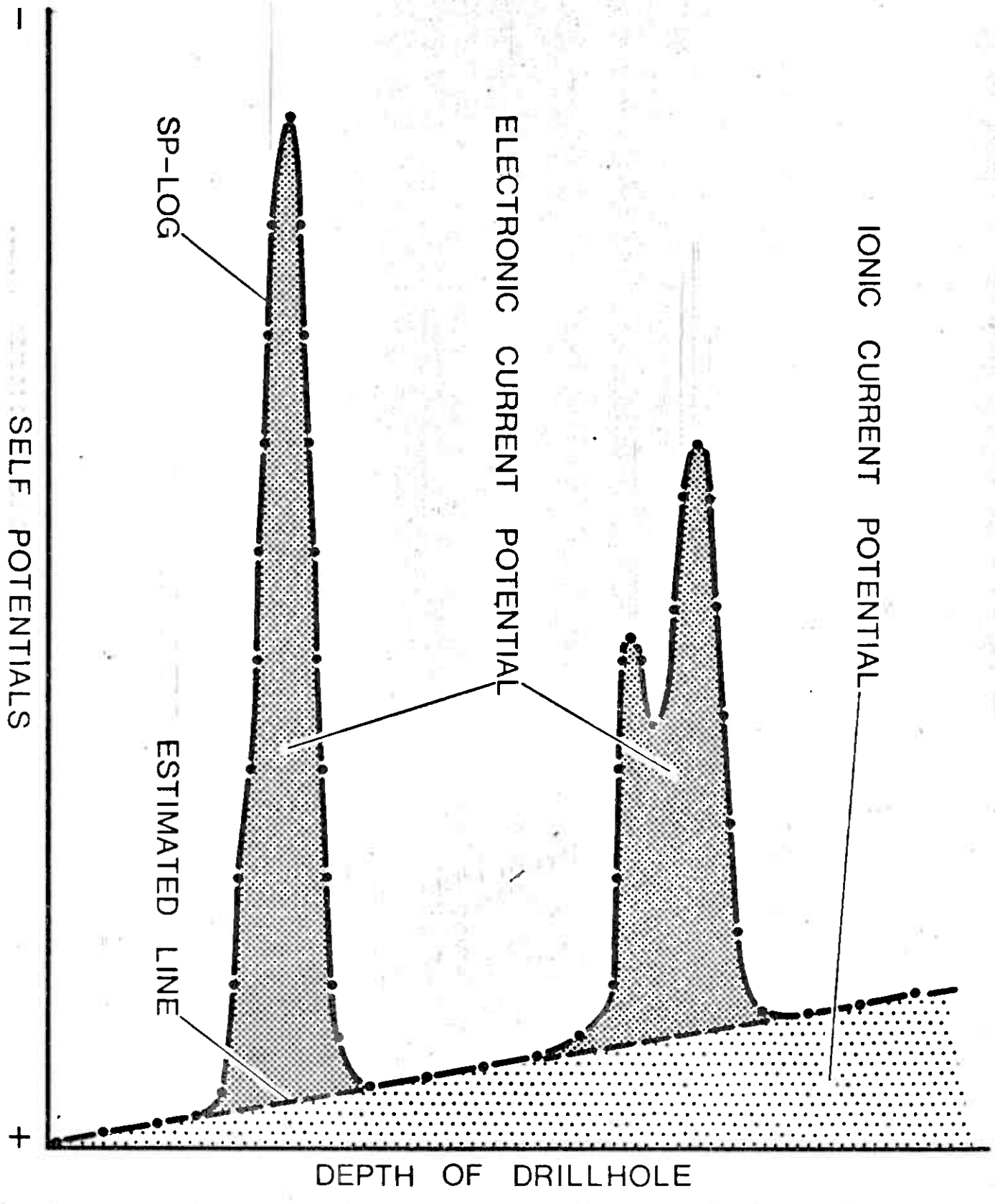

SP-LOG
ELECTRONIC CURRENT POTENTIAL
IONIC CURRENT POTENTIAL
ESTIMATED LINE
SELF POTENTIALS
−
+
DEPTH OF DRILLHOLE

FIG. 7

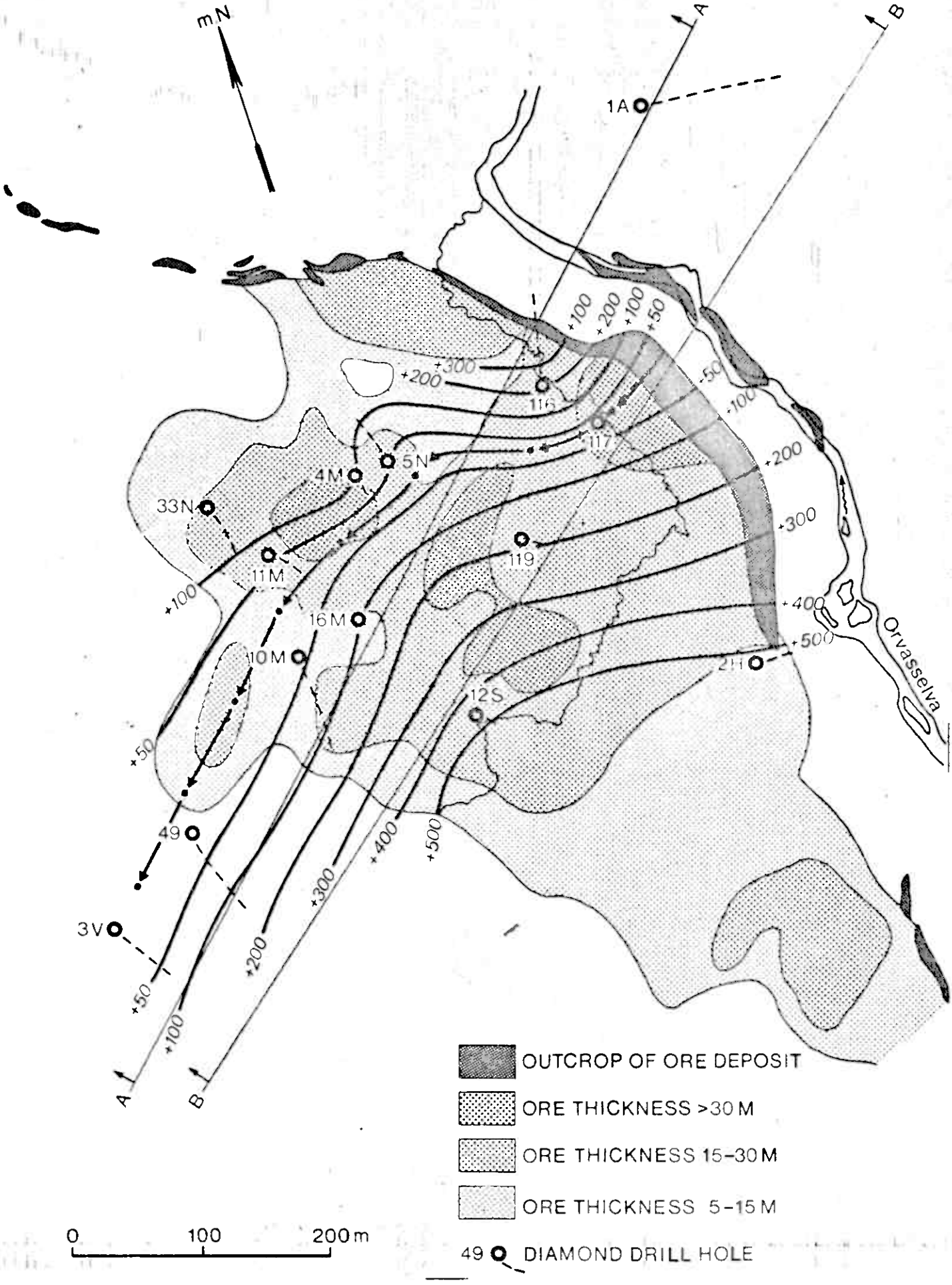
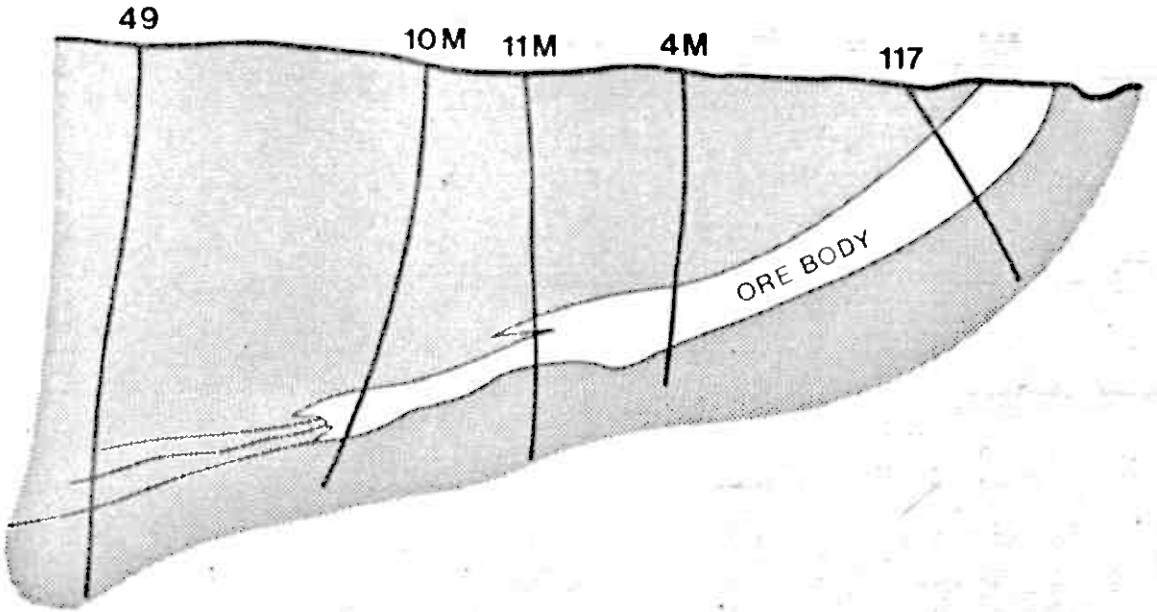

mN
A
B
1A
+100
+200
+100
+50
+300
+200
116
117
+50
+100
+200
+300
+400
+500
5N
4M
33N
11M
119
+100
16M
10M
2H
12S
Orvasselva
+50
49
3V
+50
+100
+200
+300
+400
+500
A
B
OUTCROP OF ORE DEPOSIT
ORE THICKNESS >30 M
ORE THICKNESS 15–30 M
ORE THICKNESS 5–15 M
49 DIAMOND DRILL HOLE
0
100
200 m

FIG. 8


49
10M
11M
4M
117
ORE BODY

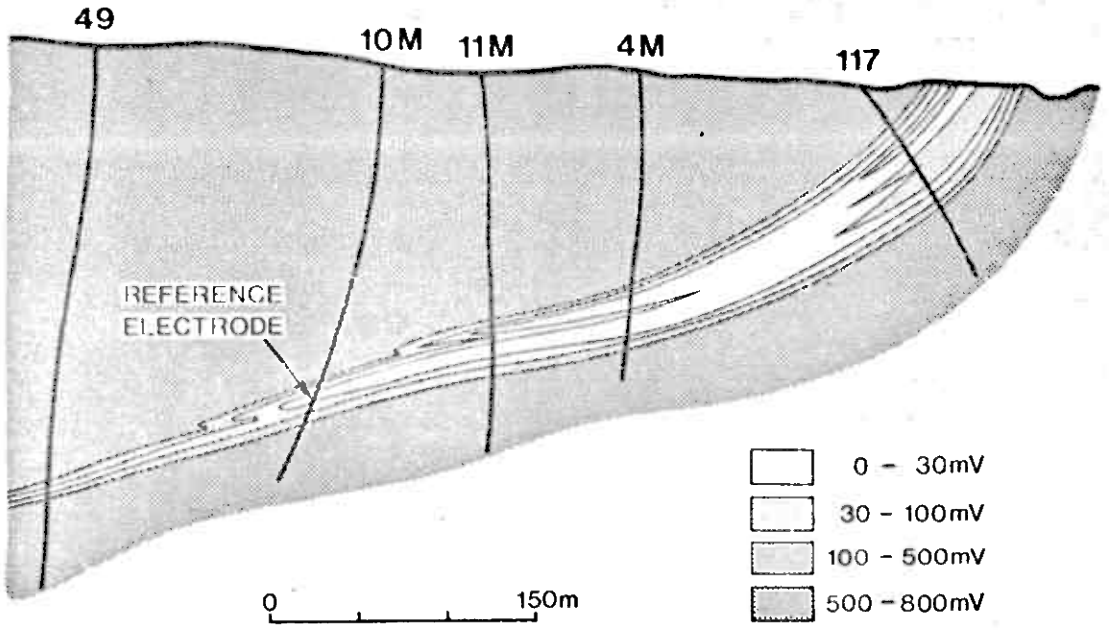

49
10M
11M
4M
117
REFERENCE
ELECTRODE
0
150m
0 - 30mV
30 - 100mV
100 - 500mV
500 - 800mV

FIG. 8

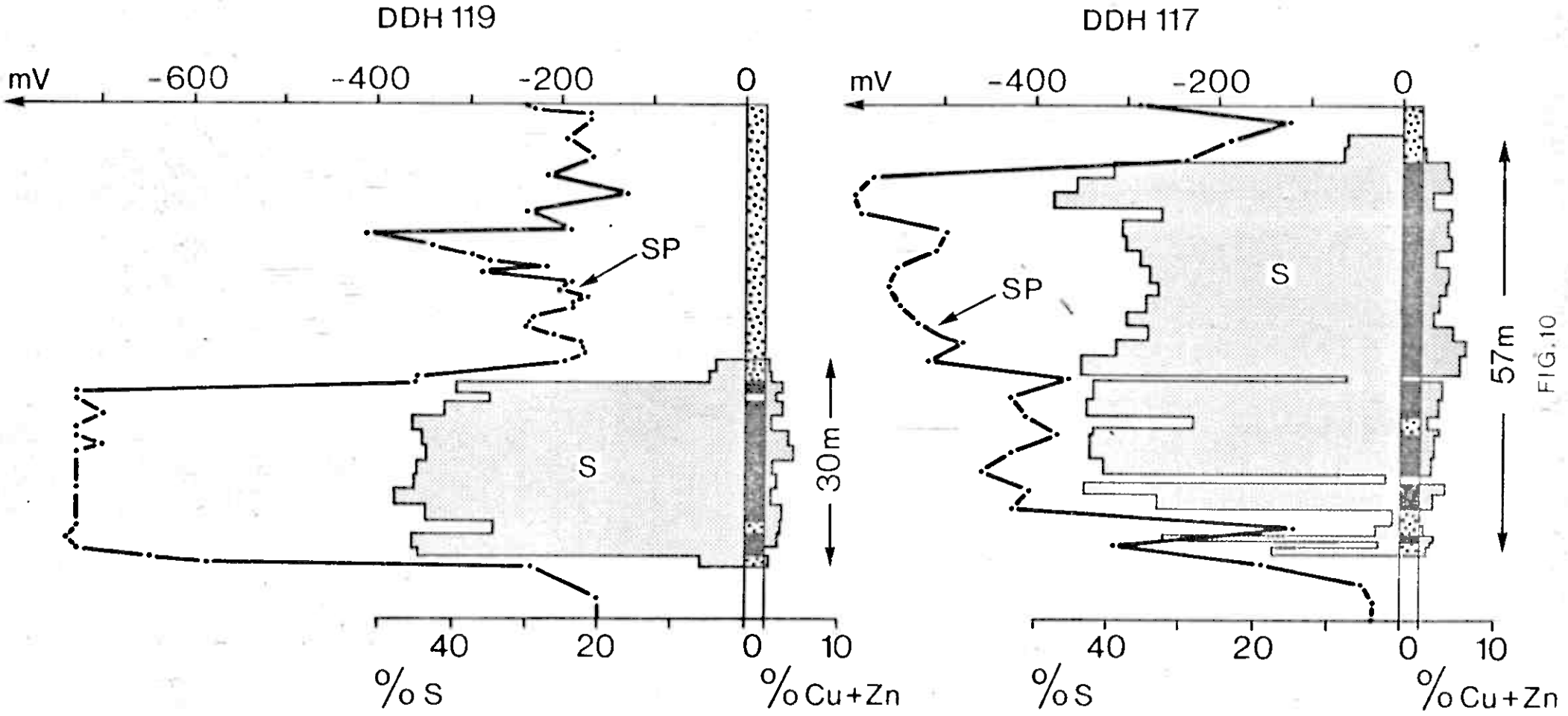

DDH 119
mV
-600
-400
-200
0
SP
S
30m
40
20
0
10
% S
% Cu+Zn
DDH 117
mV
-400
-200
0
SP
S
57m
40
20
0
10
% S
% Cu+Zn

FIG.10

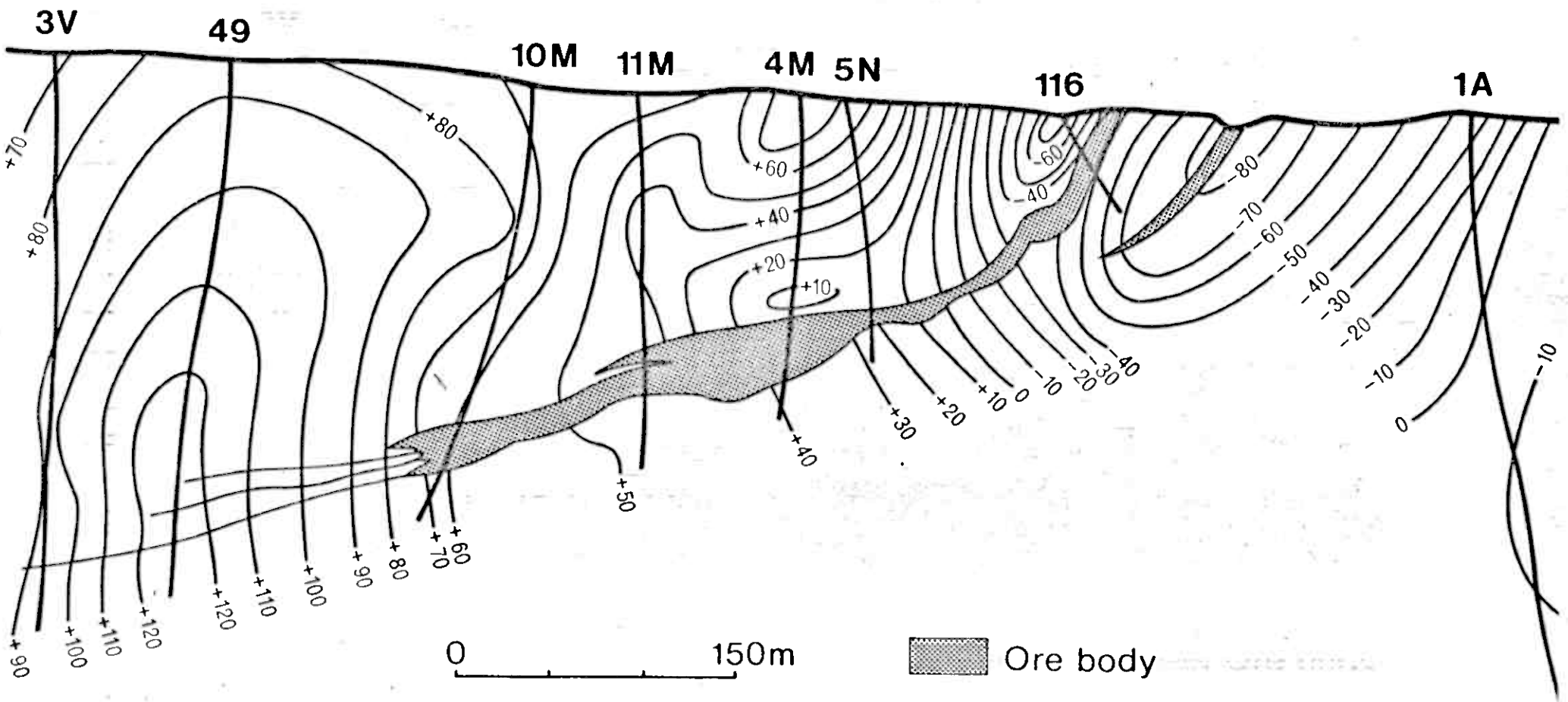

3V
49
10M
11M
4M
5N
116
1A
+70
+80
+80
+60
+40
+20
+10
-60
-40
-80
-70
-60
-50
-40
-30
-20
-10
0
-10
+90
+100
+110
+120
+120
+110
+100
+90
+80
+70
+60
+50
+40
+30
+20
+10
0
-10
-20
-30
-40
0
150m
Ore body

FIG. 11

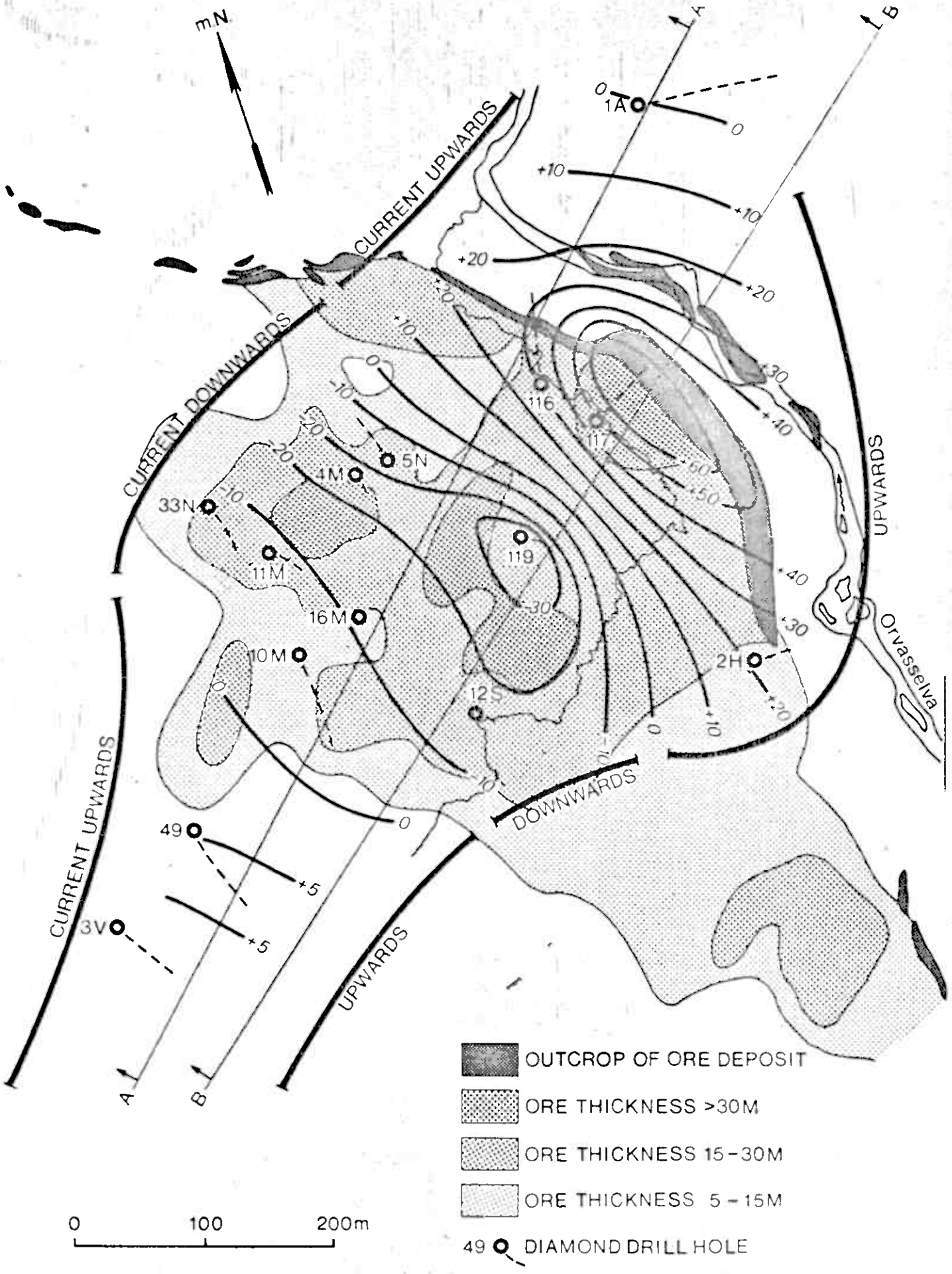

mN
A
B
1A
0
+10
+20
+30
+40
+50
+60
CURRENT UPWARDS
CURRENT DOWNWARDS
UPWARDS
DOWNWARDS
Orvasselva
116
117
119
5N
4M
33N
11M
16M
10M
2H
12S
49
3V
-10
-20
-30
+5
OUTCROP OF ORE DEPOSIT
ORE THICKNESS >30M
ORE THICKNESS 15-30M
ORE THICKNESS 5-15M
DIAMOND DRILL HOLE
0
100
200m

FIG.12

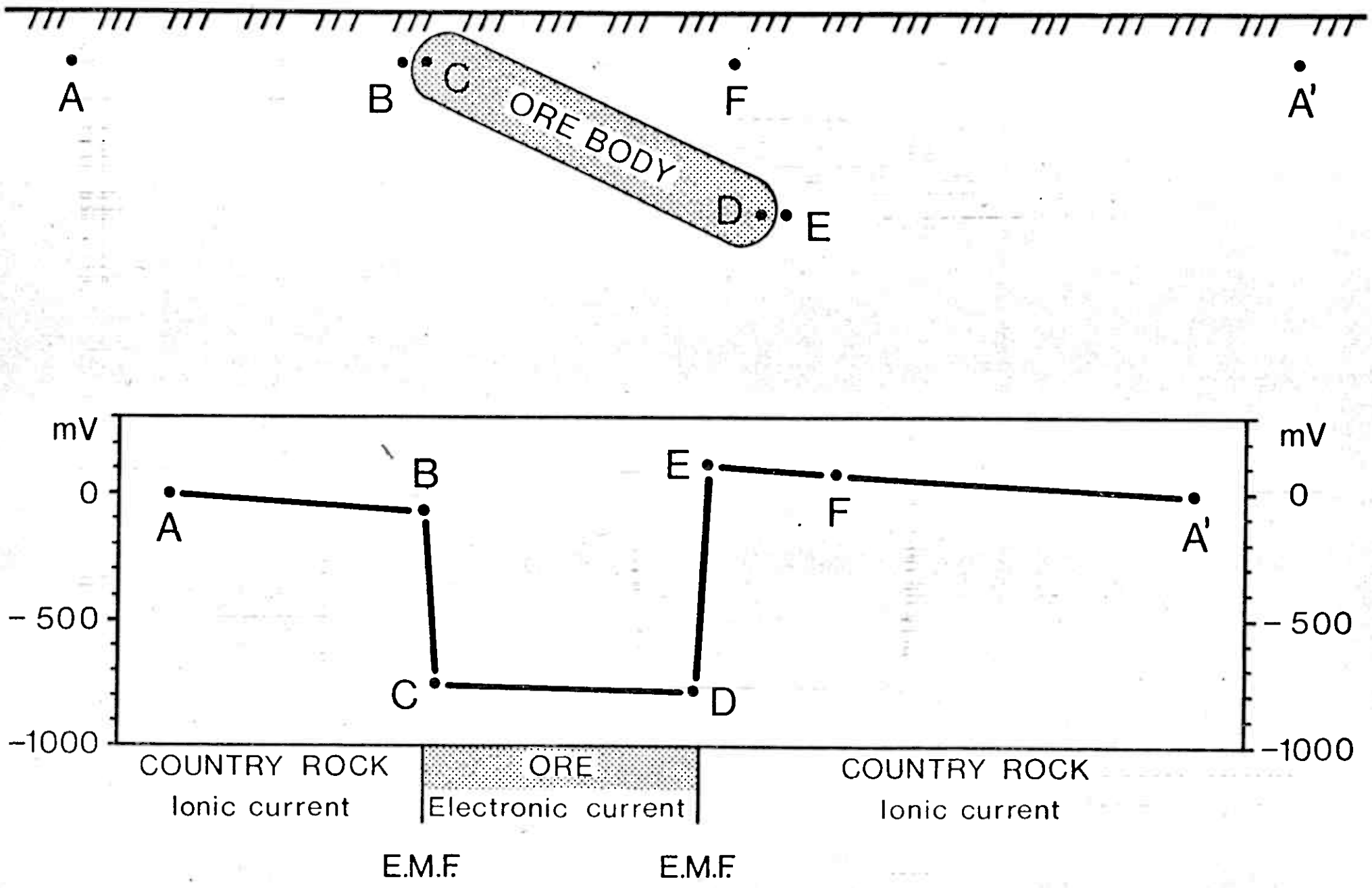

A
B
C
ORE BODY
D
E
F
A'
mV
0
-500
-1000
mV
0
-500
-1000
A
B
C
D
E
F
A'
COUNTRY ROCK
Ionic current
ORE
Electronic current
COUNTRY ROCK
Ionic current
E.M.F.
E.M.F.

FIG. 13