



# Direktoratet for mineralforvaltning

med Bergmesteren for Svalbard

Postboks 3021, N-7441 Trondheim

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LITHOGEOKJEMI

L Ø K K E N

1984-1985

Bind 1

LITHOGEOKJEMISKE

UNDERSØKELSER

I

LØKKEN - OMRÅDET

1984 - 1985

LV - rapport nr.30

LITHOGEOKJEMISKE UNDERSØKELSER I

LØKKENOMRADET 1984 - 1985

Lithogeochemical survey in the Løkken Area 1984 - 1985

Sammenstilt og bearbejdet av Gudmund Grammeltvedt

Mearbeidere: Tor Grenne  
Tor Valseth  
Åse Bollingmo

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## SAMMENDRAG

De lithogeokjemiske undersøkelserne i Løkkenområdet dekker et areal på ca. 80 km<sup>2</sup>. Det ble tatt 1608 prøver av uforvitret berg i profiler. Profilavstanden var 500 m, og det var 50 m mellom prøvene i hvert profil. Over Løkken- og Høydal - forekomstene ble det prøvetatt mellom-profiler. Feltarbeidet ble utført i 1984. Prøvene ble analysert på 38 elementer med atomabsorpsjon (AAS) og/eller røntgen (XRF).

Hensikten med den lithogeokjemiske undersøkelse var å finne tilførseloner for nye malmbeforekomster. Metoden er en indirekte dypmalmløttingsmetode. Ved å registrere tilførseloner i dagen kan disse følges mot dypet og mot en eventuell massiv sulfidforekomst. Undersøkelsen ville i tillegg vise den lithogeokjemiske fordelingen i bergartene. Malmbeforekomstene i Løkken - området ligger i en bestemt strategisk posisjon i lagrekken. Sannsynligheten for å finne nye malmer i denne posisjonen er større enn i feltet forøvrig.

Analyseresultatene ble plottet ut på kart i målestokk 1:20.000. Det ble dessuten produsert 10 forholdstallkart. Databearbeidelsen ble konsentrert om faktoranalyse på 21 elementer. I rapporten er følgende karter behandlet:

7 elementkart, 5 forholdstallkart, 9 faktorkart og 4 sammenstilte kart. Alle kartene er gitt i målestokk 1:50.000.

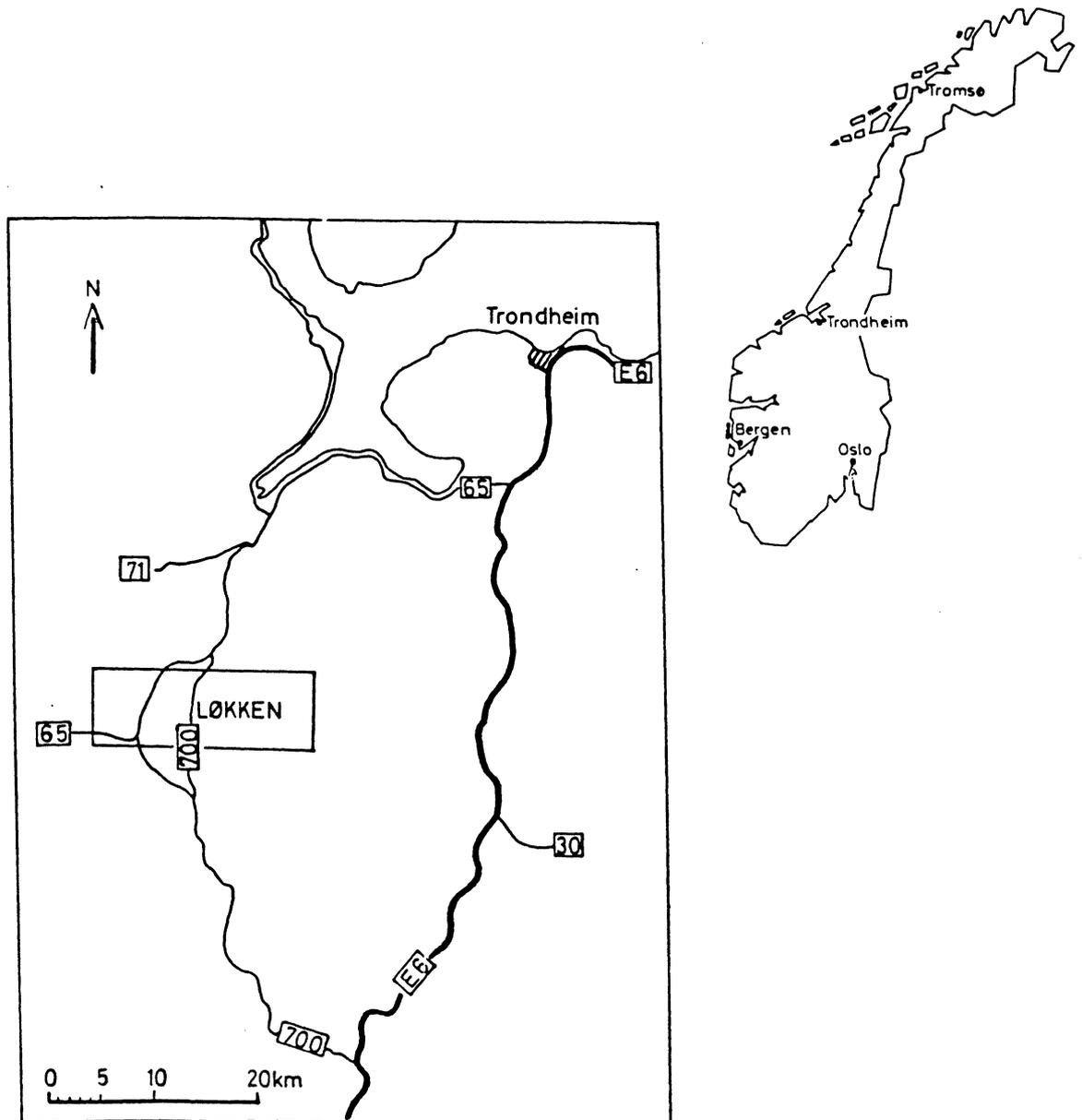
Rapportene gir en summarisk oversikt over tidligere arbeider i området og de senere års objektundersøkelser.

## KONKLUSJON

Den lithogeokjemiske undersøkelse i Løkkenområdet viser klare anomalier over Løkken - og Høydalsforekomstene. Anomale områder (Cu,Zn,S) finnes sydvest for Løkken, mellom Løkken og Høydal og øst for Høydal i samme strategisk nivå som de to grubene. Mer diffuse anomale områder finnes ved Åmot grube, området nord for Løkken og ved Dragset grube. Lithogeokjemisk er det en markert grense ved malmnivået. Bergartene over malmnivået har et høyere innhold av Cr, og Ni mens bergartene under er markert med høyere Zr, MgO, Ti og V.

Lithogeokjemiske undersøkelser vil være en viktig metode for videre dypmalmløting i hele Løkkenfeltet. Her er forutsetningen tilstede for å få en lithogeokjemisk kartlegging av bergartene og registrer tilførsel-/omvandlingssoner. Antall elementer som analyseres kan begrenses i forhold til det som er utført i denne undersøkelsen. Metoden gir ikke noe enstydig svar på om den finnes økonomiske malmer i undersøkelsesområdet, men må benyttes sammen med andre metoder.

FIGUR 1



Figur 1. Oversiktskart  
Location map

## 1. INNLEDNING

### 1.1 Beliggenhet - Topografi - Løsmasser

Området som er undersøkt ligger ved Løkken Grube, ca. 70 km syd for Trondheim (figur 1). Det dekker den nordlige del av Løkkenfeltet og begrenses mot øst av UTM - kordinat 46,5, og mot syd av 96,5, mot vest 26,5 og mot nord 103. Det dekker et område på 120 km<sup>2</sup>. Topografien er tildels kraftig med steile åser og dype daler. Høyden over havet varierer fra 150 til 540 meter. Hele området er dekket av bunnmorene og i Løkkendalen og Orkladalen er det tykke avsetninger med glasifluvialt materiale. Små gras- og torvmyrer er karakteristisk for området. Beboede og dyrkede områder er knyttet til de to hoveddalene. Blotningsgraden er forholdsvis liten.

Løkken Grube ligger sentralt i området. I tillegg til Løkken ligger det 3 mindre gruver innenfor området: Høydal (37,98), Dragset (27,101) og Amot (41,100).

### 1.2 Tidligere undersøkelser.

Det har vært gruvedrift på Løkken siden 1654. Høydal og Dragset gruber ble nedlagt ca. 1910 og Amot ca. 1880. Løkken er fortsatt i produksjon.

Malmletingen har i stor grad vært knyttet til disse forekomstene, og spesielt Løkken. De første diamantboringer ble utført i 1906. I 1926 ble de første geofysiske målingene gjennomført. Geologiske undersøkelser har vært utført kontinuerlig. Det første Geologiske kart over Løkkenfeltet ble publisert i 1951 (C.W.Carstens). Systematiske geokjemiske undersøkelser har ikke vært utført. C.W.Carstens gjorde en undersøkelse av sporelementer i vasskis og massiv malm for å bruke dette som en indikator i malmletingen, uten at det lyktes. 1969 ble de første undersøkelser med bekkersedimenter utført i området mellom Orkla og Dragset (22). I 1982/83 ble det tatt moreneprøver (1km.grid) i hele feltet. Jordprøver over området er vist i bilag 1 (Cu) og 2 (Zn).

I 1969 ble det utført geokjemiske undersøkelser av 5 borhull i gruva (23). Alle borhullene passerte malmen. 140 prøver ble analysert på følgende elementer:

Zu, Ni, Co, Cu, Pb, Mu, Cr, Mo, Cd, V og Ag. Undersøkelsen viste at Ni og Cr er høyere i bergartene strategisk over kisser enn under.

Det har vært lagt mest vekt på geofysiske undersøkelser i feltet. AB Elektrisk Malmleting og Geofysisk Malmleting, senere NGU har utført store oppdrag. Løkken har vært mye benyttet for utvikling av dypmalmletingsmetoder. Turam - metoden er den metode som er mest benyttet i området og i Løkken Grube. Gradient-IP er målt i Høydals-område (21,24). Likeledes ble det jordet i hovedmalmen på Løkkenmalmen (Astrup grubeområde) med fjernelektrode mot Storås og målt IP i dagen mellom Astrup sjakt og Dragset (31). I perioden 1976 - 1982 ble det utført refleksjonsseismiske målinger på Løkkenmalmen og i akseretninger mot vest (33-36, 43, 44, 51).

Gravimetrisk målinger ble utført av NGU i 1975 og 1981 (50). Pol - dipol IP ble benyttet i området i 1982 - 83 (52, 53).

Bilag 3 og 4 viser en oversikt over geofysiske bakkemålinger.

Helikoptermålinger ble utført i 1969 - 70 (Terratest) og i 1981 (Dighem). Bilag 5 viser HMAG over området.

### 1.3 Geologi

De senere års geologiske undersøkelser har lagt grunnlaget for de lithogeokjemiske undersøkelsene.

En sammenstilling av Løkken - områdets geologi av Tor Grenne, er vedlagt i Appendix 1.

Løkkenområdet tilhører et offeolitt - fragment og består vesentlig av metalvulkanitter, gangkompleks og gabbro. Bergartene kan grovt deles enn i to enheter: undre og øvre putelava. Den undre enhet består av gabbro, gangkompleks og putelava. I den øvre er det ved siden av putelava en rekke lag av jaspis, vasskis og brekksje. Malmforkomstene ligger nær overgangen mellom de to vulkanske enhetene, (geologisk kart, bilag 6).

Området ligger i dag invertert med de eldste bergarter i de sentrale soner. Flere skyvedekker og forkastninger kompliserer den geologiske tolkning.

Malmdannelsen er studert ved Høydal og Gammelgruva på Løkken. Det er antatt at de er knyttet til jordskorpebevegelser og ligger langs en gammel spredningsakse. Typisk for forekomstene er en forholdsvis stor tilførselsone med tilhørende omvandling av de vulkanske bergartene. Tabell 1 viser den omvandling som har skjedd ved Gammelgruva (L.V. rapport nr.21, ref.55).

## I SULFIDARER

- Avtagende åretetthet mot dypet.
- Anrikning av metaller øverst (uregelmessig).

## II PRIMÆR DISPERSJON

## a) Sulfid disseminasjon

- sterkt avtagende mot dypet
- Cu anrikning øverst og sentralt
- Zn anrikning øverst og perifert

## b) Ikke - sulfider

- Mn anrikning perifert mot dypet
- B anrikning i øvre deler

## III MINERALOGISK / KJEMISK OMVANDLING

## a) kvarts - sericitt omvandling (øverste 40 - 50 m)

- +  $\text{SiO}_2$ ,  $\text{K}_2\text{O}$
- $\text{CaO}$ ,  $\text{Na}_2\text{O}$ ,  $\text{MgO}$

## b) Albitt omvandling (ytte øvre deler)

- +  $\text{Na}_2\text{O}$ ,  $\text{SiO}_2$
- $\text{CaO}$ ,  $(\text{MgO})$

## c) Kloritt - kvarts omvandling (dypere deler)

- $\text{FeO}$  (tot)
- $\text{SiO}_2$ ,  $\text{CaO}$ ,  $\text{Na}_2\text{O}$

Tabell 1. Karakteristika i Løkken Grubers tilførselsone  
 Characteristica of the feeder - zone, Løkken Mine

#### 1.4 Objekt - undersøkelser. 1970 - 1984

Utenfor Løkken Gruber har Høydal - området vært gjenstand for de fleste undersøkelser.

Høydal (32). Det har vært boret der i flere perioder. Fra undersøkelser utført før 1968 er det lite som er rapportert. I 1974 - 1976 ble de siste undersøkelser utført ved Høydal. Arbeidene er beskrevet i rapporten "Høydal's feltet. Undersøkelser 1974 - 1976 med oversikt over tidligere arbeider"(ref.32). Det ble påvist ca. 1 mill. tonn malm med 1,15 % Cu og 0,5 % Zn.

Damlia. Det ble boret 2 hull der i 1971 for å undersøke en geofysisk anomali. Vasskis ble påvist.

Dragset. I 1972 ble det utført geofysiske undersøkelser og diamantboring. Konklusjonen ble at gruve er utdrevet og at det ikke finnes nye malmer i grubens umiddelbare nærhet.

Trevja. (29) Området ble undersøkt i 1974 med diamantboringer. Ingen malmhorisonter ble påvist (ref.29: "Diamantboring, Trevja 1974").

Segelvann/Sugustad området (39,40,41,48) ble undersøkt i perioden 1980 -1982. Det var en oppfølging av de seismiske undersøkelser. Tre borhull ble boret, men det ble ikke påvist malm.

Brannåsen (46) ble undersøkt med geologi, geofysikk og diamantboring i 1983. Det ble ikke påvist økonomiske malmer.

Svinsås (52,53,56,57) ble undersøkt i 1982 - 83 med geologi, lithogeokjemi, geofysikk og diamantboring. Det ble ikke påvist økonomiske malmer.

Høgåsen (53,58) ble undersøkt med geofysikk og diamantboring i 1982 - 83. Vasskis uten økonomisk interesse ble påvist.

Blokkum. (43,44,61). Det ble diamantboret et borhull der i 1984 for å undersøke en geologisk indikasjon på en tilførselsone.

## 2. LITHOGEOKJEMISKE UNDERSØKELSER

### 2.1 Innledning

Hensikten med de lithogeokjemiske undersøkelserne var å finne nye tilførseloner og dermed kunne finne nye malmforkomster. Da bergartene ligger invertert og er lite omvandlet, vil en utgående tilførselsone kunne vise oss veien til en ikke utgående malmforkomst (fig.2). Ut fra de studier som er utført på Høydal og Løkken, vil en tilførselsone klart kunne spores minst 500 m fra en forekomst (21).

I 1982 - 83 ble det utført lithogeokjemiske undersøkelser ved Svinsås (56). Prøvene ble analysert hos Bondar - Clegg, Canada. Element- og symbolkart er laget av Outokumpu for alle elementene. Det er laget separate kart i målestokk 1:20.000 (arkivert hos Løkken Gruber).

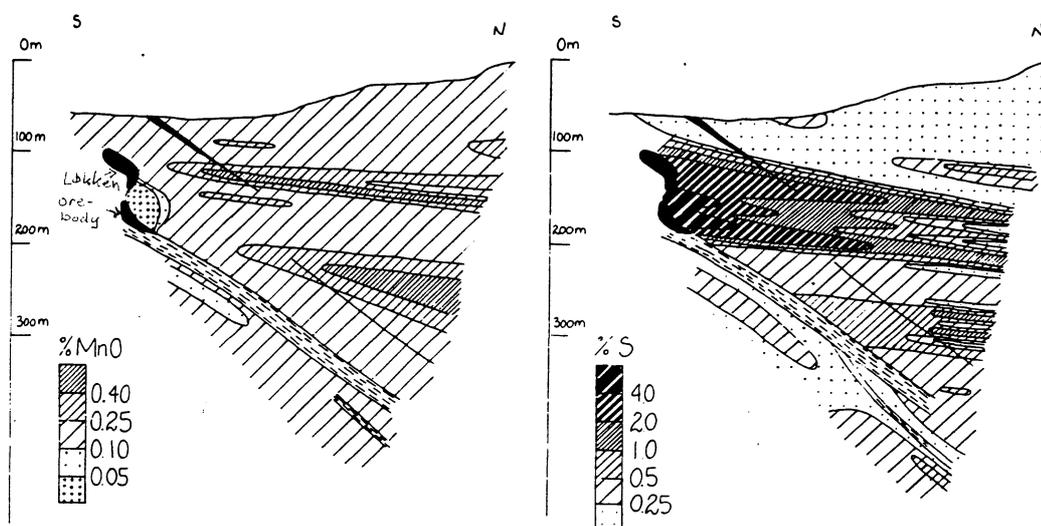


Fig.2. Tilførselsone Løkken grube.  
Feeder zone Løkken Mine.

## 2.2 Prøvetakning.

Det ble lagt opp til en prøvetagning av feltet med profiler i 500m avstand og 50 m mellom prøvepunktene i profilet. Ved Høydal og Løkken ble det også tatt mellomprofiler. Prøvetagningen skjedde sommeren 1984 (kart, bilag 7).

Prøvene ble tatt av friskt, fast fjell. Forvittringshuden ble fjernet. De fleste prøvene ble tatt for hånd. Noen ble tatt med kjerneboring. Størelsen på prøvene var 250 - 500 g. Hver prøve og prøvepunkt ble beskrevet av lederen for prøvetagerlaget. Prøvetagningen ble utført av to lag med to personer på hvert lag. Tor Grenne var ansvarlig for opplæring og opplegg. Tor Valseth var ansvarlig for den praktiske gjennomføring.

Det ble tilsammen tatt 1608 prøver.

## 2.3 Analyse

Prøvene ble sendt til Outokumpu OY's laboratorium i Espo. De var ansvarlig for knusing, bearbeidelse og analyse.

Outokumpu OY utførte AAS - analyse på følgende elementer: Cu, Zn, Ni, Co, Pb, S, Li. Ag - analyse ble utført på endel prøver, men ble avbrutt p.g.a. lavt Ag - innhold. XRF - analyse ble utført på oppdrag hos Rautaruukki OY, på følgende elementer: Na<sub>2</sub>, MgO, Al<sub>2</sub>O<sub>3</sub>, SiO<sub>2</sub>, P, S, Cl, K<sub>2</sub>O, CaO, Ti, V, Cr, Mn, Fe, Ni, Cu, Zn, As, Rb, Sr, Y, Zr, Nb, Mo, Sn, Sb, Cs, Ba, La, Ce, Ta, Pb, Bi, Th, U

Analyseresultatene er vist i bind 2.

## 2.4 Databehandling

Outokumpu OY har utført all databearbeidelse av analyseresultatene. Alle resultater er oppbevart på "tape" og "floppy disks".

#### 2.4.1 Elementkart

Alle elementene er plottet på kart i målestokk 1:20.000 med analyseverdi og endel også som symbolkart. Disse kartene er ikke vedlagt rapporten, men oppbevares i Løkken Gruber A/S og Outokumpu OY's arkiver. Det er laget frekvensdiagrammer av de fleste elementer, figur 3-21.

For de elementer som har vist størst variasjon er symbolkart i målestokk 1:50.000 vedlagt rapporten (bilag 8 - 14).

#### 2.4.2 Spesiell kart.

For bedre å vurdere resultatene ble det fremstilt 10 kart over forholdstallet mellom to elementer. Forholdet mellom "stabile" elementer og mer mobile ble beregnet og plottet ut som verdi- og symbolkart. Likeledes forholdet mellom typiske elementer i tilførselssonen.

Følgende forhold ble valgt:

S1:  $\text{CaO}/\text{MgO}$ , S2:  $\text{CaO}/\text{Cr}$ , S3:  $\text{Mn}/\text{Ti}$ , S4:  $\text{Mn}/\text{V}$ , S5:  $\text{Mn}/\text{Fe}$ , S6:  $\text{Fe}/\text{Ti}$ , S7:  $\text{Fe}/\text{v}$ , S8:  $\text{Na}_2\text{O}/\text{SiO}_2$ , S9:  $\text{MgO}/\text{Cr}$  og S10:  $\text{Ba}/\text{K}_2\text{O}$ .

Symbolkart for S2, S4, S5, S6 og S9 målestokk 1:50.000 er i bilag 16 - 20. Alle kartene i målestokk 1:20.000 er i vårt arkiv og legges ikke ved rapporten.

Det ble også utarbeidet et kart over  $\text{Cu}/\text{Zn}$  - faktor. Dette er vist i et sammenstilt kart, bilag 27.

#### 2.4.3 Faktoranalyse.

21 elementer ble valgt for videre databehandling. Disse var: Cu, Zn, Ni, Sr, As, Ba, S, Mn, Cr, Fe,  $\text{Na}_2\text{O}$ , MgO,  $\text{Al}_2\text{O}_3$ ,  $\text{SiO}_2$ , P,  $\text{K}_2\text{O}$ , CaO, Ti, V, Zr, Cl.

1667 prøver var med i analysen. Av disse er 1608 fra Løkkenfeltet og de øvrige fra gruben og Nord-Trøndelag. En tilsvarende analyse ble utført på 1542 grønnstensprøver. Resultatene er diskutert i kapitell 3.3. Kartene fra faktoranalysen i målestokk 1:20.000 er arkivert i vårt arkiv.

#### 2.4.4 Regresjonsanalyse

For å prøve å få en bedre forståelse av anomaliene ble det utarbeidet regresjonskurver for Zr mot Zn, Cu,  $\text{SiO}_2$ , CaO,  $\text{Fe}_2\text{O}_3$ , MnO, MgO og  $\text{Na}_2\text{O}$  (tabell 2). Zr er regnet for det mest stabile element ved metamorf omvandling, samtidig som det anrikes i magmaet under differensiasjonsprosessen. De øvrige elementer vil ha en primær variasjon ved siden av variasjon i en omvandlingssone (avvik fra den primære sammensetning). Dersom det kunne fremstilles en regresjonskurve over den antatte primære variasjon, ville avvik fra kurven være en anomali. Figur 22 - 29 viser eksempler op regresjonskurver. Datamengden ved høye Zr - gehalter blir for dårlig for en sikker statistisk behandling. Videre bearbeidelse av disse data er foreløbig ikke utført.

FILE: X X A \*\*\* OUTUKUMPU OY / ATK-KESKUS \*\*\*

POLYNOMIAL REGRESSION LOKKEN 8.11.1985

INDEPENDENT VARIABLE: ZR

| DEPENDENT VARIABLE | INTERCEPT  | REGRESSION COEFFICIENTS | DEGREE      |             |
|--------------------|------------|-------------------------|-------------|-------------|
|                    |            | 1. DEGREE               | 2. DEGREE   |             |
|                    |            | 1. DEGREE               | 3. DEGREE   |             |
| ZN                 | 63.1565    | 43.2085E-2              | -1.91364E-4 | -3.43639E-7 |
| CU                 | 44.3285    | 18.0208E-4              | -7.23634E-4 | 52.12159E-8 |
| SI02               | 45.8876E+4 | 40.7930E+1              | 39.09570E-2 | -7.61850E-4 |
| CA0                | 12.2373E+4 | -5.6494E+2              | 11.6800E-1  | -6.49455E-4 |
| FE2O3              | 86.2067E+3 | 46.1409E+1              | -1.81641    | 13.84507E-4 |
| MNO                | 14.3751E+2 | 46.1926E-1              | -2.13784E-2 | 16.54265E-6 |
| MGO                | 87.5650E+3 | -2.7569E+2              | 33.10428E-2 | -1.28810E-4 |
| NA2O               | 25.7568E+3 | 19.6867E+1              | -4.22881E-1 | 27.04430E-5 |

Tabell 2 Regresjonsanalyse  
Regression analyses

### 3. RESULTATER

Resultatene fra de lithogeokjemiske undersøkelsene er samlet i dette kapitell. Alle kartene so ligger ved rapporten er i målestokk 1:50.000. Denne målestokk er valgt av praktiske grunner. Hovedtendensene vil klart gå frem i denne målestokken. Alle kartene er gitt som symbolkart. Orginalkartene i målestokk 1:20.000 finnes i Løkken Gurber A/S og Outokumpu Oy's arkiver. Alle kartene bør vurderes sammen med det geologiske kartet som "overlay" (bilag 6).

#### 3.1 Elementkart.

Av de 37 elementene som ble analysert, er 7 elementkart lagt ved rapporten. Disse er Cu, Ni, Cr, MnO, As, Cl og Zr. De fleste elementkart viser ingen systematisk variasjon hverken over variasjon i bergarter eller kjente tilførselsoener. Cu, Zn og S er de dominerende elementer i Løkkenfeltets malforekomster. De påviste tilførselsoenene ved Høydal og Løkken har anomale Zn og S - verdier mens Cu innholdet er lavt.

Cu: kartet, bilag 8 gir ingen klare anomalier. Det er et anomalt område NØ for Løkken Grubers utgående og et NØ for Høydal. Ved Høydal finnes det også klare lave områder, noe som kan være typisk for en tilførselsoene. Det synes som om nedre putelava har høyere Cu - verdier enn de øvre. I profil 42,5 er det anomalie Cu - verdier rett syd for gabbroen.

Ni: kartet, bilag 9 viser klart at Ni følger bergartene. Øvre putelava har et betydelig høyere Ni - innhold enn de nedre. Den geologiske kartlagte grensen mellom øvre og nedre putelava er noe lavere i stratigrafien enn den geokjemiske grense.

Cr: kartet, bilag 10 viser samme trekk som Ni med høye Cr - verdier i øvre putelava og lave i de nedre. Gabbroen ved Løkken har og høye Cr - verdier, noe vi ikke finner i gabbroen i øst.

MnO: karter, bilag 11 viser høye Mn - verdier over tilførselssonene til Løkken og Høydal. Det er forøvrig ikke noe klart mønster, men det synes som prøver nær vasskis/jaspis har høye Mn - verdier.

As: kartet, bilag 12 viser høye verdier over gabbroen og i nesten alle prøvene i vest (Dragset - området). Øvre putelava i Brannåsen (P43.5, 44.0, 44.5) og Gaddåsen (P33.0, 33.5, 34.0) viser og høy As.

Cl: kartet, bilag 13 viser klare anomalier ved alle gabbroer. Ved Høydal og Høgåsen strekker de seg betydelig syd for gabbroene. Arsaken til Cl - anomaliene kan være gabbroens primære sammensetning (primær hornblende gabbro).

Zr: kartet, bilag 14 viser at Zr i store trekk følger grønnsteinenes inndeling. Det vil si den har motsatt mønster av Ni og Cr med høyt Zr - innhold i nedre putelava og lavt i øvre.

Kartet, bilag 15 viser en sammenstilling av fire kart: Zr/F2g (Ni, Cr) / F2a (Ti,V) / S9 (MgO/Cr). Dette kartet viser klart bergartsfordelingen innenfor området. Øvre putelava har høy Ni, Cr og ingen av de andre elementer. Et unntak er øvre putelava i Gaddåsen (P33.0 - 34.0) som har høy Zr verdier ved siden av Ni, Cr. Gabbroen i øst skiller seg fra de øvrige gabbroer med mangel på høy Ni, Cr. Det samme gjelder gabbroen i P 33.5 (Høgåsen).

I bilag 34 er vist et sammenstilt kart Cr, Ni, Zr, MgO/Cr.

### 3.2 Forholdstallkart

Kartene over forholdstallet mellom to elementer viser i store trekk ikke mer enn elementkartene. Der det ene elementet dominerer, vil kartbildet bli dominert av dette elementet. 5 kart er vedlagt for å illustrere denne karttype.

S2 CaO/Cr: kartet, bilag 16 viser sammen mønster som for Cr, med høye forholdstall i nedre putelava og lave i øvre.

S4 Mn/V: kartet, bilag 17 viser ingen klare trender.

S5 Mn/Fe: bilag 18. Tilførselssonene ved Høydal og Løkken kommer klart frem. Dessuten er det høye forholdstall i områder med vasskis og jaspis.

S6 Fe/Ti: bilag 19. Vasskis og jaspis gir også her overveiende høye forholdstall. Gabbroen ved Løkken skiller seg fra de øvrige med et høyt Fe/Ti - forhold.

S9 MgO/Cr: Bilag 20. Dette forholdet følger i store trekk motsatt trend av Cr. Det er høye forholdstall i nedre putelava.

### 3.3 Faktoranalyse

Resultatet av faktoranalysen er vedlagt i bind 2. Tabell 3 - 5 viser en sammenstilling av resultatene. Tabell 3a og b viser korrelasjonskoeffisientene for alle prøver (3a) og for grønnsteiner (3b). I tabell 4 og 5 er faktorene sammenstilt.

3.3.1 Faktor F3. Som det går frem av tabell 4 og 5 er faktor F3 malmfaktoren. Cu og S har størst vekt i tabell 4a og 5a, Cu og Zn i tabell 4b og Cu, Zn og S i tabell 5b. Symbokolkartene, bilag 21 - 23, viser plottet av F3g og F3a, alle bergarter og F3a<sup>x</sup>, grønnsteiner. De tre kartene er sammenstilt i bilag 24. Det går tydelig frem av kartene at undre putelava har høyere innhold av Cu, Zn og S enn øvre. Tilførselssonene ved Høydal er klart markert i profil P38.0, P38.5, og P39.0. Fra tidligere undersøkelser i Høydal vet vi at tilførselssonene har en vinkel med bergartenes strøkretning. Anomalien i P37 ligger i riktig strategrafisk nivå. Tidligere undersøkelser har ikke vist noe malm. Den anomale sonen i P36 kan tilhøre Løkkenforekomstens tilførselsone som vi finner i P35. De høye faktorverdier i P31 - P34 ligger alle i et interessant strategrafisk nivå øverst i undre putalava. Dette vil tilsvare omtrentlig strategrafisk nivå til Løkkenmalmen. I området er det registrert svak Cu - mineralisering. Dragset grube kommer frem i P27,5.

Øst for Høydal er det høye faktorverdier i flere profiler. Anomaliene i P40 - P41 har karakteristika av en tilførselsone, men det er ikke påvist mineralisering i området. Det samme gjelder anomaliene i P42.5, og P43 og P44. Disse anomaliene er alle knyttet til et profil og synes ikke å ha sammenheng med en større tilførselsone.

I nord er det klare anomalier NV for Åmot grube P40 - P41.5. Disse er knyttet til det mineraliserte området som ble boret opp i 1984, uten at økonomisk malm ble påvist (54).

3.3.2 F9a, F10g. Faktor F9a har dominerende vekt på S. (symbolkart, bilag 25) og F10g har dominerende vekt på Zn (symbolkart bilag 26). En sammenstilling av disse to kart og Cu - Zn faktor er vist i bilag 27. Tilførselsone for Høydal og Løkken kommer tydelig frem. F9a og F10g følger i store trekk F3 - faktorene. Cu - Zn faktoren gir større spredning.

3.3.3 F11a. Denne faktor har størst vekt på Mn. Mn er et element som viser anrikning i tilførselonen. Symbolkartet, bilag 28 viser omtrent det samme mønster som elementkartet for MnO, bilag 11. Tilførselsone på Høydal og Løkken kommer frem. Videre viser det høye verdier nær vasskis/jaspis horisonter.

3.3.4 F1g.F2a. Disse faktorene har størst vekt på Fe, Ti og V. Symbolkartene, bilag 29 og 30, viser ikke et enstydig mønster, men det er overveiende høyere verdier i nedre putelava enn i øvre. Vasskis/jaspislag synes å gi høyere verdier. Gabbroen i øst har høyere verdier enn de øvrige gabbroer.

3.3.5 F2g har størst vekt på Ni og Cr. Symbolkartet, bilag 31 viser i store trekk samme mønster som for elementkartene Ni og Cr (bilag 9 og 10) med høye verdier i øvre putelava og de sentrale gabbroer.

Løkken Area. Lithochemistry

|                                |      | Logaritmisk |      |      |      |      |      |      |      |      |      |                   |      |                                |                  |      |                  |      |      |      |      |     |  |                                |
|--------------------------------|------|-------------|------|------|------|------|------|------|------|------|------|-------------------|------|--------------------------------|------------------|------|------------------|------|------|------|------|-----|--|--------------------------------|
|                                |      | Cu          | Zn   | Ni   | Sr   | As   | Ba   | S    | Mn   | Cr   | Fe   | Na <sub>2</sub> O | MgO  | Al <sub>2</sub> O <sub>3</sub> | SiO <sub>2</sub> | P    | K <sub>2</sub> O | CaO  | Ti   | V    | Zr   | Cl  |  |                                |
| Cu                             |      | .44         | .18  | .01  | .01  | -.09 | .39  | .36  | .15  | .31  | -.13 | .24               | -.05 | -.36                           | .13              | -.15 | .18              | .21  | .24  | -.03 | .03  |     |  | Cu                             |
| Zn                             | .69  |             | -.03 | -.15 | -.02 | -.09 | .32  | .45  | -.01 | .44  | -.03 | .21               | .01  | -.26                           | .27              | -.14 | -.08             | .36  | .34  | .13  | -.03 |     |  | Zn                             |
| Ni                             | .07  | .00         |      | .05  | -.14 | .02  | -.29 | .29  | .76  | .12  | -.32 | .63               | .15  | -.57                           | -.24             | .12  | .52              | -.05 | .19  | -.44 | .00  |     |  | Ni                             |
| Sr                             | .04  | -.03        | .02  |      | -.02 | .06  | -.11 | .05  | .07  | -.02 | -.09 | .05               | .22  | -.19                           | .08              | .07  | .44              | .06  | .05  | .01  | -.07 |     |  | Sr                             |
| As                             | -.01 | .01         | -.14 | .06  |      |      | .05  | .09  | -.18 | .00  | -.15 | -.11              | -.20 | -.13                           | .17              | -.17 | -.02             | -.11 | -.19 | -.17 | -.08 | .05 |  | As                             |
| Ba                             | .06  | .01         | .01  | .13  | .03  |      | -.09 | -.23 | .09  | -.32 | -.14 | -.18              | .06  | .17                            | -.14             | .71  | -.23             | -.37 | -.32 | .00  | -.10 |     |  | Ba                             |
| S                              | .33  | .35         | -.08 | -.02 | .17  | .00  |      | .14  | -.28 | .25  | -.01 | -.12              | -.27 | .01                            | .20              | -.22 | -.20             | .16  | .09  | .19  | -.04 |     |  | S                              |
| Mn                             | .19  | .39         | .08  | .00  | -.15 | -.12 | .10  |      | .13  | .72  | -.17 | .68               | -.02 | -.64                           | .20              | -.28 | .46              | .55  | .61  | -.08 | .10  |     |  | Mn                             |
| Cr                             | .00  | -.04        | .80  | .00  | .03  | .03  | -.10 | .02  |      | -.11 | -.32 | .47               | .09  | -.39                           | .35              | .15  | .40              | -.24 | -.10 | -.40 | -.03 |     |  | Cr                             |
| Fe                             | .25  | .30         | -.08 | -.03 | -.16 | -.24 | .39  | .55  | -.21 |      | -.12 | .58               | .04  | -.62                           | .41              | -.31 | .30              | .75  | .80  | .03  | .14  |     |  | Fe                             |
| Na <sub>2</sub> O              | -.08 | -.05        | -.38 | -.20 | -.05 | -.10 | -.11 | -.23 | -.41 | -.17 |      | -.29              | .27  | .37                            | .30              | -.13 | -.25             | .17  | .02  | .32  | -.10 |     |  | Na <sub>2</sub> O              |
| MgO                            | -.01 | .00         | .59  | .03  | -.22 | -.11 | -.13 | .39  | .59  | .22  | -.50 |                   | .15  | -.72                           | -.05             | -.14 | .56              | .34  | .53  | -.39 | .02  |     |  | MgO                            |
| Al <sub>2</sub> O <sub>3</sub> | -.02 | -.02        | .05  | .13  | -.11 | .06  | -.25 | -.16 | .06  | -.21 | .14  | .02               |      | -.25                           | .02              | .19  | .19              | .15  | .14  | -.08 | -.21 |     |  | Al <sub>2</sub> O <sub>3</sub> |
| SiO <sub>2</sub>               | -.13 | -.12        | -.42 | -.11 | .36  | .23  | -.05 | -.47 | -.31 | -.51 | .44  | -.66              | -.25 |                                | .02              | .09  | -.68             | -.42 | -.58 | .31  | -.13 |     |  | SiO <sub>2</sub>               |
| P                              | .02  | .06         | -.25 | .25  | -.06 | .10  | .05  | .01  | -.30 | .17  | .30  | -.28              | .01  | .08                            |                  | -.15 | -.06             | .63  | .36  | .66  | -.14 |     |  | P                              |
| K <sub>2</sub> O               | .00  | -.02        | .07  | .02  | -.02 | .63  | -.03 | -.24 | .09  | -.26 | -.20 | -.14              | .22  | .16                            | -.02             |      | -.13             | -.28 | -.23 | -.06 | .05  |     |  | K <sub>2</sub> O               |
| CaO                            | -.03 | -.15        | .32  | .32  | .01  | -.17 | -.13 | .12  | .35  | -.08 | -.52 | .31               | .10  | -.60                           | -.24             | -.16 |                  | .26  | .42  | -.39 | .19  |     |  | CaO                            |
| Ti                             | -.01 | .10         | -.25 | .00  | -.15 | -.26 | -.03 | .38  | -.36 | .63  | .12  | -.01              | -.06 | -.32                           | .37              | -.24 | -.03             |      | .79  | .39  | .12  |     |  | Ti                             |
| V                              | -.04 | .06         | -.14 | .00  | -.15 | -.27 | -.04 | .35  | -.27 | .66  | .01  | .11               | -.02 | -.44                           | .11              | -.20 | .06              | .77  |      | -.06 | .14  |     |  | V                              |
| Zr                             | .11  | .09         | -.31 | .15  | .01  | .12  | .04  | -.10 | -.32 | -.04 | .29  | -.40              | -.07 | .35                            | .53              | .04  | -.31             | .21  | -.15 |      | -.09 |     |  | Zr                             |
| Cl                             | .01  | -.08        | -.03 | .02  | .04  | -.01 | -.03 | .05  | -.02 | .07  | -.14 | .10               | -.07 | -.05                           | -.08             | -.01 | .16              | .14  | .11  | -.05 |      |     |  | Cl                             |
|                                |      | Linear      |      |      |      |      |      |      |      |      |      |                   |      |                                |                  |      |                  |      |      |      |      |     |  |                                |
|                                |      | Cu          | Zn   | Ni   | Sr   | As   | Ba   | S    | Mn   | Cr   | Fe   | Na <sub>2</sub> O | MgO  | Al <sub>2</sub> O <sub>3</sub> | SiO <sub>2</sub> | P    | K <sub>2</sub> O | CaO  | Ti   | V    | Zr   | Cl  |  |                                |

3a All rock types

|                                |      | Logaritmisk |      |      |      |      |      |      |      |      |      |                   |      |                                |                  |      |                  |      |      |      |      |    |  |                                |
|--------------------------------|------|-------------|------|------|------|------|------|------|------|------|------|-------------------|------|--------------------------------|------------------|------|------------------|------|------|------|------|----|--|--------------------------------|
|                                |      | Cu          | Zn   | Ni   | Sr   | As   | Ba   | S    | Mn   | Cr   | Fe   | Na <sub>2</sub> O | MgO  | Al <sub>2</sub> O <sub>3</sub> | SiO <sub>2</sub> | P    | K <sub>2</sub> O | CaO  | Ti   | V    | Zr   | Cl |  |                                |
| Cu                             |      | .33         | .11  | .05  | .04  | -.01 | .30  | .20  | .16  | .05  | -.13 | .11               | -.01 | -.27                           | -.02             | -.07 | .13              | .03  | .06  | -.03 | -.13 |    |  | Cu                             |
| Zn                             | .80  |             | -.09 | -.12 | .04  | .00  | .27  | .29  | -.07 | .30  | -.05 | -.01              | .04  | -.11                           | .17              | -.08 | -.24             | .23  | .18  | .19  | -.15 |    |  | Zn                             |
| Ni                             | .07  | .02         |      | .07  | -.04 | .13  | -.34 | .07  | .77  | -.23 | -.35 | .47               | .11  | -.46                           | -.39             | .24  | .42              | -.38 | -.18 | -.41 | .02  |    |  | Ni                             |
| Sr                             | .05  | .01         | .02  |      | -.02 | .05  | -.03 | .06  | .08  | .03  | -.13 | .07               | .12  | -.22                           | .01              | .06  | .46              | .06  | .07  | .01  | -.11 |    |  | Sr                             |
| As                             | -.02 | .01         | -.08 | .04  |      | -.02 | .02  | -.13 | .06  | -.11 | -.04 | -.10              | .01  | .09                            | -.09             | -.06 | .02              | -.08 | -.07 | -.07 | -.18 |    |  | As                             |
| Ba                             | .10  | .08         | .14  | .05  | .04  |      | -.03 | -.06 | .18  | -.15 | -.24 | .08               | .11  | -.08                           | -.12             | .66  | -.08             | -.22 | -.21 | -.12 | -.06 |    |  | Ba                             |
| S                              | .73  | .72         | -.06 | .02  | .06  | .09  |      | .12  | -.26 | .17  | .04  | -.12              | -.20 | .05                            | .21              | -.20 | -.14             | .27  | .10  | .25  | -.15 |    |  | S                              |
| Mn                             | .21  | .33         | .02  | .05  | -.09 | .03  | .16  |      | .08  | .48  | -.18 | .53               | -.19 | -.44                           | .03              | -.22 | .29              | .31  | .34  | .07  | .05  |    |  | Mn                             |
| Cr                             | .00  | -.03        | .83  | .03  | .01  | .16  | -.10 | .02  |      | -.28 | -.24 | .47               | .09  | -.39                           | -.41             | .23  | .38              | -.48 | -.28 | -.40 | .00  |    |  | Cr                             |
| Fe                             | .33  | .33         | -.21 | .04  | -.14 | -.11 | .27  | .45  | -.28 |      | -.12 | .26               | -.13 | -.31                           | .35              | -.22 | -.05             | .66  | .67  | .33  | .17  |    |  | Fe                             |
| Na <sub>2</sub> O              | -.09 | -.03        | -.38 | -.31 | .05  | -.22 | .00  | -.23 | -.41 | -.13 |      | -.38              | .14  | .52                            | .25              | -.24 | -.26             | .15  | .06  | .20  | .03  |    |  | Na <sub>2</sub> O              |
| MgO                            | -.02 | -.04        | .53  | .04  | -.13 | .14  | -.09 | .34  | .58  | .12  | -.53 |                   | .08  | -.53                           | -.28             | -.02 | .31              | -.03 | .14  | -.28 | .02  |    |  | MgO                            |
| Al <sub>2</sub> O <sub>3</sub> | -.01 | .03         | .00  | .07  | .03  | .09  | -.07 | -.21 | .01  | -.16 | .11  | -.14              |      | -.12                           | -.15             | .25  | -.03             | .10  | .01  | -.17 | -.20 |    |  | Al <sub>2</sub> O <sub>3</sub> |
| SiO <sub>2</sub>               | -.20 | -.13        | -.38 | -.21 | .11  | -.04 | -.05 | -.36 | -.34 | -.31 | .57  | -.49              | -.13 |                                | .19              | -.08 | -.57             | -.06 | -.25 | .22  | -.03 |    |  | SiO <sub>2</sub>               |
| P                              | .03  | .06         | -.33 | .02  | -.05 | -.07 | .06  | -.06 | -.96 | .23  | .29  | -.34              | -.12 | .25                            |                  | -.15 | -.21             | .65  | .37  | .65  | -.05 |    |  | P                              |
| K <sub>2</sub> O               | .01  | .01         | -.17 | -.01 | -.06 | .58  | -.04 | -.18 | .18  | -.15 | -.29 | -.03              | .30  | -.06                           | -.06             |      | -.03             | -.24 | -.17 | -.17 | .07  |    |  | K <sub>2</sub> O               |
| CaO                            | -.03 | -.15        | .26  | .37  | .11  | -.07 | -.11 | .06  | .29  | -.23 | -.51 | .10               | -.08 | -.55                           | -.29             | .07  |                  | .01  | .19  | -.29 | .14  |    |  | CaO                            |
| Ti                             | -.02 | .04         | -.43 | .01  | -.04 | -.18 | .05  | .23  | -.47 | .60  | .10  | -.15              | -.16 | -.06                           | .51              | -.17 | -.14             |      | .69  | .68  | .19  |    |  | Ti                             |
| V                              | -.07 | -.01        | -.31 | .01  | -.07 | -.17 | -.04 | .16  | -.40 | .62  | .06  | -.13              | -.03 | -.16                           | .21              | -.07 | -.12             | .68  |      | .12  | .16  |    |  | V                              |
| Zr                             | .21  | .23         | -.35 | -.01 | -.03 | -.04 | .24  | .08  | -.40 | .31  | .22  | -.31              | -.16 | .27                            | .63              | -.11 | -.28             | .58  | .11  |      | .03  |    |  | Zr                             |
| Cl                             | -.01 | -.07        | -.03 | -.01 | -.04 | .00  | -.03 | .04  | .03  | .11  | .06  | .05               | .13  | .02                            | .00              | -.01 | .05              | .13  | .06  | .06  |      |    |  | Cl                             |
|                                |      | Linear      |      |      |      |      |      |      |      |      |      |                   |      |                                |                  |      |                  |      |      |      |      |    |  |                                |
|                                |      | Cu          | Zn   | Ni   | Sr   | As   | Ba   | S    | Mn   | Cr   | Fe   | Na <sub>2</sub> O | MgO  | Al <sub>2</sub> O <sub>3</sub> | SiO <sub>2</sub> | P    | K <sub>2</sub> O | CaO  | Ti   | V    | Zr   | Cl |  |                                |

3b Greenstones

Tabell 3 Korrelasjonskoeffisient

Correlation coefficients. No. of samples 1667 (a) and 1542 (b)

## Løkken Area. Litho geochemistry.

All rock types. No. of samples 1667. No. of variables 21.

Factor analysis. Rotated factor Matrix.

|                                | F1g  | F2g                    | F3g             | F4g                    | F5g   | F6g       | F7g  | F8g  | F9g           | F10g               | Communalities |
|--------------------------------|--|------------------------|-----------------|------------------------|---|-----------|------|------|---------------|--------------------|---------------|
| Cu                             | .17  | .26                    | -.78            | -.06                   | -.02  | .08       | -.02 | -.10 | .05           | .31                | .83           |
| Zn                             | .32  | -.01                   | -.25            | -.03                   | -.02  | -.13      | -.02 | .04  | .12           | .85                | .93           |
| Ni                             | .23  | .87                    | .03             | .08                    | .00   | .01       | -.08 | .02  | -.20          | -.04               | .87           |
| Sr                             | .02  | .01                    | .02             | .05                    | -.04  | .95       | -.00 | .05  | .06           | -.06               | .91           |
| As                             | -.14   | -.05                   | -.04            | -.01                   | .07   | -.01      | -.98 | -.03 | -.08          | .01                | .99           |
| Ba                             | -.22   | .01                    | .00             | .89                    | .06   | .01       | -.02 | .10  | -.02          | .02                | .85           |
| S                              | .11  | -.35                   | -.80            | -.06                   | .19   | -.11      | -.04 | .12  | .06           | .00                | .85           |
| Mn                             | .75  | .19                    | -.11            | -.16                   | .15   | .07       | .12  | -.01 | .00           | .29                | .76           |
| Cr                             | -.07   | .91                    | .03             | .07                    | .06   | .05       | -.03 | .03  | -.18          | .05                | .87           |
| Fe                             | .90  | -.05                   | -.14            | -.14                   | .11   | -.05      | .03  | -.03 | .13           | .12                | .90           |
| Na <sub>2</sub> O              | -.17   | -.23                   | .01             | -.22                   | -.70  | -.23      | .09  | -.03 | .34           | -.10               | .80           |
| MgO                            | .67  | .53                    | .05             | -.08                   | .05   | .02       | .11  | .09  | -.23          | .07                | .84           |
| Al <sub>2</sub> O <sub>3</sub> | .14  | .09                    | .15             | .18                    | -.82  | .24       | .03  | .18  | -.12          | .08                | .87           |
| SiO <sub>2</sub>               | -.72   | -.43                   | .12             | .00                    | .02   | -.25      | -.07 | .05  | .20           | -.09               | .83           |
| P                              | .32  | -.17                   | -.09            | -.04                   | -.08  | .03       | .06  | .12  | .83           | .02                | .86           |
| K <sub>2</sub> O               | -.16   | .09                    | .11             | .90                    | -.09  | .01       | .03  | -.11 | -.04          | -.05               | .89           |
| CaO                            | .45  | .46                    | .00             | -.17                   | -.05  | .54       | .03  | -.19 | -.19          | -.20               | .95           |
| Ti                             | .76  | -.01                   | -.04            | -.18                   | -.17  | .03       | .03  | -.11 | .49           | .05                | .91           |
| V                              | .90  | -.02                   | -.05            | -.12                   | -.16  | .00       | .01  | -.09 | .09           | .00                | .86           |
| Zr                             | -.12   | -.27                   | -.01            | .00                    | .02   | -.01      | .04  | .02  | .88           | .10                | .88           |
| Cl                             | .12  | -.04                   | .02             | .01                    | .11   | -.02      | -.03 | -.96 | -.09          | -.02               | .96           |
| Principal loading              | Fe<br>V<br>Ti<br>Mn<br>SiO <sub>2</sub><br>CaO | Cr<br>Ni<br>MgO<br>CaO | S<br>Cu<br>(Zn) | K <sub>2</sub> O<br>Ba | Al <sub>2</sub> O <sub>3</sub><br>Na <sub>2</sub> O | Sr<br>CaO | As   | Cl   | Zr<br>P<br>Ti | Zn<br>(Cu)<br>(Mn) |               |

## 4a Logarithmic

|                                | F1a  | F2a                               | F3a                     | F4a     | F5a                            | F6a                    | F7a                            | F8a  | F9a     | F10a | F11a      | Communalities |
|--------------------------------|--|-----------------------------------|-------------------------|---------|--------------------------------|------------------------|--------------------------------|------|---------|------|-----------|---------------|
| Cu                             | .03  | .00                               | .92                     | .04     | .06                            | .02                    | -.01                           | .03  | .14     | -.06 | .04       | .87           |
| Zn                             | -.01   | .08                               | .87                     | .04     | -.09                           | .02                    | .03                            | -.07 | .12     | .06  | -.25      | .86           |
| Ni                             | .91  | -.08                              | .05                     | -.10    | .03                            | .02                    | .01                            | -.04 | -.03    | -.07 | .05       | .87           |
| Sr                             | -.09   | -.09                              | -.04                    | .32     | .80                            | .07                    | .13                            | -.02 | .04     | .03  | -.13      | .81           |
| As                             | -.09   | -.12                              | .00                     | -.03    | .04                            | -.01                   | -.06                           | .03  | .08     | .97  | .06       | .99           |
| Ba                             | -.04   | -.23                              | .01                     | .12     | .02                            | .85                    | .00                            | .01  | .00     | .01  | -.11      | .81           |
| S                              | -.07   | .01                               | .26                     | .01     | -.02                           | -.01                   | .14                            | -.02 | .91     | .10  | .02       | .94           |
| Mn                             | .11  | .37                               | .26                     | -.06    | .07                            | -.10                   | -.11                           | .01  | .00     | -.06 | .79       | .87           |
| Cr                             | .89  | -.23                              | -.01                    | -.13    | .06                            | .02                    | .02                            | -.01 | -.05    | .05  | .01       | .88           |
| Fe                             | .00  | .74                               | .18                     | .03     | -.02                           | -.12                   | -.12                           | .02  | .42     | -.11 | -.30      | .90           |
| Na <sub>2</sub> O              | -.44   | -.11                              | -.06                    | .34     | -.53                           | -.29                   | .29                            | -.08 | -.12    | -.11 | .12       | .82           |
| MgO                            | .72  | .12                               | -.07                    | -.24    | .09                            | -.08                   | .02                            | .09  | -.02    | -.15 | -.44      | .84           |
| Al <sub>2</sub> O <sub>3</sub> | .04  | -.02                              | .02                     | -.03    | .08                            | .11                    | .95                            | -.03 | -.14    | -.05 | .08       | .95           |
| SiO <sub>2</sub>               | -.49   | -.54                              | -.10                    | .21     | -.38                           | .14                    | -.27                           | -.01 | -.13    | -.18 | .18       | .91           |
| P                              | -.13   | .20                               | -.05                    | .86     | .04                            | .04                    | .09                            | -.06 | .10     | -.02 | -.02      | .82           |
| K <sub>2</sub> O               | .04  | -.08                              | .02                     | -.05    | -.04                           | .90                    | .11                            | .00  | -.02    | -.02 | .22       | .89           |
| CaO                            | .32  | .09                               | -.02                    | -.30    | .76                            | -.20                   | .02                            | .10  | -.15    | .01  | .13       | .86           |
| Ti                             | -.16   | .86                               | .02                     | .28     | -.03                           | -.15                   | -.03                           | .09  | -.11    | -.03 | -.08      | .90           |
| V                              | -.11   | .91                               | -.04                    | -.07    | .01                            | -.11                   | .03                            | .02  | -.05    | -.04 | -.06      | .88           |
| Zr                             | -.24   | -.07                              | .15                     | .80     | -.03                           | .05                    | -.15                           | .01  | -.10    | .00  | .10       | .77           |
| Cl                             | .00  | .08                               | -.03                    | -.05    | .06                            | .01                    | -.03                           | .99  | -.01    | .03  | -.02      | .99           |
| Principal loading              | Ni<br>Cr<br>MgO<br>SiO <sub>2</sub><br>Na <sub>2</sub> O | V<br>Ti<br>Fe<br>SiO <sub>2</sub> | Cu<br>Zn<br>(S)<br>(Mn) | P<br>Zr | Sr<br>CaO<br>Na <sub>2</sub> O | K <sub>2</sub> O<br>Ba | Al <sub>2</sub> O <sub>3</sub> | Cl   | S<br>Fe | As   | Mn<br>MgO |               |

## 4b Linear

Tabell 4. Faktoranalyse, alle prøver

Greenstones. No. of samples 1542. No. of variables 21.

Factor analysis. Rotated factor Matrix

|                                | F1g*          | F2g*                | F3g*    | F4g*                   | F5g*      | F6g*                                 | F7g* | F8g*  | F9g* | F10g*                                    | F11g*      | Communi-<br>alities |
|--------------------------------|---------------|---------------------|---------|------------------------|-----------|--------------------------------------|------|---|------|--|------------|---------------------|
| Cu                             | .02           | .01                 | -.80    | -.05                   | .07       | -.05                                 | .02  | .22   | .01  | .02                                      | -.27       | .77                 |
| Zn                             | -.14          | .14                 | -.27    | -.01                   | -.15      | -.11                                 | .06  | -.05  | -.05 | .08                                      | -.83       | .86                 |
| Ni                             | .19           | -.11                | .03     | .07                    | .03       | -.10                                 | -.04 | .87   | .03  | .15                                      | .05        | .85                 |
| Sr                             | -.07          | -.01                | .03     | .06                    | .92       | -.07                                 | -.03 | -.01  | -.11 | .08                                      | .02        | .89                 |
| As                             | .06           | -.05                | -.01    | -.03                   | .00       | .01                                  | .98  | -.01  | -.10 | .02                                      | -.03       | .98                 |
| Ba                             | .08           | -.07                | -.01    | .92                    | .02       | .06                                  | -.01 | -.10  | -.09 | .02                                      | -.04       | .89                 |
| S                              | -.13          | .11                 | -.71    | -.01                   | -.06      | .26                                  | -.02 | -.36  | -.21 | .04                                      | .01        | .78                 |
| Mn                             | .08           | .56                 | -.04    | -.07                   | .20       | .45                                  | -.14 | .22   | -.06 | -.06                                     | -.45       | .86                 |
| Cr                             | .19           | -.19                | -.02    | .12                    | .06       | .02                                  | .07  | .86   | .00  | .22                                      | -.02       | .84                 |
| Fe                             | -.25          | .79                 | .03     | -.10                   | -.04      | .10                                  | -.08 | -.15  | .04  | .22                                      | -.22       | .84                 |
| Na <sub>2</sub> O              | -.14          | -.05                | .02     | -.18                   | -.10      | -.15                                 | -.04 | -.24  | .00  | -.88                                     | -.06       | .93                 |
| MgO                            | .28           | .44                 | .11     | .04                    | .03       | .32                                  | -.14 | .59   | -.24 | .13                                      | -.09       | .84                 |
| Al <sub>2</sub> O <sub>3</sub> | .16           | .05                 | .10     | .14                    | .09       | -.85                                 | -.03 | .05   | -.18 | -.13                                     | -.11       | .85                 |
| SiO <sub>2</sub>               | -.16          | -.44                | .17     | -.02                   | -.27      | .09                                  | .11  | -.49  | .01  | -.46                                     | .08        | .81                 |
| P                              | -.84          | .21                 | -.07    | -.04                   | -.05      | .00                                  | -.03 | -.19  | -.08 | -.11                                     | .06        | .82                 |
| K <sub>2</sub> O               | .04           | -.12                | -.07    | .85                    | -.01      | -.24                                 | -.02 | .12   | .13  | .13                                      | .07        | .85                 |
| CaO                            | .19           | .21                 | -.13    | -.12                   | .65       | .05                                  | .07  | .45   | .20  | .08                                      | .25        | .86                 |
| Ti                             | -.67          | .61                 | -.07    | -.12                   | .06       | .03                                  | .01  | -.17  | .13  | -.07                                     | -.06       | .91                 |
| V                              | -.18          | .87                 | -.09    | -.11                   | .05       | -.15                                 | .04  | -.09  | .13  | -.05                                     | .07        | .87                 |
| Zr                             | -.86          | .02                 | .03     | -.06                   | .01       | .14                                  | -.05 | -.24  | .01  | -.04                                     | -.19       | .86                 |
| Cl                             | .02           | .14                 | .12     | .03                    | -.04      | .14                                  | -.11 | .00   | .93  | .00                                      | .05        | .93                 |
| Principal<br>loading           | Zr<br>P<br>Ti | V<br>Fe<br>Ti<br>Mn | Cu<br>S | Ba<br>K <sub>2</sub> O | Sr<br>CaO | Al <sub>2</sub> O <sub>3</sub><br>Mn | As   | Ni<br>Cr<br>MgO<br>(SiO <sub>2</sub> )<br>(CaO) | Cl   | Na <sub>2</sub> O<br>(SiO <sub>2</sub> ) | Zn<br>(Mn) |                     |

5a Logarithmic

|                                | F1*  | F2*           | F3*           | F4*                    | F5*       | F6*     | F7*  | F8*  | F9*                            | F10*      | Communi-<br>alities |
|--------------------------------|--|---------------|---------------|------------------------|-----------|---------|------|------|--------------------------------|-----------|---------------------|
| Cu                             | .06  | .02           | -.92          | .02                    | .06       | .05     | .02  | .05  | .01                            | -.02      | .87                 |
| Zn                             | .01  | .05           | -.90          | .03                    | -.05      | .06     | -.06 | -.01 | .07                            | -.15      | .86                 |
| Ni                             | .88  | -.19          | -.04          | .06                    | .05       | -.14    | -.02 | .07  | .01                            | .07       | .85                 |
| Sr                             | -.09   | -.14          | .01           | .01                    | .81       | .18     | .02  | .00  | .24                            | -.23      | .83                 |
| As                             | -.05   | -.06          | -.02          | -.04                   | .05       | -.03    | -.02 | .99  | .01                            | .05       | .99                 |
| Ba                             | .06  | -.17          | -.07          | .87                    | .00       | -.01    | .01  | .02  | -.01                           | -.16      | .82                 |
| S                              | -.09   | .00           | -.88          | .02                    | -.02      | .06     | .00  | -.06 | -.07                           | -.02      | .80                 |
| Mn                             | -.07   | .26           | -.22          | -.05                   | .09       | -.06    | -.02 | .05  | -.17                           | .76       | .72                 |
| Cr                             | .87  | -.28          | .03           | .08                    | .07       | -.17    | -.01 | -.03 | .01                            | -.01      | .87                 |
| Fe                             | -.04   | .74           | -.30          | -.06                   | -.03      | .19     | .08  | .08  | -.03                           | -.37      | .83                 |
| Na <sub>2</sub> O              | -.47   | -.17          | .03           | -.35                   | -.55      | .19     | -.04 | .11  | .21                            | .16       | .79                 |
| MgO                            | .69  | .03           | .10           | .05                    | .04       | -.19    | .06  | .05  | -.07                           | -.54      | .84                 |
| Al <sub>2</sub> O <sub>3</sub> | -.01   | .00           | .00           | .13                    | .01       | -.13    | -.07 | -.02 | .92                            | .15       | .92                 |
| SiO <sub>2</sub>               | -.50   | -.45          | .15           | -.01                   | -.50      | .29     | .07  | -.11 | -.09                           | .12       | .84                 |
| P                              | -.17   | .16           | .00           | -.03                   | -.07      | .85     | -.05 | .04  | -.02                           | .12       | .81                 |
| K <sub>2</sub> O               | .12  | .02           | .01           | .87                    | -.01      | -.05    | .00  | .04  | .18                            | .24       | .87                 |
| CaO                            | .21  | .00           | .06           | -.11                   | .80       | -.30    | .01  | -.06 | -.22                           | .23       | .89                 |
| Ti                             | -.22   | .72           | .04           | -.10                   | .01       | .51     | .07  | -.02 | -.09                           | -.09      | .87                 |
| V                              | -.22   | .87           | .09           | -.06                   | -.03      | .04     | .01  | .03  | .04                            | -.01      | .82                 |
| Zr                             | -.22   | .11           | -.21          | -.02                   | -.06      | .82     | .05  | -.01 | -.12                           | -.03      | .81                 |
| Cl                             | .00  | .07           | .03           | .00                    | .02       | .01     | .99  | .02  | -.07                           | .00       | .99                 |
| Principal<br>loading           | Ni<br>Cr<br>MgO<br>SiO <sub>2</sub><br>Na <sub>2</sub> O | V<br>Fe<br>Ti | Cu<br>Zn<br>S | Ba<br>K <sub>2</sub> O | Sr<br>CaO | P<br>Zr | Cl   | As   | Al <sub>2</sub> O <sub>3</sub> | Mn<br>MgO |                     |

5b Linear

Tabell 5. Faktoranalyse, grønnsteiner

#### 4. DISKUSJON OG KONKLUSJON

Resultatene av de lithogeokjemiske undersøkelsene viser at det under visse forutsetninger kan være en viktig prospekteringsmetode. Ut fra den bearbeidelse vi hittil har gjort, kan det trekkes den konklusjon at antall analyserte elementer kan begrenses. Av totalt 37 analyserte elementer er 21 benyttet i den videre bearbeidelse. Dette antallet kan ytterligere reduseres i en eventuell videreføring av de lithogeokjemiske undersøkelsene i Løkkenfeltet. Følgende elementer eller kombinasjon av disse, synes å gi den beste fordeling og systemastikk: Cu, Zn, S, Ni, Cr, Fe, Zr, Ti, V, Mn, MgO og Cl. Disse elementene definerer i store trekk bergartsinndeling og mineralisering.

##### 4.1 Anomale områder

Faktorkartene der Cu, Zn, S er med (bilag 21 - 27), gir betydelig bedre anomalibilder enn elementkartene alene. Over Løkken og Høydal er prøvetetten større. For å ta bort denne effekten er mellomprofilene tatt bort på vedlagte kart. Prøvetettheten er omtrentlig lik i hele feltet så langt blottningsgraden gjør det mulig.

Spesielt tilførselsonene på Høydal er kraftig markert. Typisk her er en retning NNØ - SSV med markert høye verdier. Ved siden av de høye verdier er det tilsvarende soner med lave faktorverdier. De lave områdene kan ha sin årsak i utlutning av metallene i sidestenene. Kartene fra F3a (bilag 22) og F10g (bilag 26) antyder en inndeling av flere tilførselsoner på Høydal.

MnO og F11a (bilag 11 og 28) viser tilsvarende anomalier. Mn anrikes i tilførselsonen, og det er ventet at dette elementet burde vise de anomale sonene.

Tilførselonen til Løkkenforekomsten er tilsynelatende mindre markert enn på Høydal. Forholdene kompliseres med et skyvedekke nord for malmsonen og den overdekte Løkkendalen. Anomalien i P36.0 er sansynlig en del av Løkkenmalms tilførselsone. Kartene for F3a (bilag 22), F10g (bilag 26) og de sammenstilte kartene bilag 24 og 27 viser denne best. Kartene for MnO - fordelingen (bilag 11 og 28) har høyere verdier i sonen, men er ikke så entydig som på Høydal.

Gruvene Dragset og Åmot kommer begge frem på kartene. Anomaliene er ikke så klart definert som på Høydal og Løkken, men de typiske tilførseloner mangler her.

En sammenstilling av alle anomalier er vist i kartet, bilag 32. Basis er bilag 24, sammenstilt kart F3g, F3a, F3a<sup>X</sup>. Heltrukken anomali er punker der alle tre faktorer er positive. Brudt linje er der en av de tre forekommer. Det må være positive verdi i mer enn et punkt i linje og/eller positiv verdier over flere linjer. Det er ikke tatt hensyn til geologien på anomalikartet.

Den sydlige del av området skiller seg klart ut med mer markerte anomalier enn i den nordre del. Nummerene nedenfor referer seg til anomalikartet.

Løkken - Høydal (1- 5) er markert med klare anomalier. Anomali 2 er en markert anomali med høye verdier i P37. Det er boret i området uten at anomalien er forklart (ref.36). Anomaliene 3a, 4a og 4b kan tilhøre samme tilførselsone mot Høydal. Anomali 3b og 5 kan tilhøre en nær parallellgående sone.

Anomali 6, 7 (og 8) ligger på et strategisk interessant nivå i lagrekken. Det er kjent vasskiser i området. EM-37 målinger ga ingen klare indikasjoner (foreløpig vurdering). Anomali 9 og 10 ligger i antatt samme geologiske nivå som Løkken - Høydal. Undersøkelser i området har påvist vasskislag, men ikke Cu/Zn mineralisering av betydning (ref.58).

Dragset grube er markert med anomali 24. Undersøkelser ved Dragset (ref.72) viser en akse ca, Ø - V med stupning mot øst. Anomali 25 markerer Åsskjerpet som er en liten forekomst av samme type som Dragset.

Åmot grube er ikke klart markert. Anomali 14 ligger i et område med høyt sulfidinnhold (ref.49,53,54). Anomali 13 er antagelig knyttet til vasskishorisonter.

I gabbroen, SØ for Åmot, er det et uregelmessig anomaliområde, anomali 12. Lokalt finnes det sulfidmineralisering i gabbroen, men anomalien er ikke tilfredstillende utredet.

Endel anomalier kan skyldes vasskishorisonter. Dette gjelder anomali 30, 31 og 32 i syd og 13, 17, 18, 19 og 20 i nord.

Bilag 33 viser en blokkinnndeling av området (500 x 500 m). I hver blokk er det beregnet et veid middel for alle malmdannede elementer pluss MnO. De to høyeste faktor/elementverdier i hvert prøvepunkt er tatt med i beregningen. Høyeste verdi er gitt vekt 2 og nest høyeste verdi vekt 1. Summen av alle vektene er så dividert med antall prøver i blokka. Følgende faktorer/elementer er tatt med i beregningen:  $F3g + F3a + F3a^X + F9a + F10g + \text{Cu-Zn-faktorer} + \text{Cu} + \text{MnO}$ . Kun blokker med mer enn 3 prøver er tatt med. Resultatet skiller seg fra anomaliekartet i bilag 32. Tilførselsonene over Høydal og Løkken har verdier over 2,0. Verdier høyere enn 2 er det i tre markerte områder øst for Høydal. Disse tilsvarer anomaliene 6, 7, 8 og 12 i bilag 32. Ved Åmot Grube er en anomali, tilsvarer nr. 14. Vest for Åmot er det en anomali over to blokker i N-S retning. SV for Løkken er det et anomaliområde tilsvarende anomali 9 og 10 i bilag 32. Ved Dragset Grube er det høye verdier (3-4) over et større område. Her synes bakgrunnsverdiene både for Zn og Mn å være høyere enn i feltet forøvrig.

#### 4.2 Lithogeokjemisk mønster i bergartene.

Det sammenstilte kartet bilag 34 over Cr, Ni, Zr og MgO/Cr gir en meget god inndeling av bergartene. Øvre putelava har et markert innhold av Cr og Ni med lavt Zr og MgO/Cr. Det er et unntak i bergartene NV for Bjørnlivann P33 - 34, som ved siden av Cr og Ni har et høyt Zr- innhold. Disse bergartene inneholder en rekke lag med kvartskeratofyr.

Strategrafisk plassering av bergartene ved Dragset grube har vært mye diskutert. Ut fra kartet, bilag 34 tilhører bergartene øst for gruva øvre putelava. Dragset grube ligger nær grensen mellom øvre og nedre, med utgående i nedre.

Gabbroen mellom Løkken og Dragset har høy Cr, Ni, mens gabbroene øst for Urvatn og nord for Høydal ikke skiller seg klart ut fra nedre putelava. Ingen av disse to har høyt Cr, Ni, men har overveiende høyt Zr og MgO/Cr. Disse to inneholder endel leuko-/gabbro og/eller granittisk materiale.

Kartet med faktor F2a, bilag 30 har Ti, V, Fe som dominerende elementer. Nedre putelava har klart høyere verdier enn øvre. Grensene mellom øvre og nedre faller meget godt sammen med den for Cr, Ni og MgO/Cr.

Gabbroen øst for Løkken har høyere F2a- verdier enn gabbroen i vest.

Mn viser et visst mønster over tilførselssonene på Løkken og Høydal. Øvre putelava har overveiende et høyere Mn- innhold enn nedre (bilag 11). Alle kartene der Mn er involvert viser omtrent samme mønster (bilag 17, 18, 28).

As viser konsentrasjoner i enkelte områder (bilag 12) uten at de klart følger bergartgrenser eller mineralisering.

Cl viser et klart mønster over og syd for gabbroene (bilag 13). Ved Høydal er det anomale klorverdier fra gabbroen og sydover til malminivået.

#### 4.3 Konklusjon

De lithogeokjemiske undersøkelser i Løkkenområdet har vist at metoden er anvendig i dypmalmløting under visse forutsetninger. Metoden gir et godt bilde av bergartsfordelingen i det undersøkte området.

I Løkkenområdet er geologien godt kartlagt, og det er utarbeidet en geologisk modell for malmdannelsen og den geologiske oppbygging. Dette har vært til stor hjelp i detaljtolkningen av de lithogeokjemiske data.

De lithogeokjemiske undersøkelsene viser at hovedtrekkene i geologien og anomaliene over grubene kommer klart frem uten geologiske vurderinger. Metoden kan benyttes selv om geologien ikke er godt kartlagt.

Databehandlingen av analyseresultatene er utført på tradisjonelt vis. En videreføring av databearbeidelsen kan gi klarere anomalier og definere omvandlingssoner bedre.

De viktigste forekomstene i Løkkenområdet, Løkken og Høydal ligger på en meget markert lithogeokjemisk grense. Anomalier på tilsvarende nivå i lagrekken bør prioriteres i de videre undersøkelser.

Etter en forhåndsvurdering av de lithogeokjemiske data, ble følgende områder målt med transient- EM (EM - 37) høsten 1985 (bilag 36):

Svinsås, Blokkum, Moen, Damlia, Høgåsen, Mogset, Høydal, Urvatnet, Åmot,

Den foreløbige vurdering av resultatene viser ingen store forekomster med massive sulfidmalmer i området.

## LITHOGEOCHEMICAL INVESTIGATION OF THE LØKKEN AREA

## SUMMARY

## Introduction

The investigated area belongs to the central part of the Norwegian Caledonides and is situated 70 km SSW of Trondheim. The main rock types in the area are basic metavolcanics and metagabbros, and are a part of the Løkken ophiolitefragmente (Appendix 1).

Since 1654 the Løkken Mine has been in production (Cu, Zn, pyrite-ore). The size of the Løkken orebody has been about 30 mill tons, and it has a shape of an irregular ruler, plunging 30° to the West. Several small mines and showings are known in the surroundings and the area has been explored since the 1920th.

The aim of the lithogeochemical exploration was to locate feeder-zones for further exploration for deep sited massive sulphide orebodies.

## Methods

The field work was carried out in the summer months of 1984. The location of the investigated area is shown in fig. 1.

The samples were collected along traverses across the strike of the greenstones (N-S). The distance between the traverses (lines) was 500 m with a spacing between sampling sites of 50 m. In some parts the area was poorly exposed. More dense sampling was done in the periphery of the Løkken and Høydal deposits.

The total amount of analysed samples was 1608. The weight of each collected sample was 250-500 g. Weathered surfaces were avoided.

The samples were analyzed by AAS and XRF. Cu, Zn Ni, Co, Pb, S, Li were determined by AAS. Na<sub>2</sub>O, MgO Al<sub>2</sub>O<sub>3</sub>, SiO<sub>2</sub>, P, S, Cl, K<sub>2</sub>O, CaO, Ti V, Cr, Mn, Fe, Ni, Cu, Zn, As, Zn, Sr Y, Zr, Nb, Mo, Sn, Sb, Cs, Ba, La, Ce, Ta, Pb, Bi, Th, U, were determined by XRF.

The analytical data are presented on maps. 7 element maps are enclosed (encl. 8-14). The ratios between 10 element-pair were calculated and presented on maps. 5 of these are enclosed (encl. 16-20). 21 elements were used in the factoranalysis. The results of these analyses are given in table 2-5. 9 factor-distributions are presented on maps (encl. 21-31).

### Geochemistry

Most of the elements do not show any obvious patterns. Maps of Cu, Ni, Cr, MnO, As, Cl and Zr are presented (encl. 8-14). Cr and Ni have a higher content in the upper pillow lavas than in the lower. Zr appear vice versa. Cl shows high values in and south of the the gabbros. The distribution of MnO shows high values in the feederzones at Løkken and Høydal and it is generally higher in the lower pillowlavas.

The ratios CaO/Cr, Mn/V, Mn/Fe, Fe/Ti and MgO/Cr are presented on maps (encl. 16-20). The distribution of the ratio MgO/Cr shows high values in the lower pillow lavas. Comparisions between different elements, ratios and factors are presented on maps, enclosures 15, 25, 27 and 34.

### Factor analysis

The aim of the factor analysis was to establish the characteristic associations between the elemnts. 21 of the most abundant elements or oxides were chosen for factor analysis. These were Cu, Zn, Ni, Sr, As, Ba, S, Mn, Cr, Fe, Na<sub>2</sub>O, MgO, Al<sub>2</sub>O<sub>3</sub>, SiO<sub>2</sub>, P, K<sub>2</sub>O, CaO, Ti, V, Zr and Cl. The factor analysis was based on both the logaritimic and linear distributions of the concentrations. All rock types were prosessed in one handling and the greenstones in another. The correlation coffisients and rotated factor matrix are presented in table 3, 4 and 5.

Table 3 indicates a high positive correlation between the elements pairs Ni-Cr, Fe-V, Fe-Ti, Ti-V, Ba-K<sub>2</sub>O and Mn-MgO both in greenstones and all rock types. There is a better correlation in greenstones than in all rock types for the oreforming elements. The element pairs Cu-Zn, Cu-S and Zn-S have a high positive correlation in greenstones (linear).

The factor analysis are presented in table 4 and 5 for all rock types and for greenstones respectively. The oreforming elements are represented in factor 3 in all tables. Cu-S have the highest loading in F3a and F3g<sup>X</sup>, Cu-Zn in F3g and Cu-Zn-S in F3a<sup>X</sup>. The distribution of the factors F3g, F3a and F3a<sup>X</sup> are presented in enclosure 21-24. The feederzones at Løkken and Høydal are well defined. At the same geological level as these deposits there are anomalies to the east and south-west. For factor F10g and F11g<sup>X</sup>, Zn have the highest loading and S in F9a. The factors F10g and F9a are presented in enclosure 25-27.

The distribution of factor F2g is presented in enclosure 31. Ni and Cr have high loading in this factor and the map illustrate the Ni-Cr distribution in the greenstones. The upper pillow lava have generally higher F2g-values than the lower. The Løkken and Høydal deposits are lying close to the border between F2g-high and -low.

## Discussion

The lithochemical investigation of the Løkken area has succeeded in locating the mineralization at Løkken and Høydal and shows a well defined lithochemical pattern in the greenstones.

The known sulphide mines and showings lie all on or close to a geochemical border in the greenstoneformation. The lithochemical picture is however more complicated in the northern part of the area, due to higher deformation. Anomalies connected to this border are supposed to be most interesting. Maps of anomalies are presented in enclosure 32 and 33. Map 1 (encl. 32) is a combined map of the factors F3g, F3a and F3a<sup>X</sup>. Points where all factors are present, are marked as an anomaly. In map 2 (encl. 33) the whole area is divided into blocks, 500 x 500 metres. The following factors/elements have influence: F3g, F3a, F3a<sup>X</sup>, F9a, F10g, F Cu-Zn, Cu and MnO. The two highest values for each factor/element in each point are given the weight 2 and 1 respectively. All weights in each block are added up and divided on the number of samples. The result is presented in enclosure 33.

These two maps of anomalies shows interesting exploration areas east of Høydal, southwest of Løkken, around Dragset and Amot mines. The anomalies are all lying close to the lithochemical border mentioned above.

## Conclusions

1. The lithochemical investigation has been able to reveal zones which are anomalous in the relation to the environment. The zones are associated with a certain geological unit in the greenstone formation. The known ore deposits are situated to the same unit, in the upper part of the lower pillowlava.
2. The greenstone formation can be separated in two main lithochemical units. One unit is high in Cr-Ni and the other is high in Zr, Ti, V and Mg.
3. The distribution of chlorine in the bedrock seems to be directly related to the occurrences of gabbros and sheeted dyke complex.

## Figurer

|        |                            |                                   |         |
|--------|----------------------------|-----------------------------------|---------|
| Fig1   | Oversiktskart              | Location map.                     | side 6  |
| Fig.2  | Tilførselsone Løkken grube | Feeder zone Løkken Mine           | side 8  |
| Fig.3  | Frekvensdiagram            | Cu                                | side 34 |
| 4      | "                          | Zn                                | " 35    |
| 5      | "                          | Ni                                | " 36    |
| 6      | "                          | Co                                | " 37    |
| 7      | "                          | Pb                                | " 38    |
| 8      | "                          | MgO                               | " 39    |
| 9      | "                          | Al <sub>2</sub> O <sub>3</sub>    | " 40    |
| 10     | "                          | SiO <sub>2</sub>                  | " 41    |
| 11     | "                          | P                                 | " 42    |
| 12     | "                          | S                                 | " 43    |
| 13     | "                          | K <sub>2</sub> O                  | " 44    |
| 14     | "                          | CaO                               | " 45    |
| 15     | "                          | Ti                                | " 46    |
| 16     | "                          | V                                 | " 47    |
| 17     | "                          | Cr                                | " 48    |
| 18     | "                          | Mn                                | " 49    |
| 19     | "                          | Fe                                | " 50    |
| 20     | "                          | Sr                                | " 51    |
| 21     | "                          | Zr                                | " 52    |
| Fig.22 | Regresjonskurve            | Zr/Zn                             | side 53 |
| 23     | "                          | Zr/Cu                             | " 54    |
| 24     | "                          | Zr/SiO <sub>2</sub>               | " 55    |
| 25     | "                          | Zr/CaO                            | " 56    |
| 26     | "                          | Zr/Fe <sub>2</sub> O <sub>3</sub> | " 57    |
| 27     | "                          | Zr/MnO                            | " 58    |
| 28     | "                          | Zr/MgO                            | " 59    |
| 29     | "                          | Zr/Na <sub>2</sub> O              | " 60    |

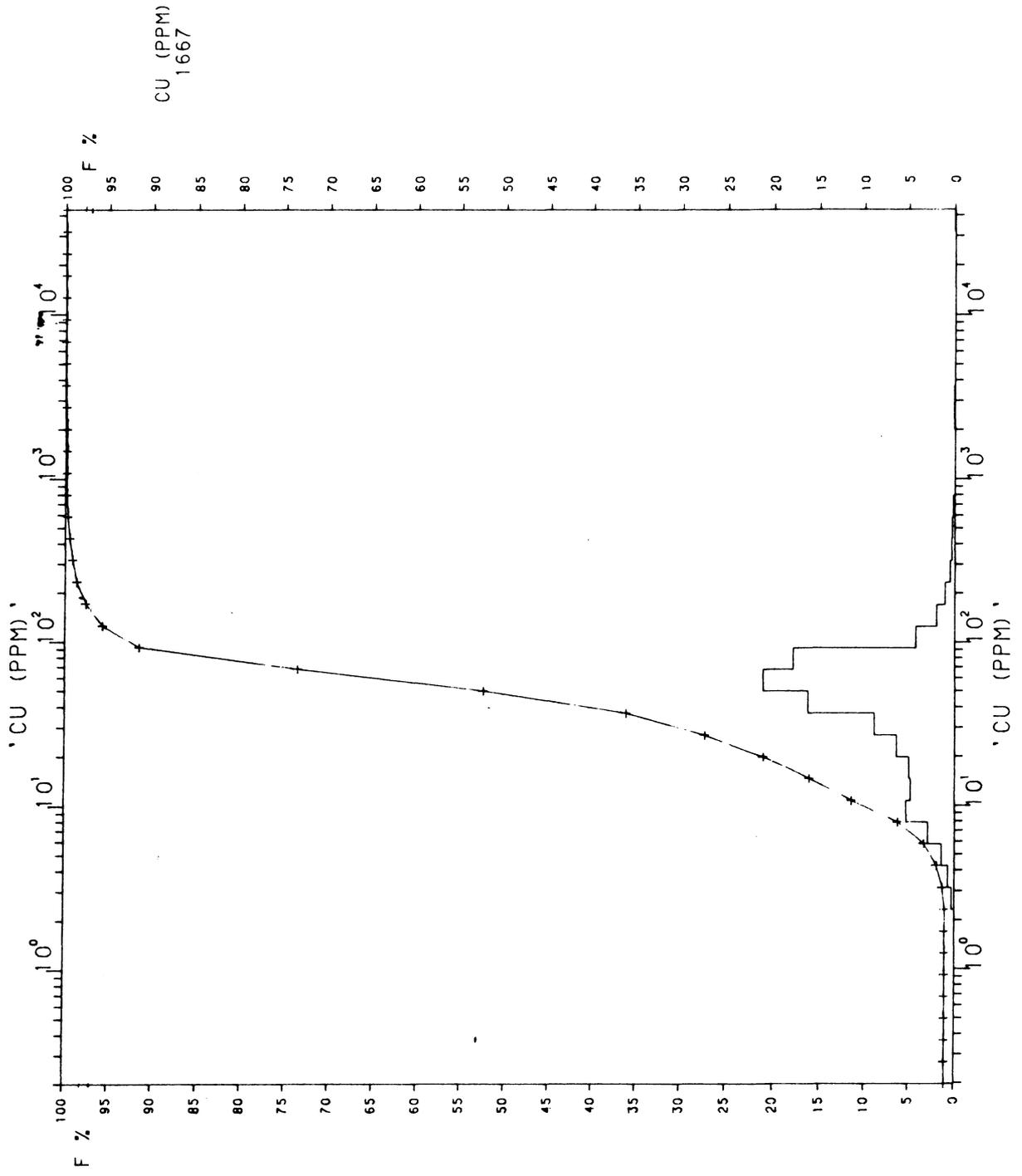


Fig. 3 FREKP/LOKKEN/OUTOKUMPU

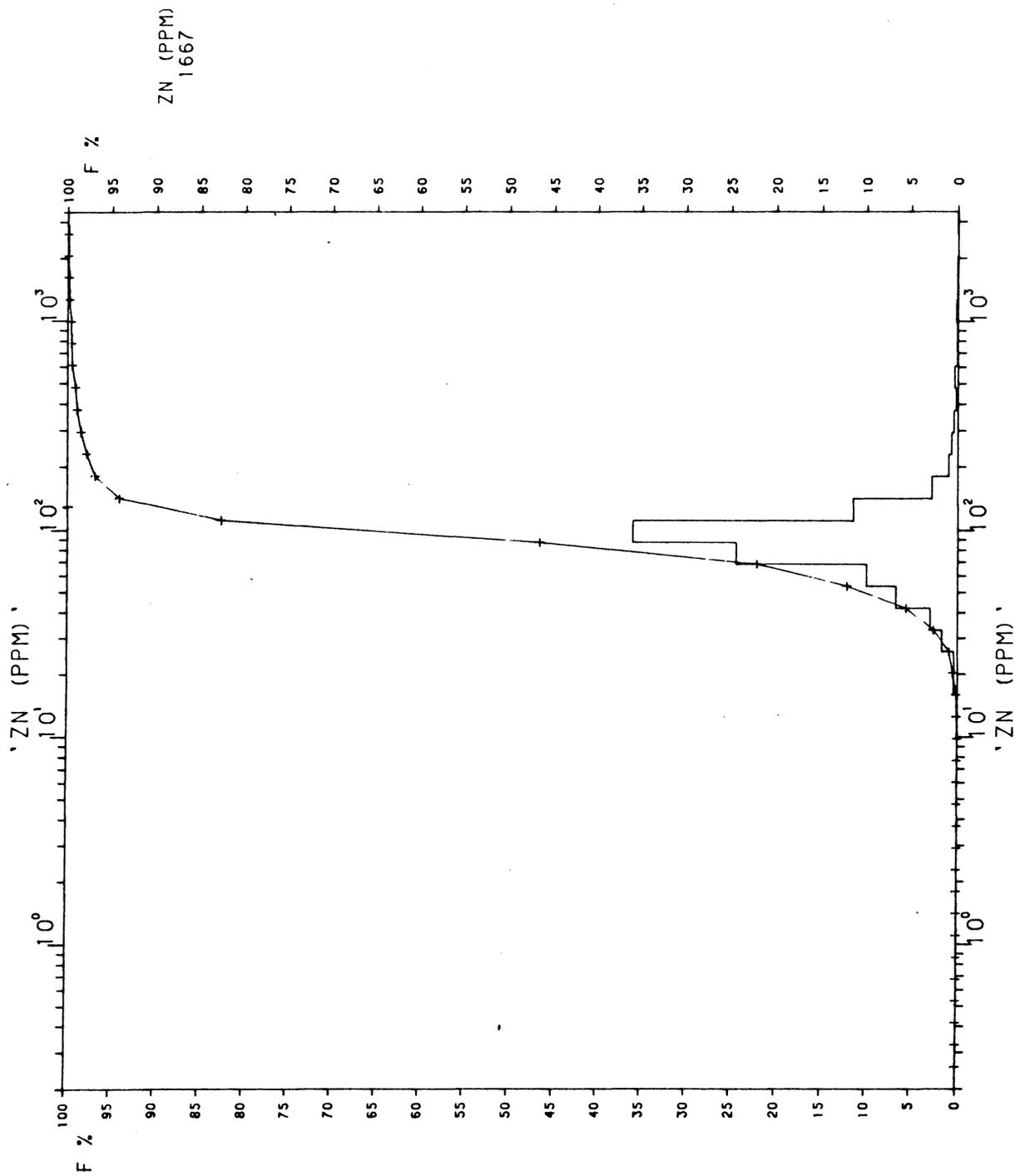


Fig 4

FREKP/LOKKEN/OUTOKUMPU

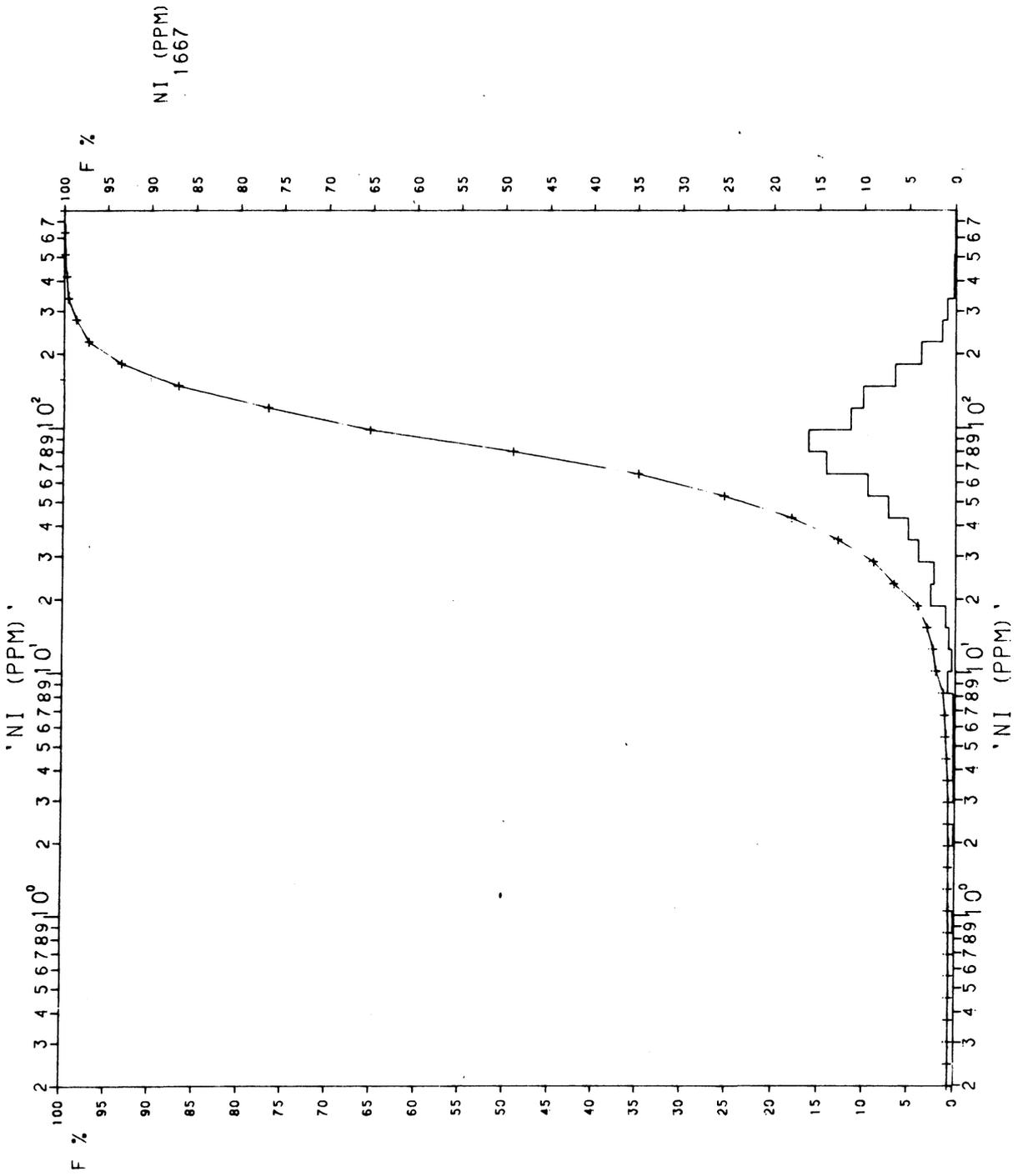


Fig 5

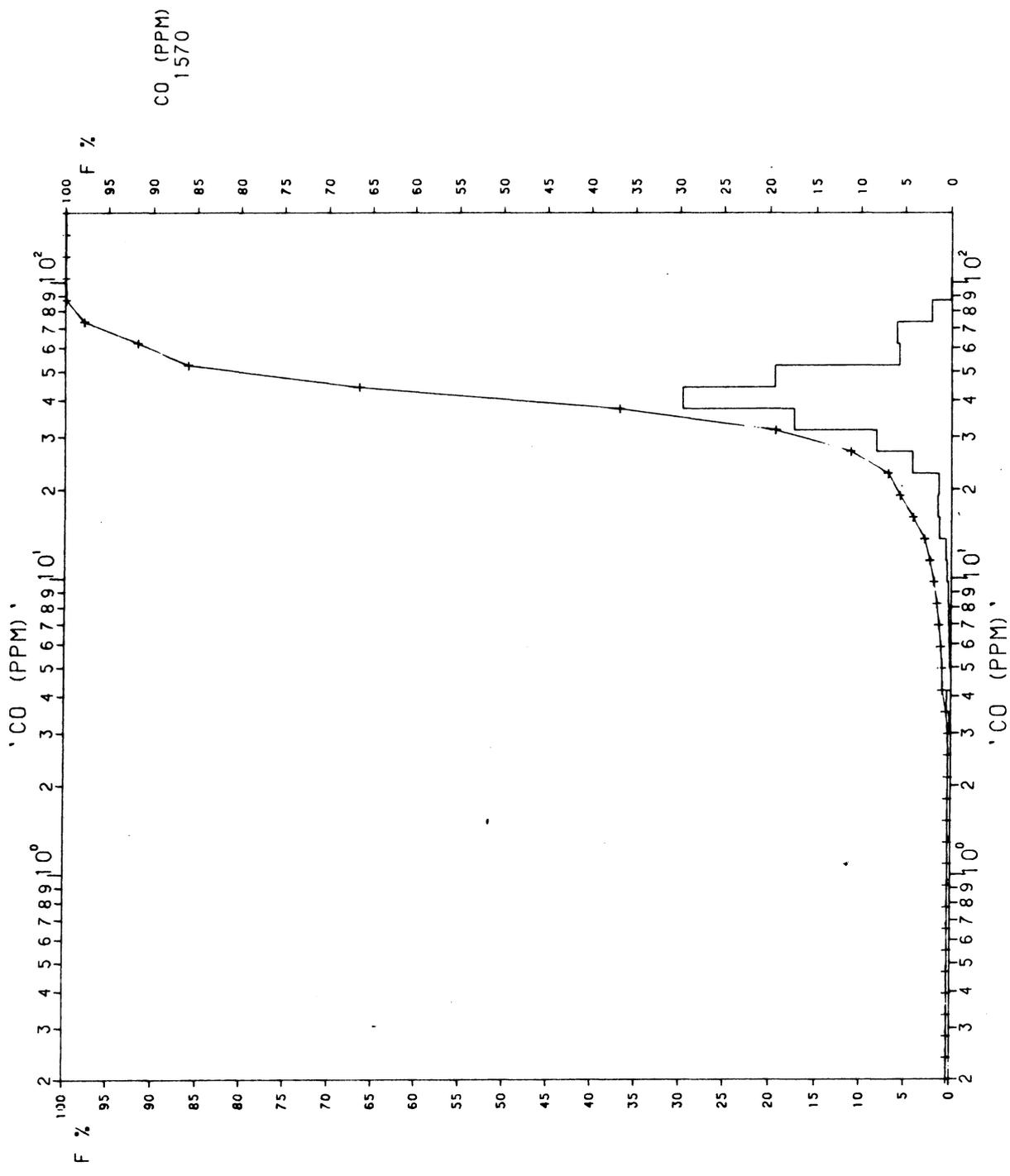


Fig 6 FREKP/LOKKEN/OUTOKUMPU

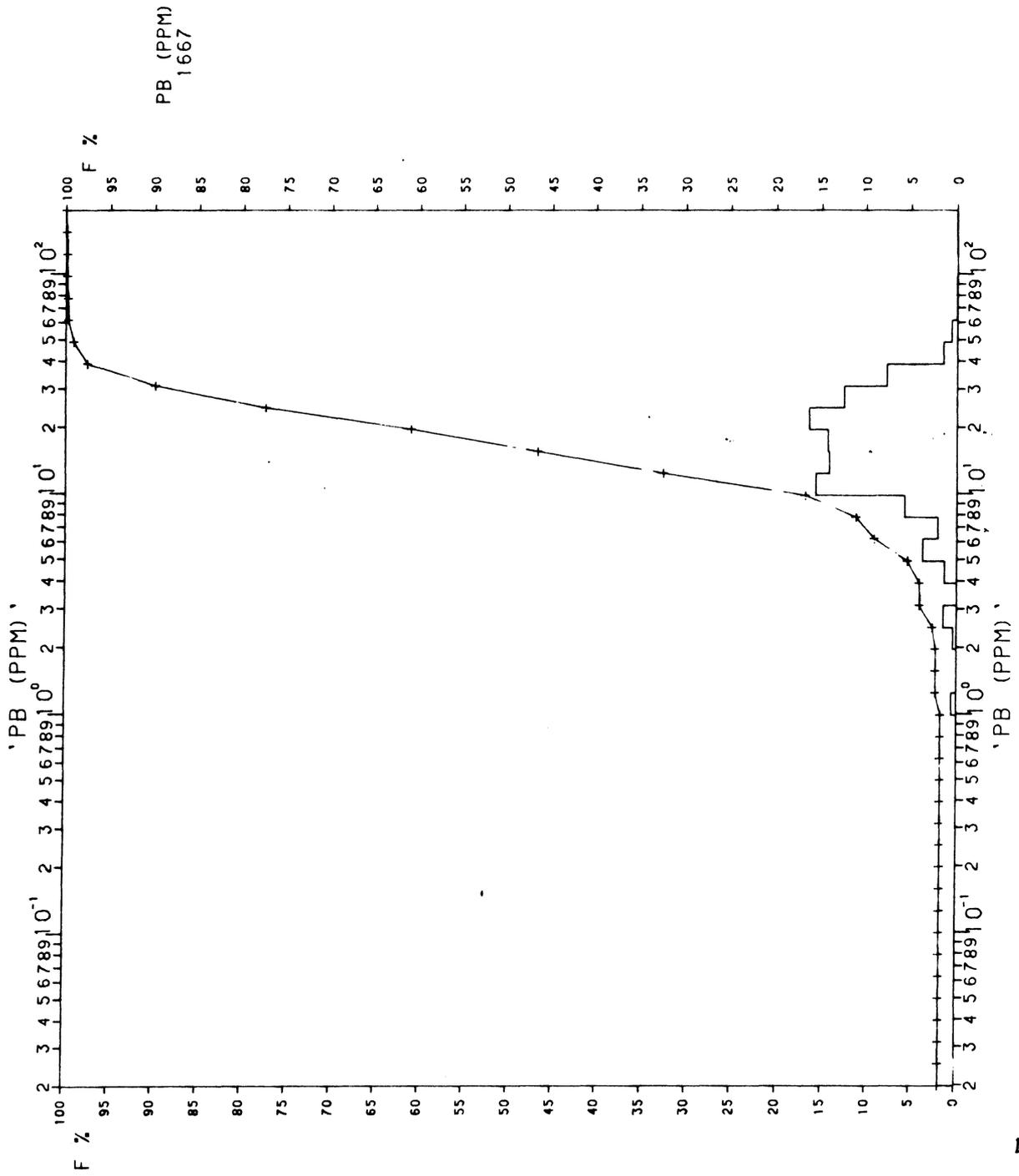


Fig 7  
FREKP/LOKKEN/OUTOKUMPU

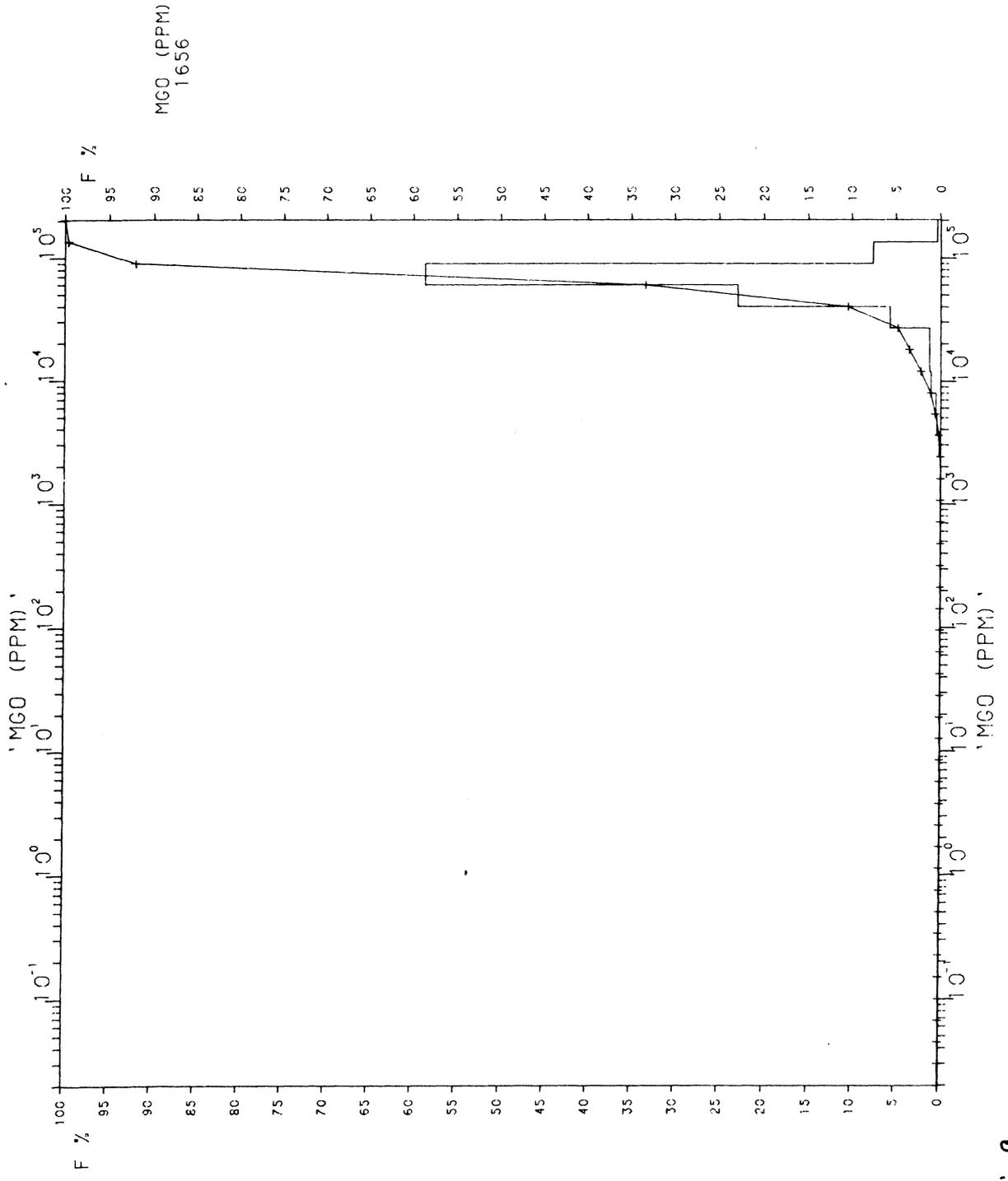


Fig 8 FREKP/LOKKEN/OUTOKUMPU

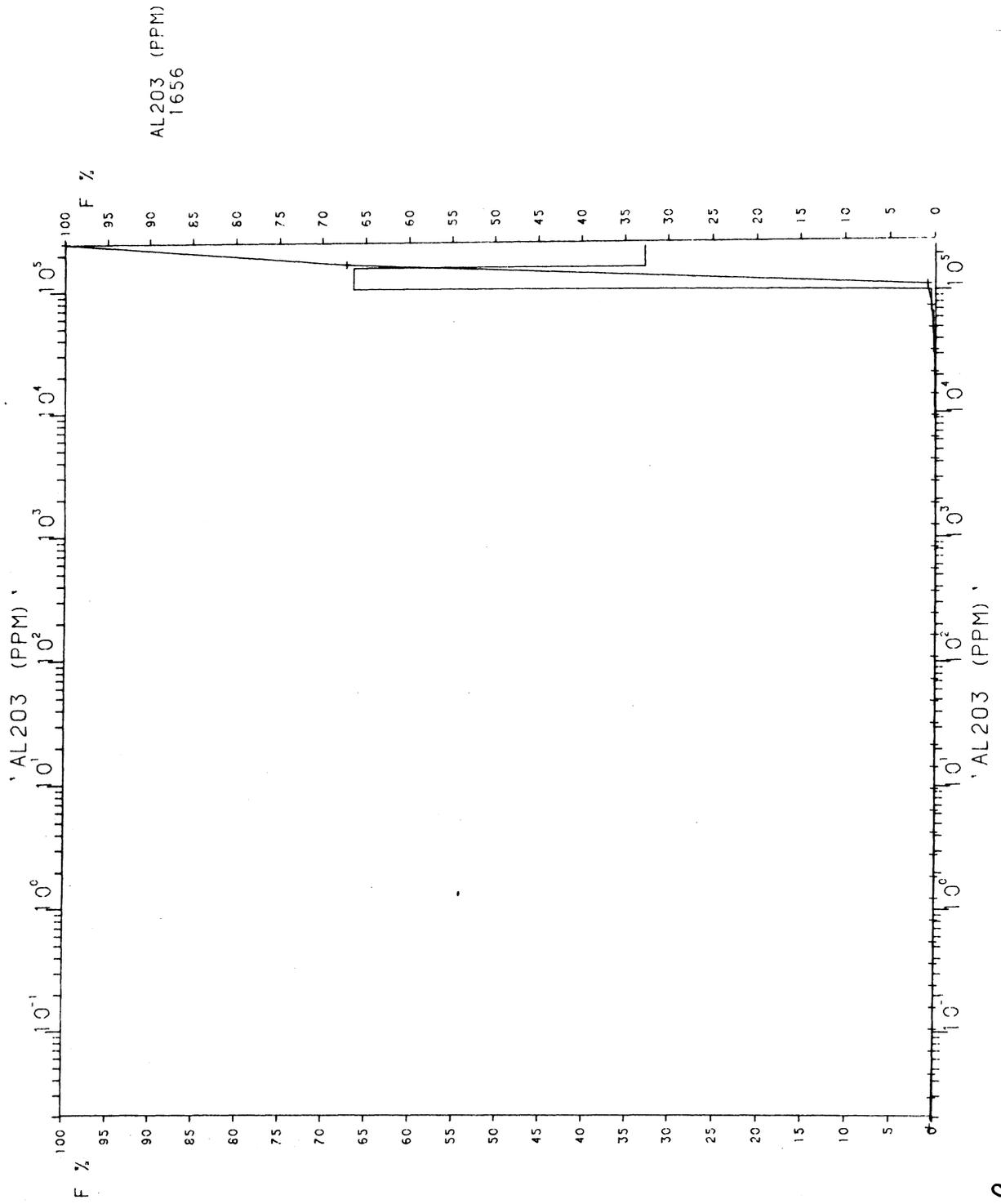


Fig9 FREKP/LOKKEN/OUTOKUMPU

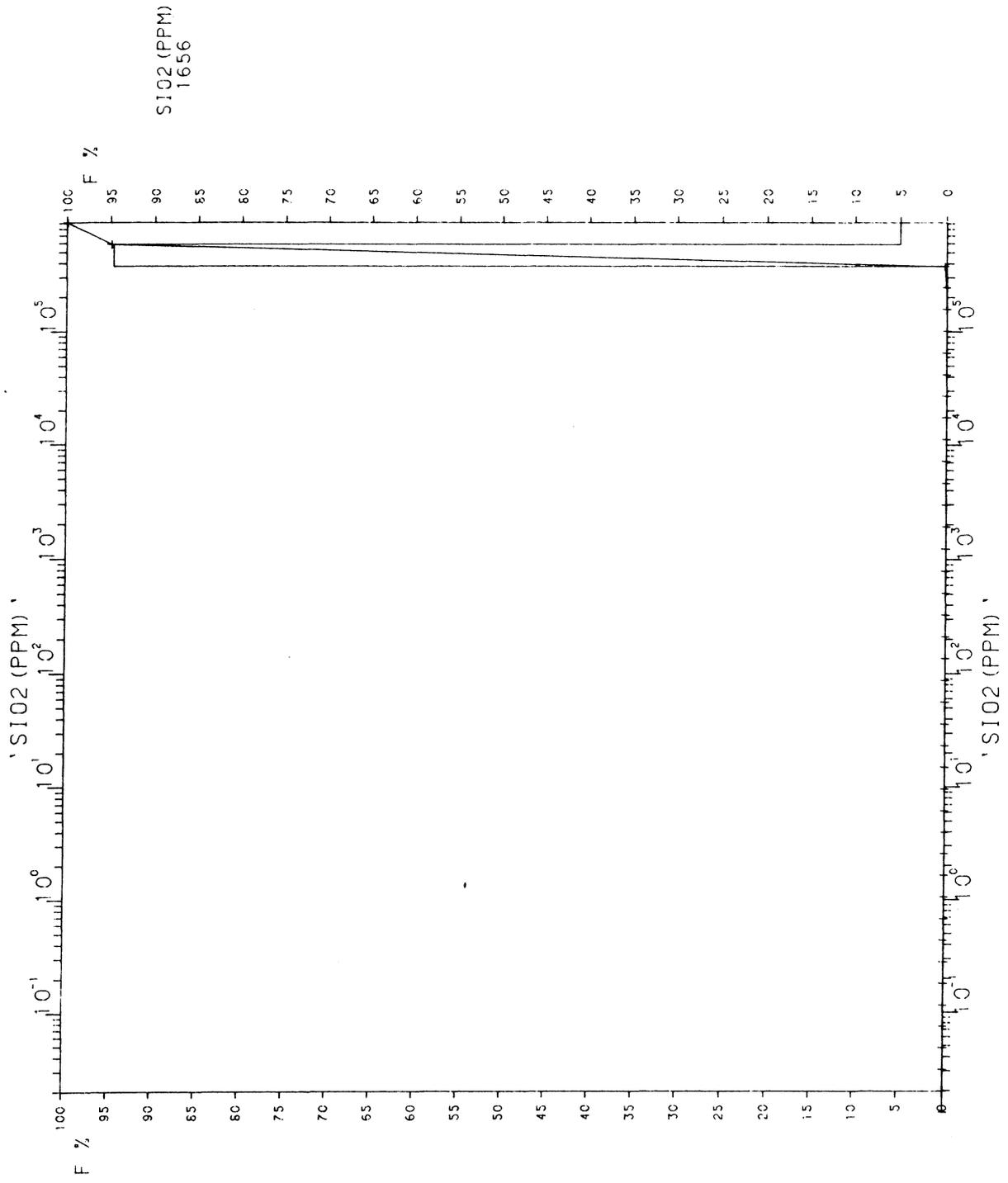


Fig 10 FREKP/LOKKEN/OUTOKUMPU

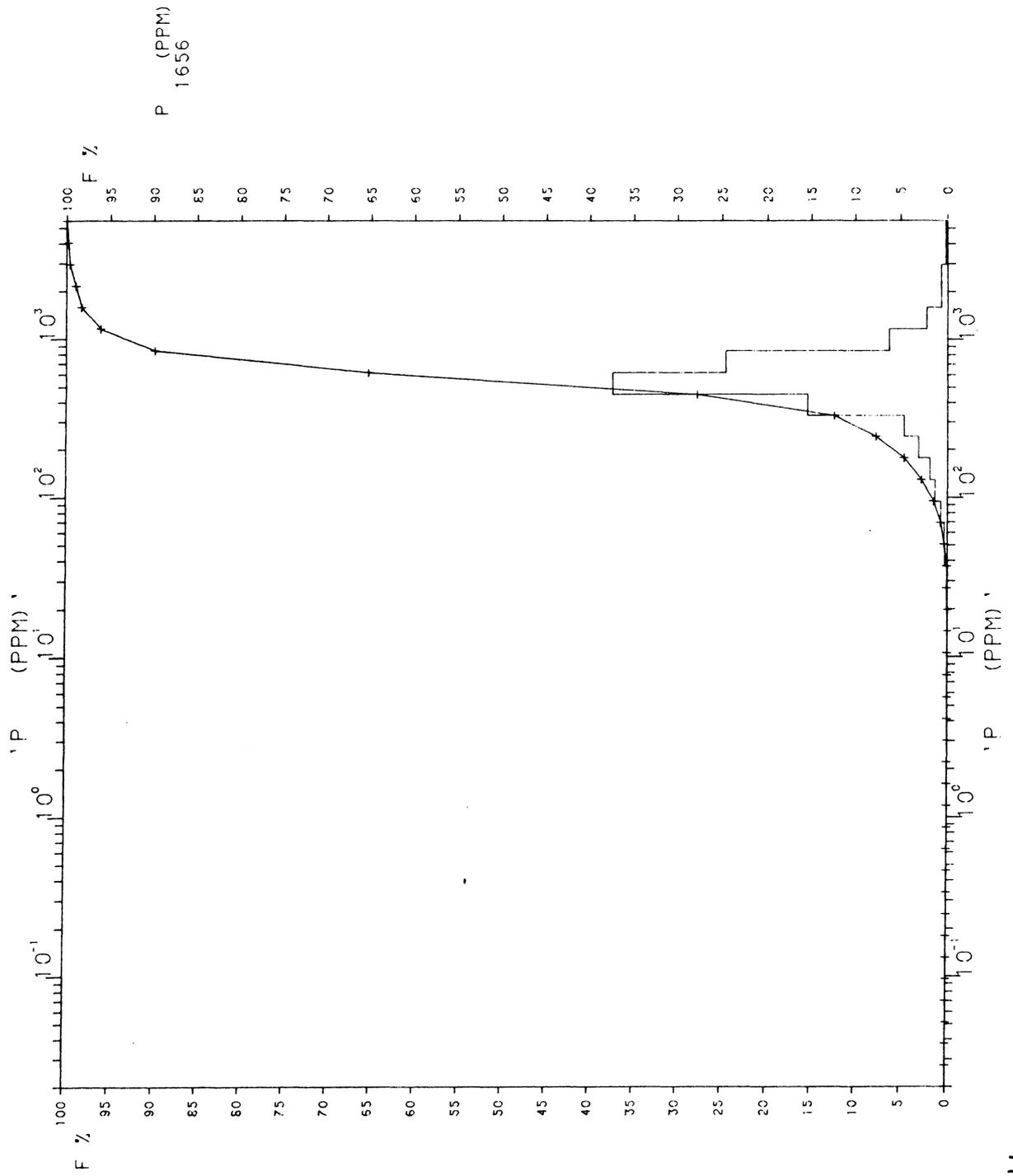


Fig 11 FREKP/LOKKEN/OUTOKUMPU

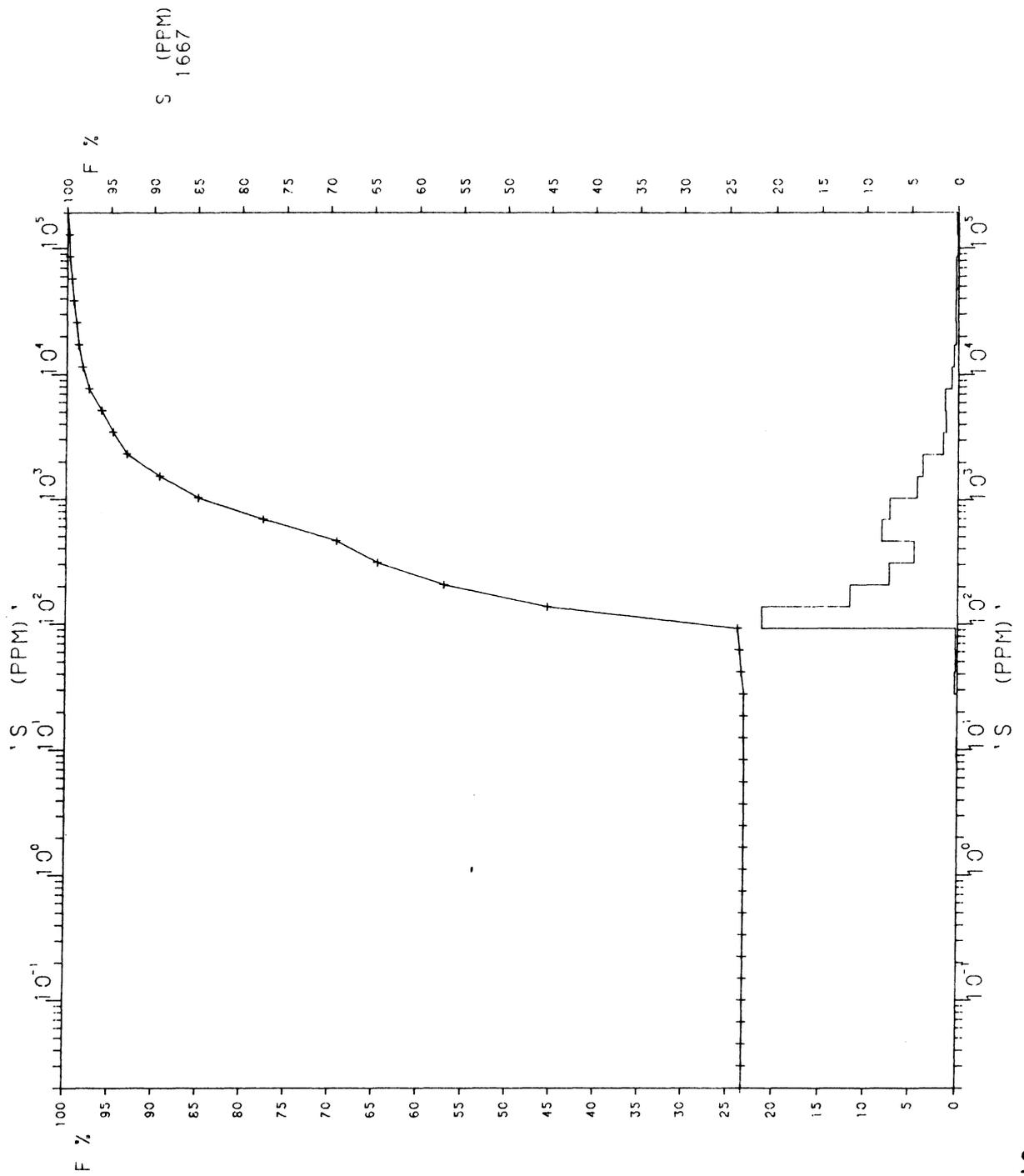


Fig 12 FREKP/LOKKEN/OUTOKUMPU

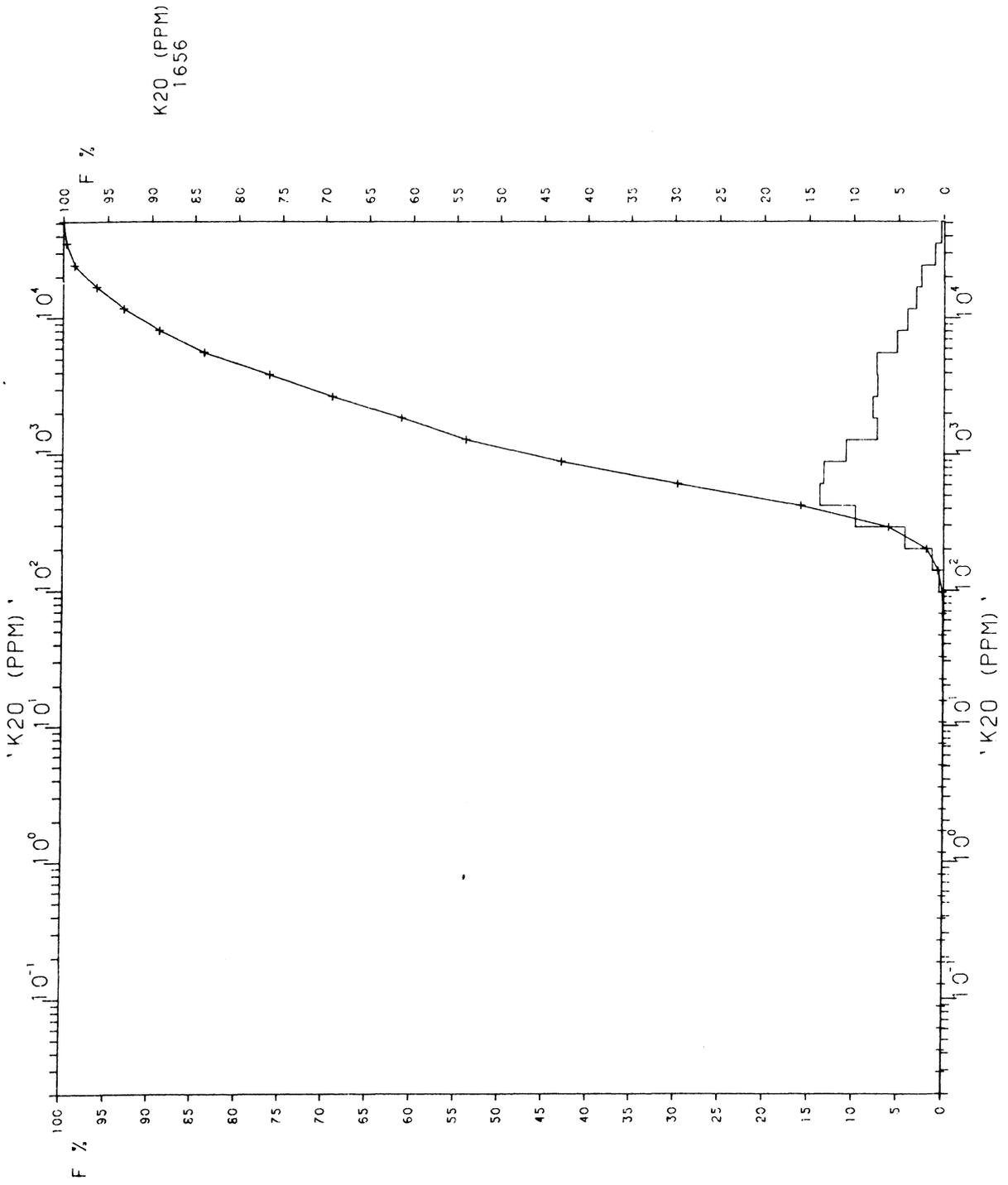


Fig 13 FREKP/LOKKEN/OUTOKUMPU

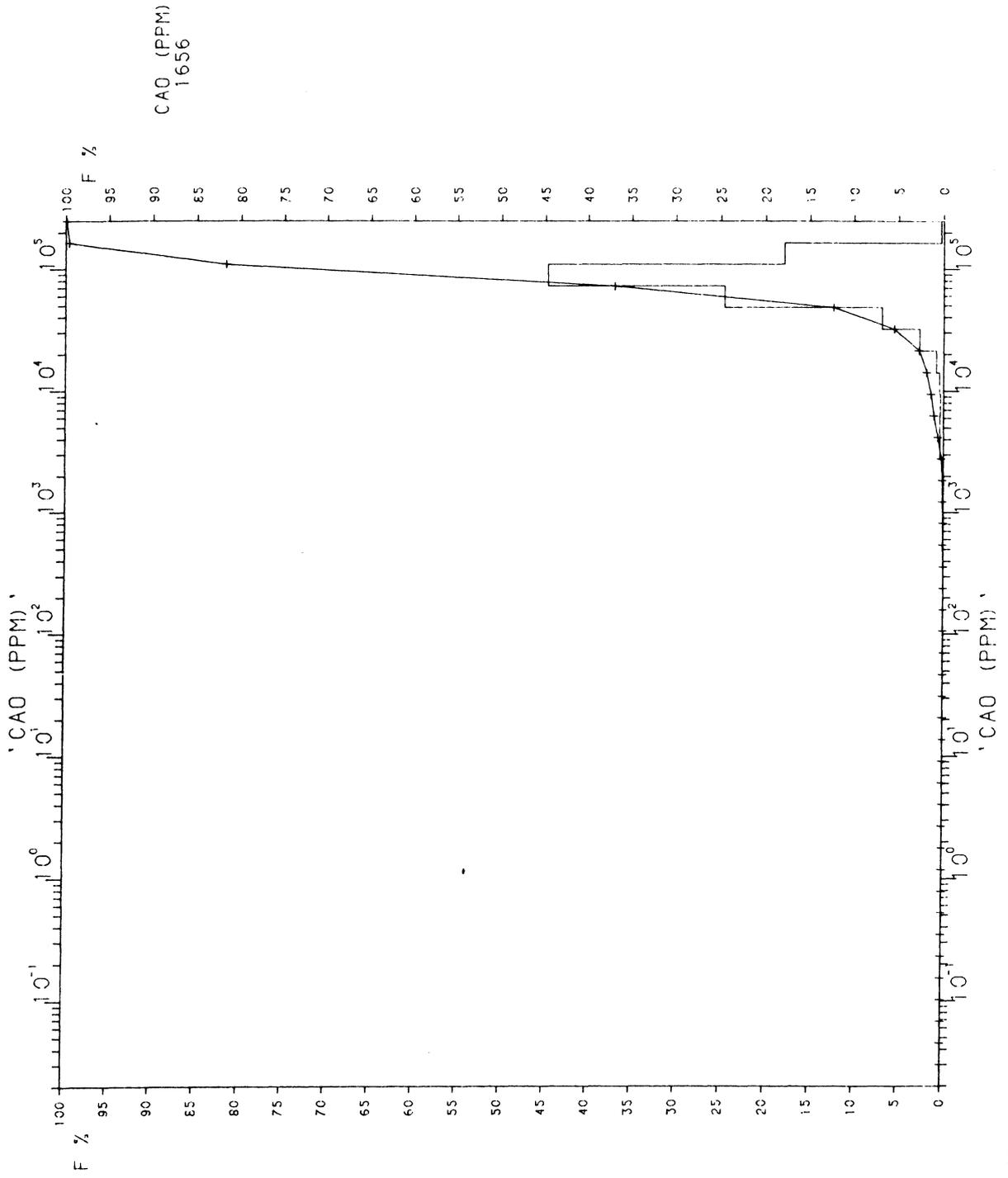


Fig 14 FREKP/LOKKEN/OUTOKUMPU

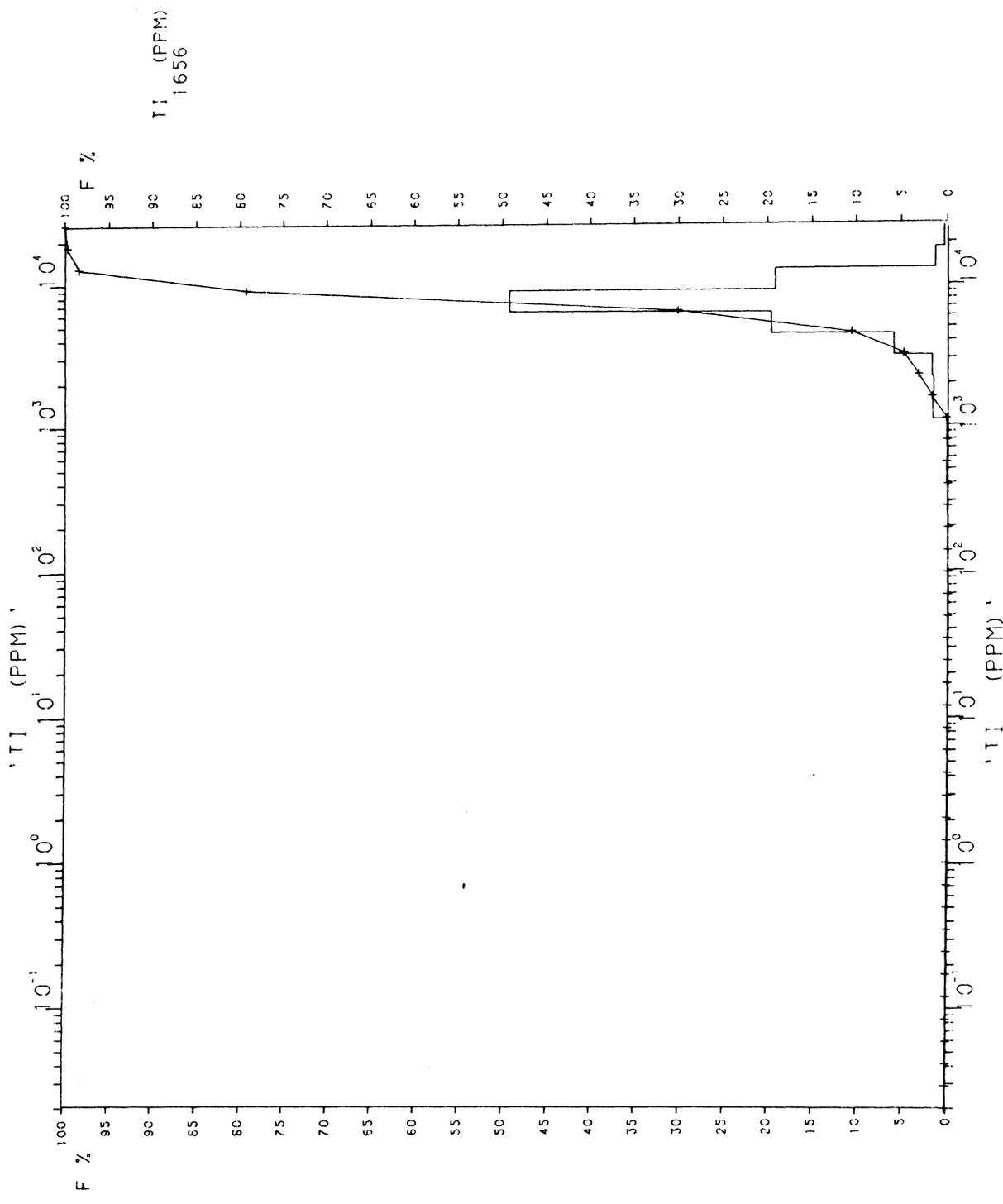


Fig 15 FREKP/LOKKEN/OUTOKUMPU

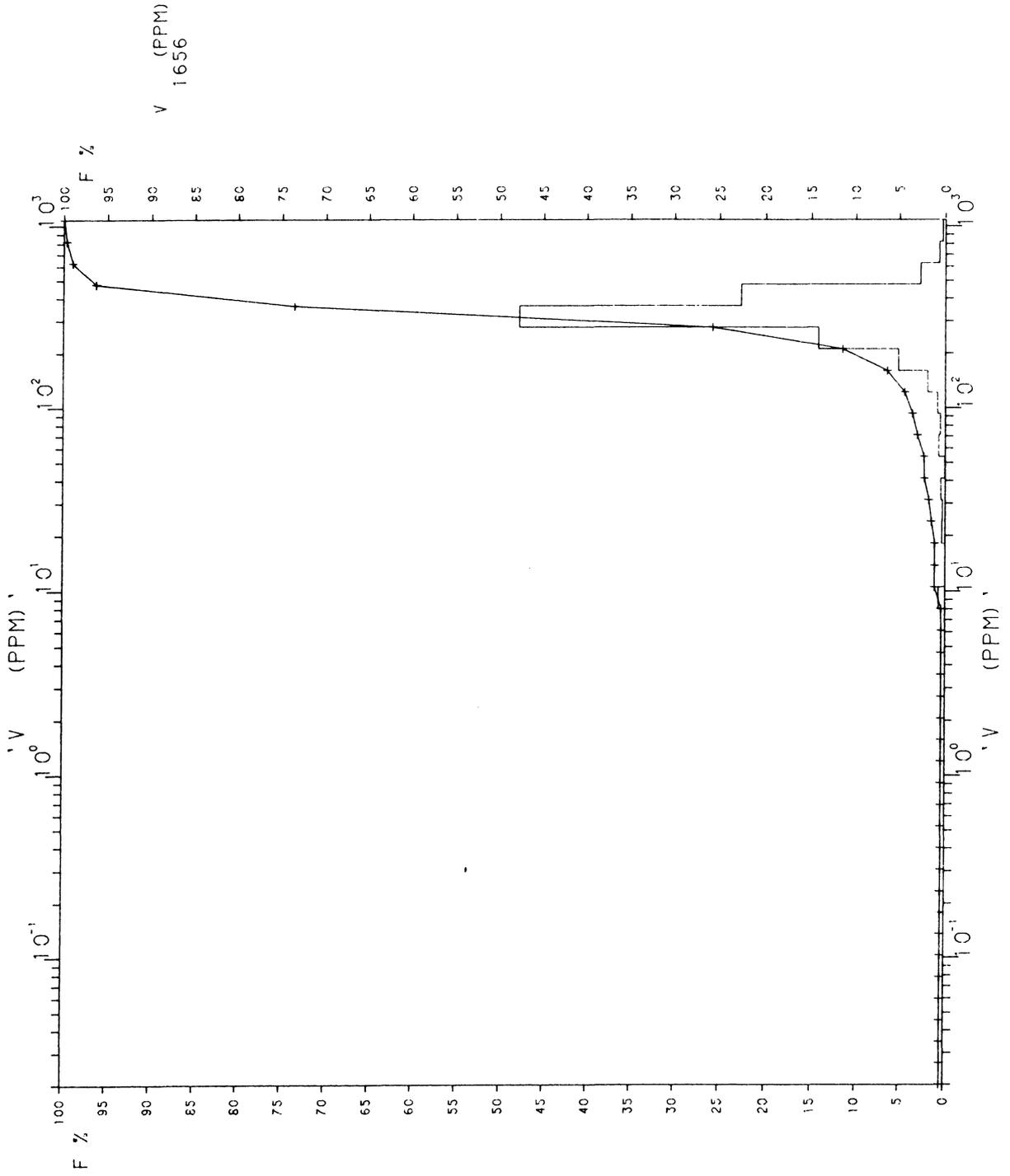
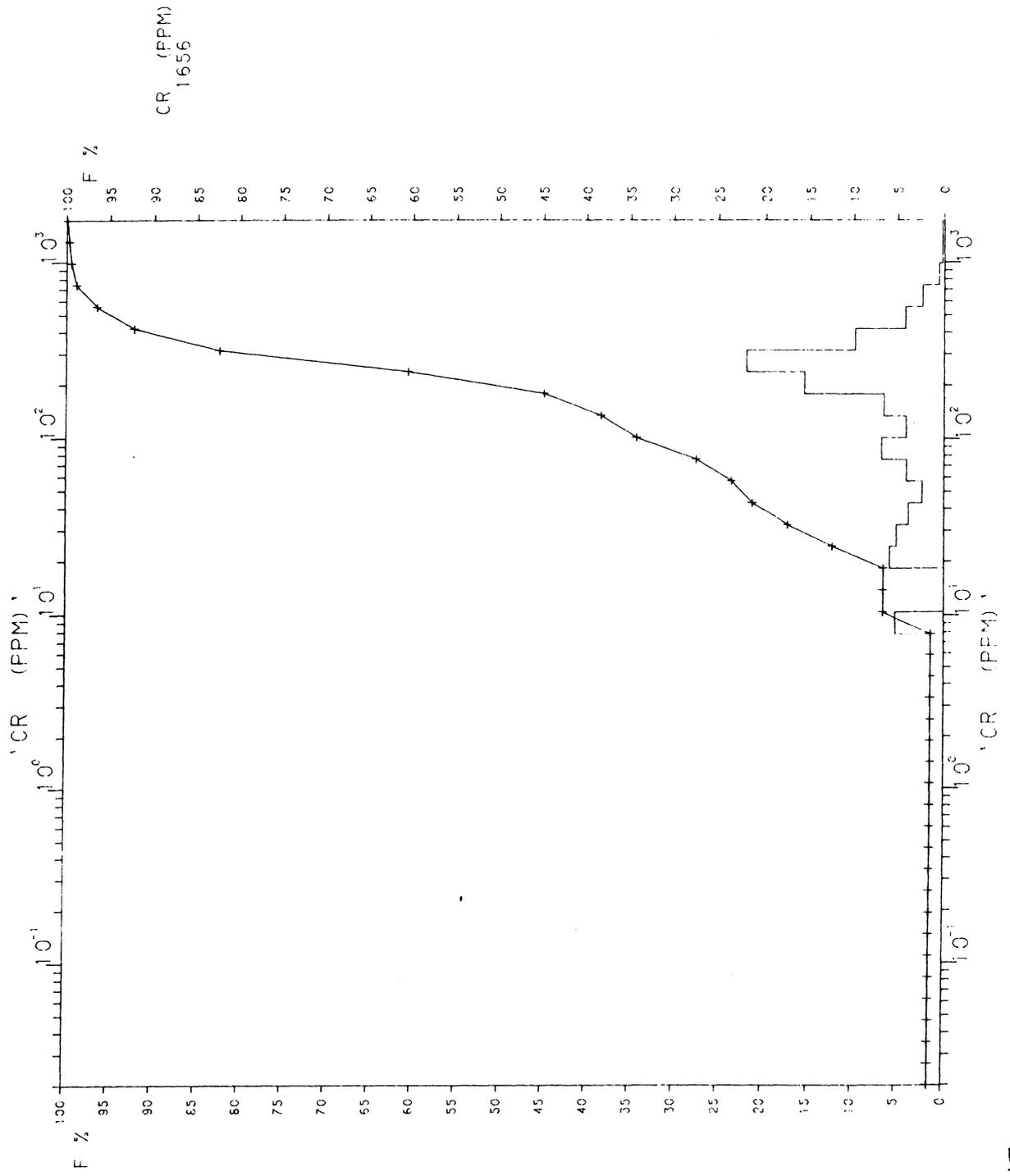


Fig 16 FREKP/LOKKEN/OUTOKUMPU



FREKP/LOKKEN/GUTOKUMPU

Fig 17

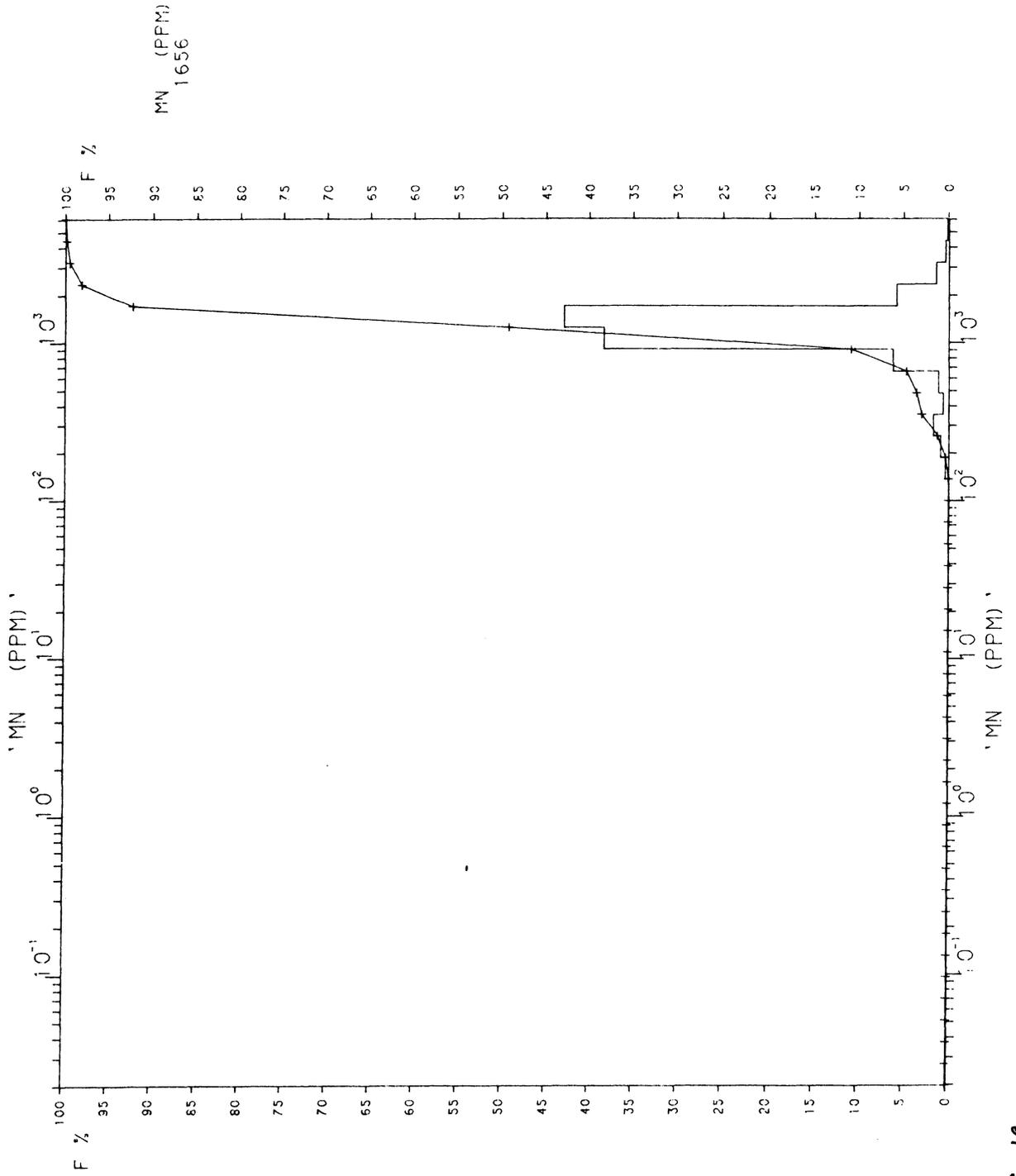


Fig 18 FREKP/LOKKEN/OUTOKUMPU

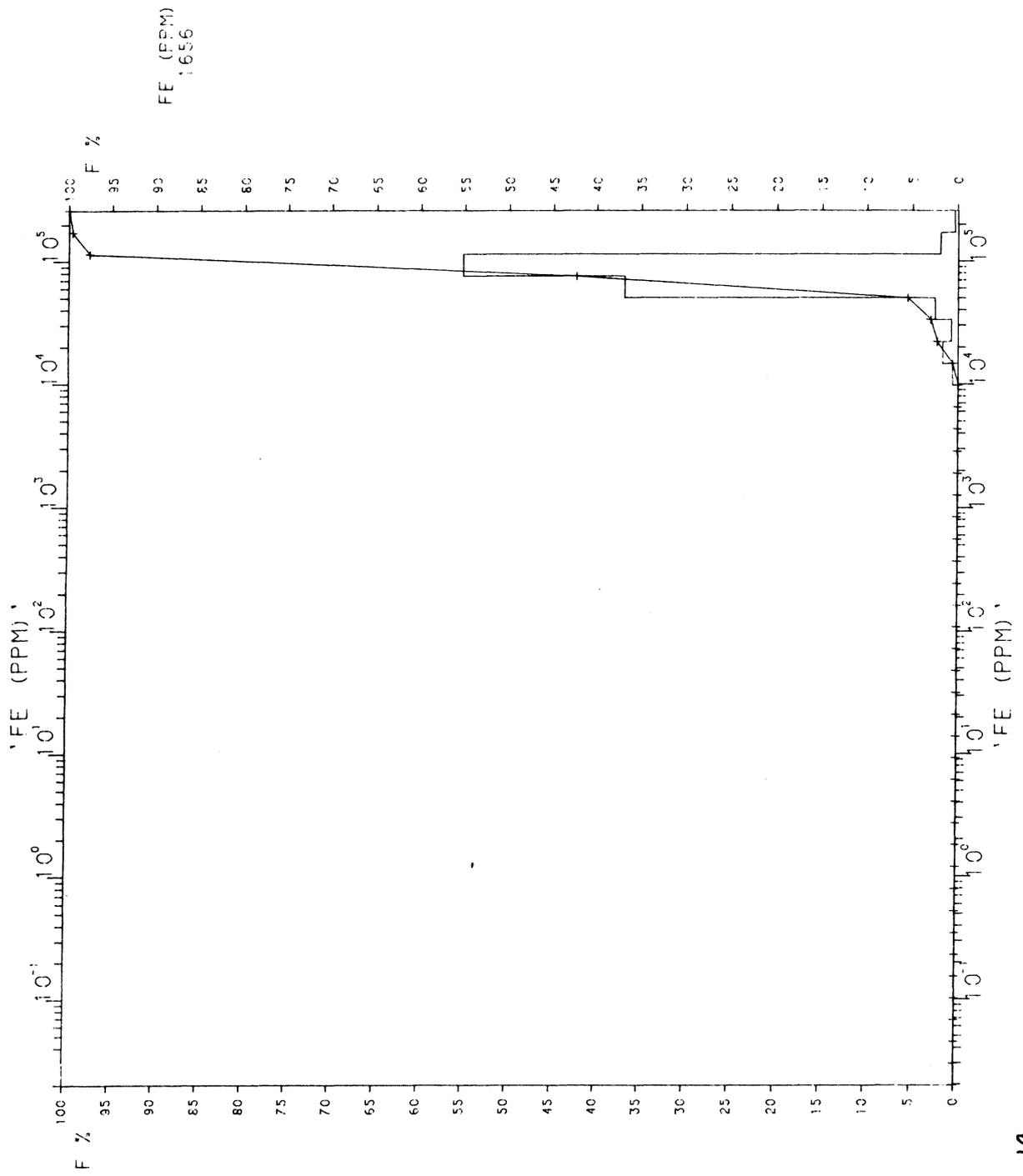


Fig 19 FREK/LOKKEN/OUTKUMPU

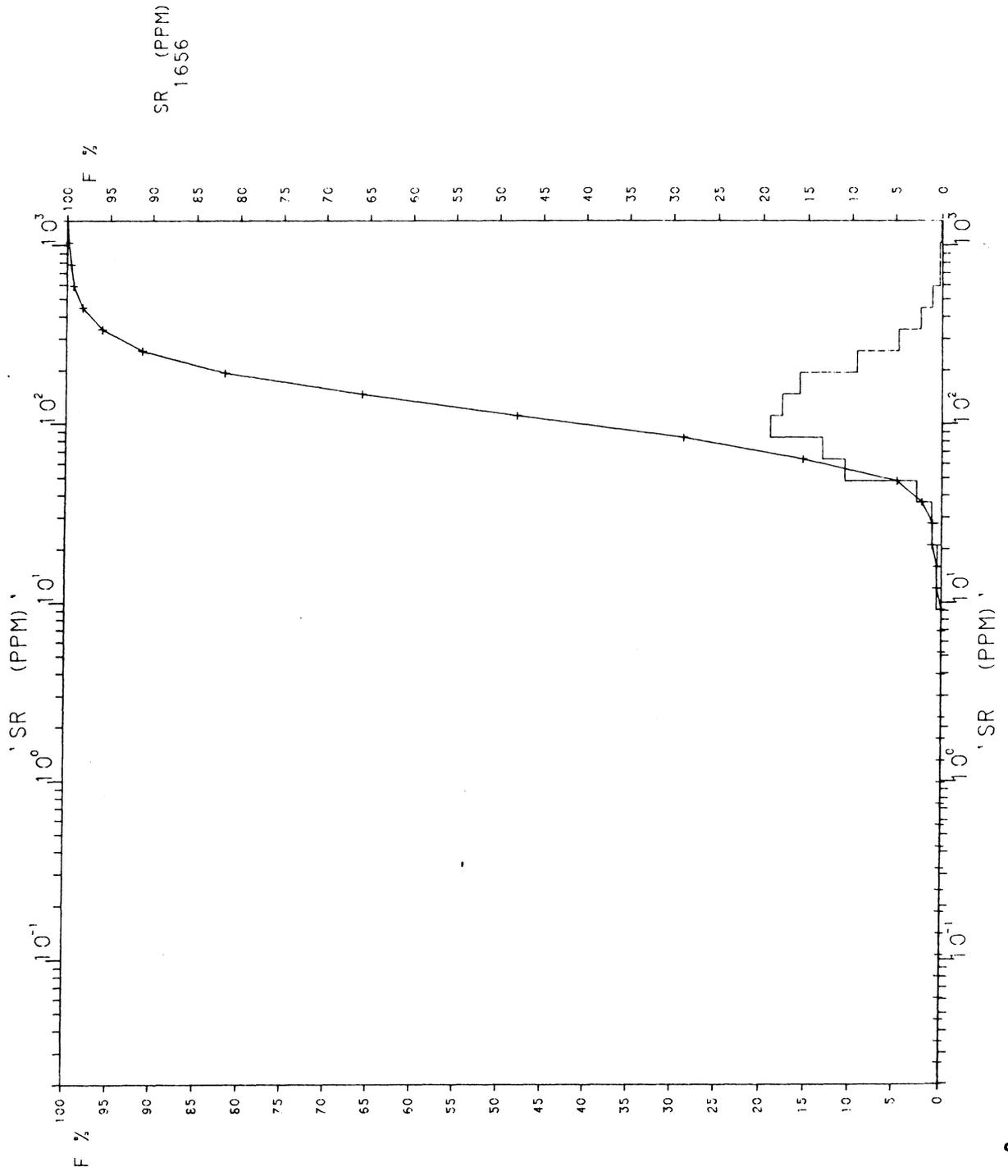


Fig 20 FREKP/LOKKEN/OUTOKUMPU

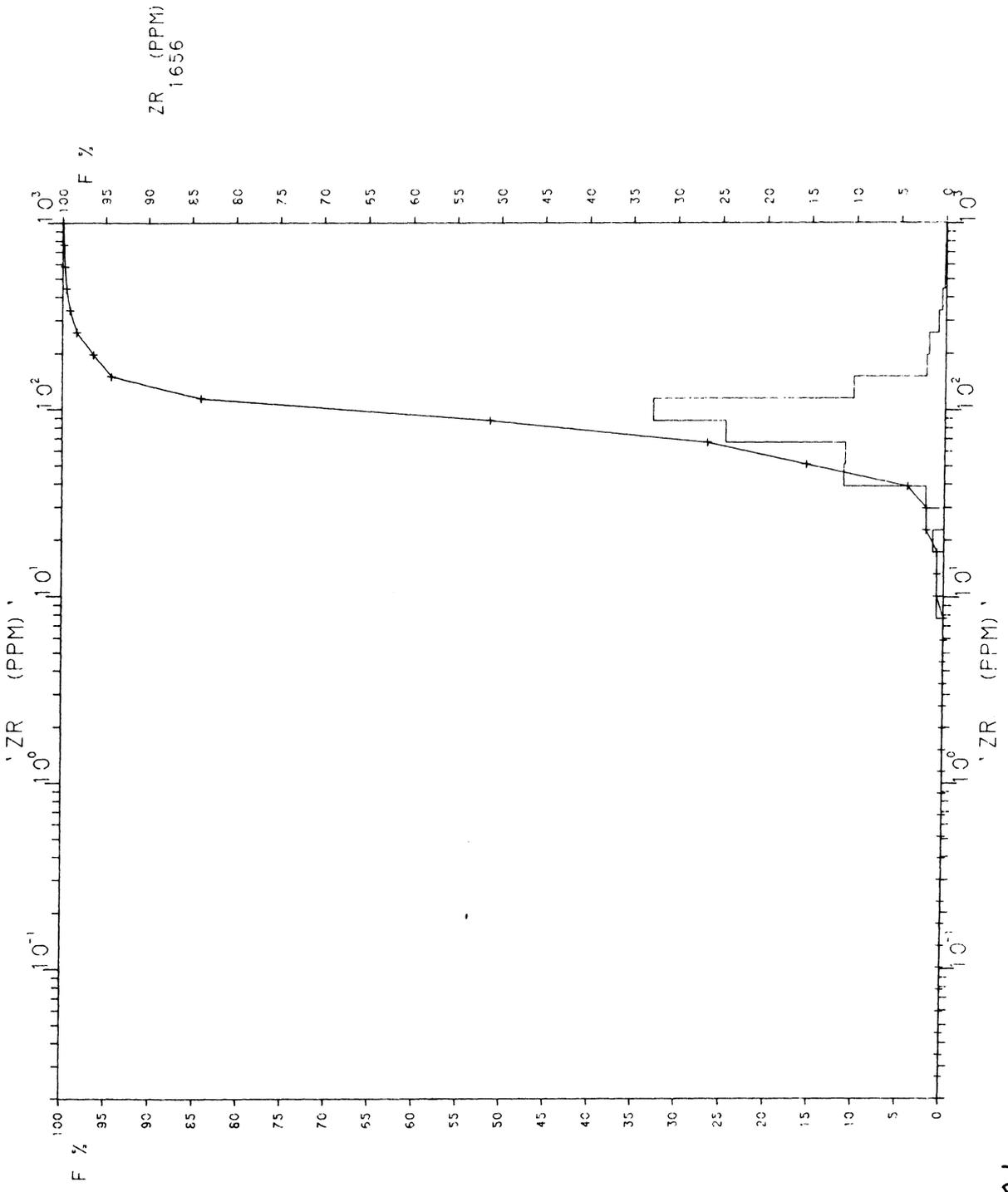
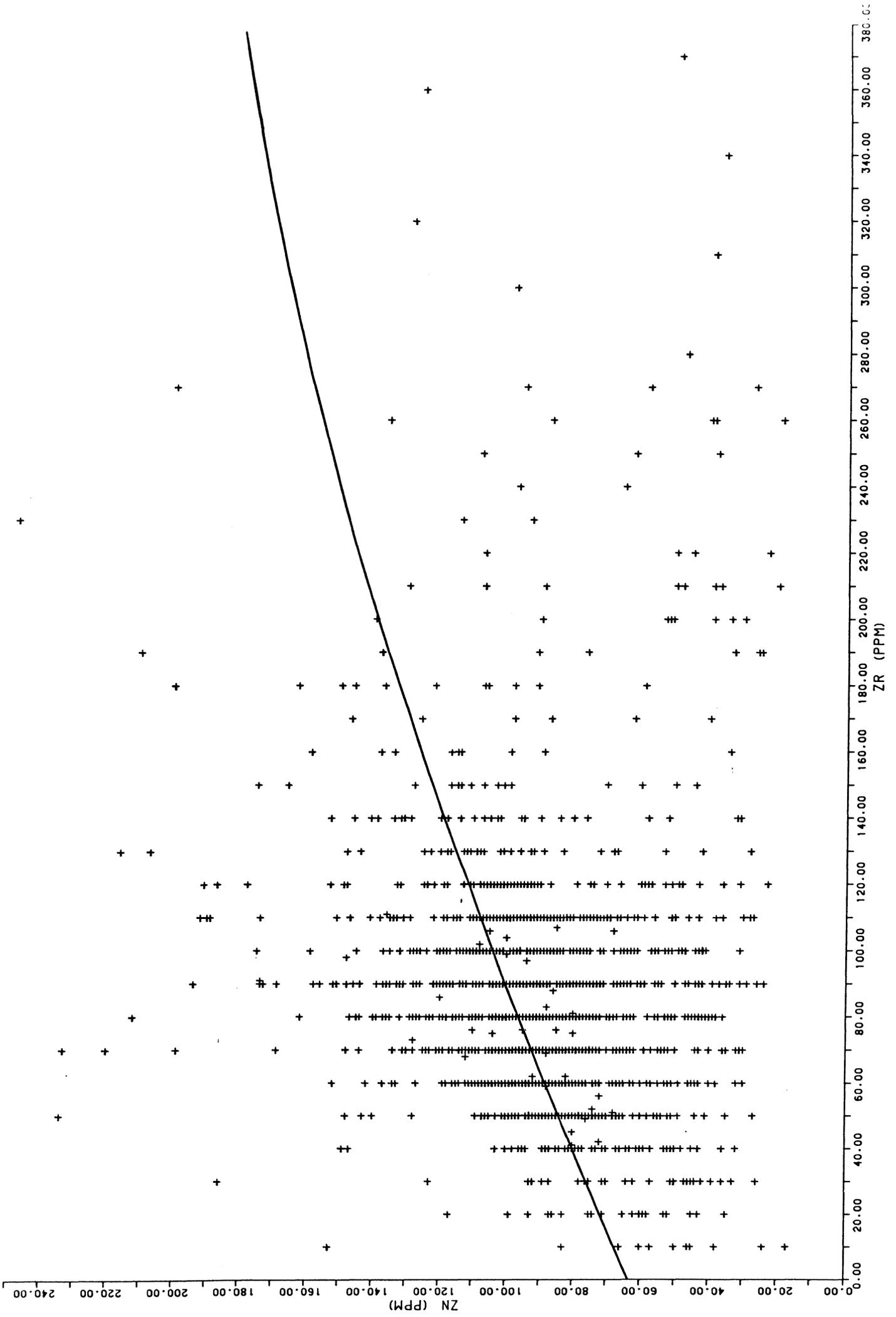


Fig 21

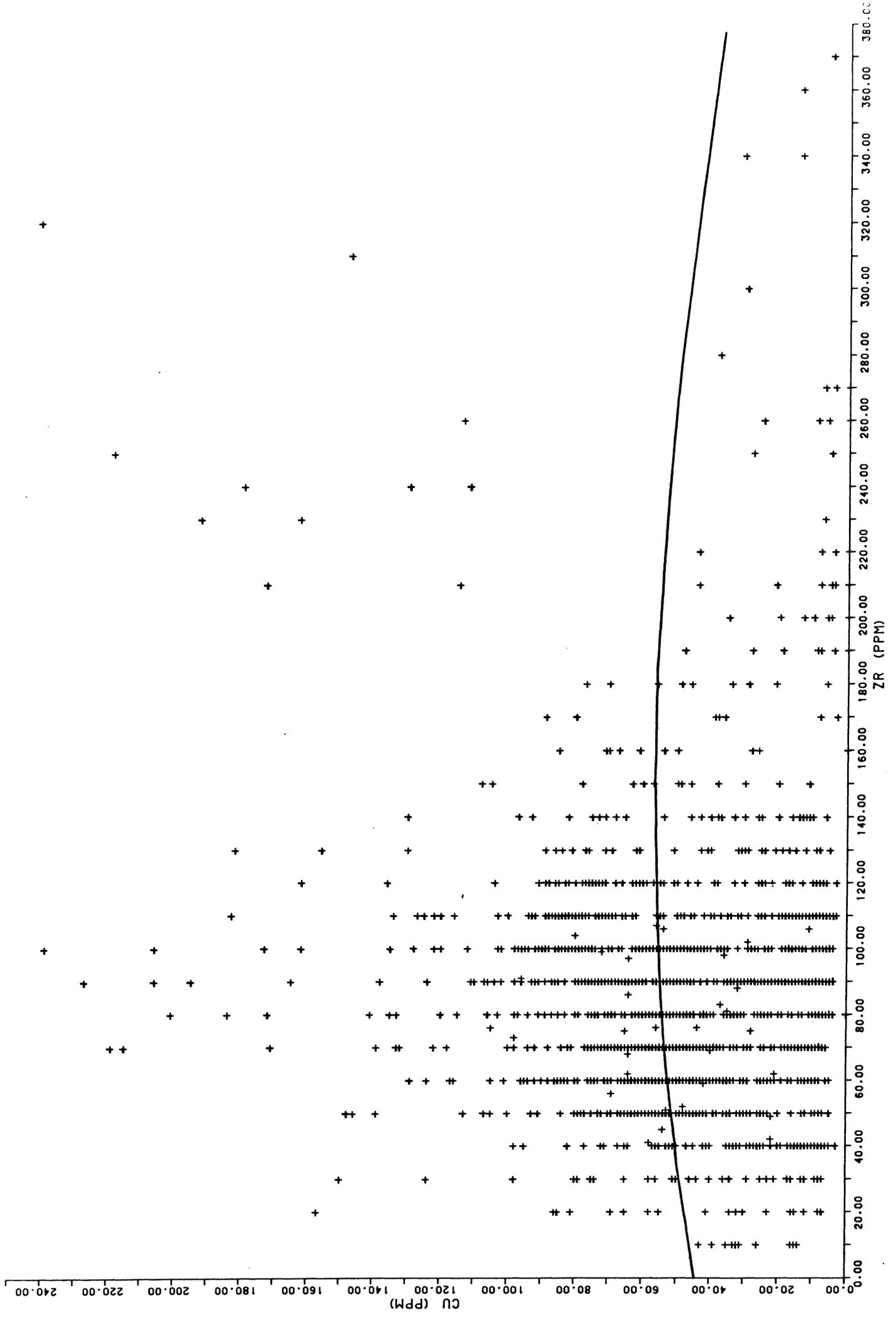
FREKP/LOKKEN/OUTKUMPU



LOKKEN

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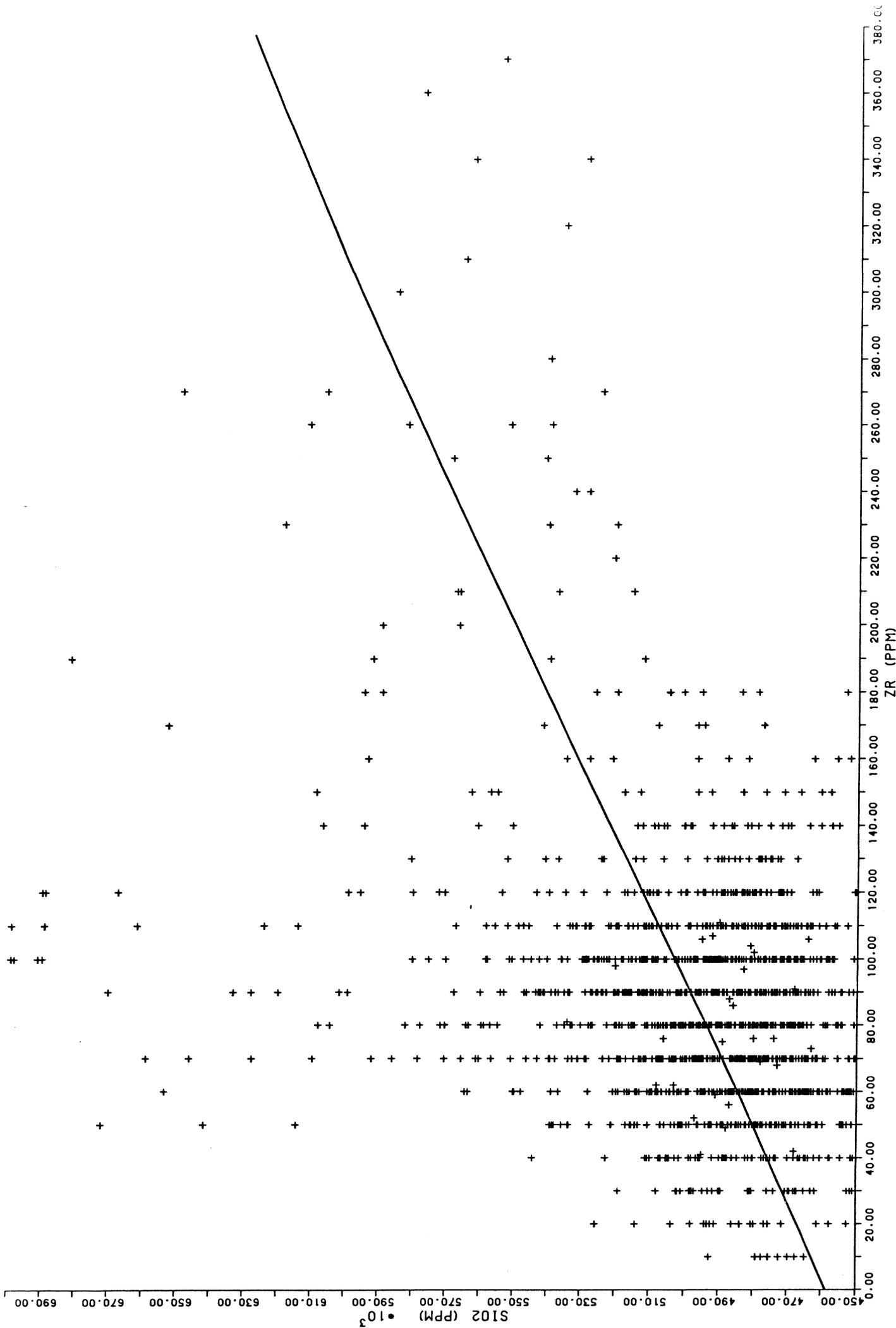
Fig 22



LOKKEN

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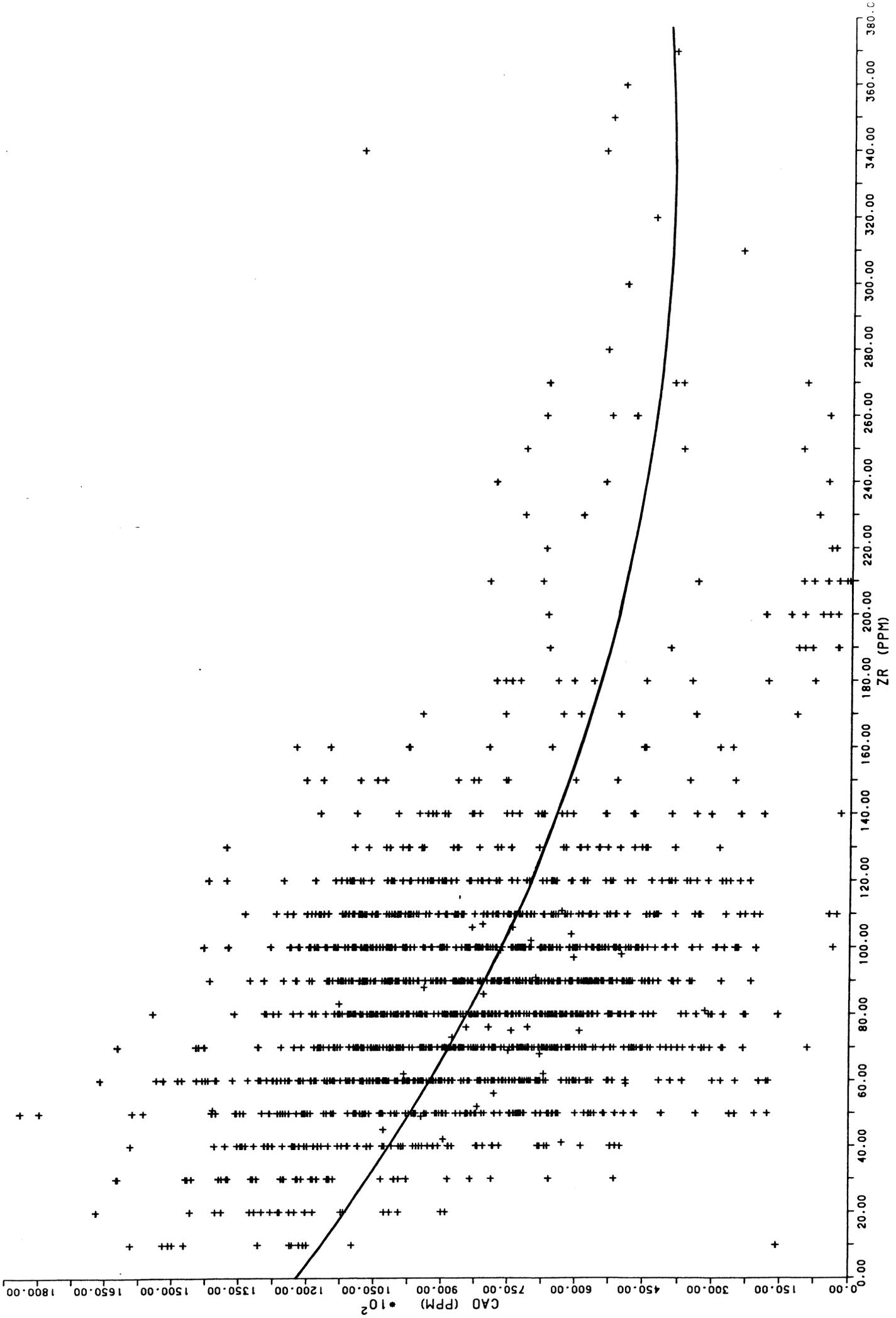
Fig 23



LOKKEN

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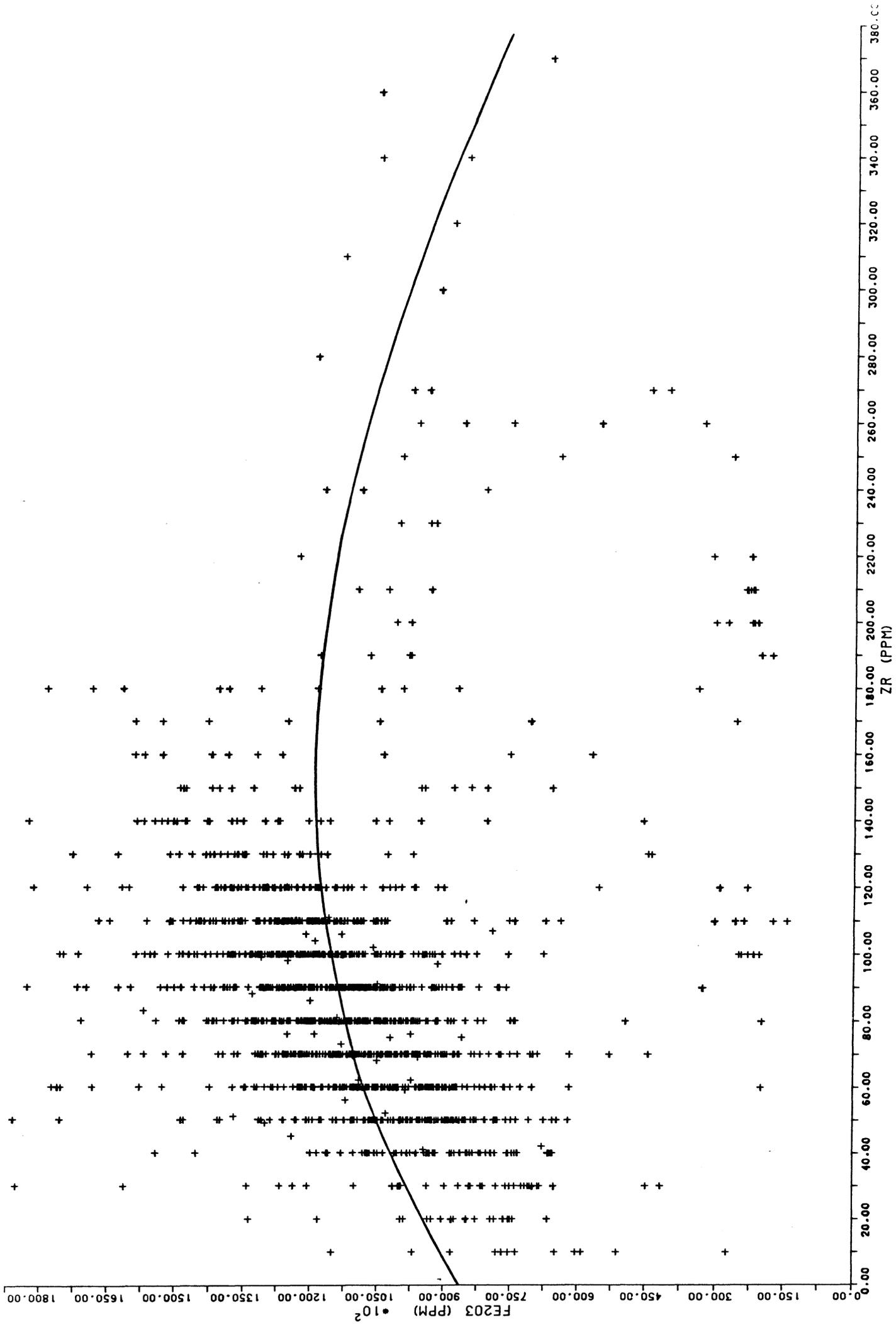
Fig 24



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Fig 25



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Fig 26

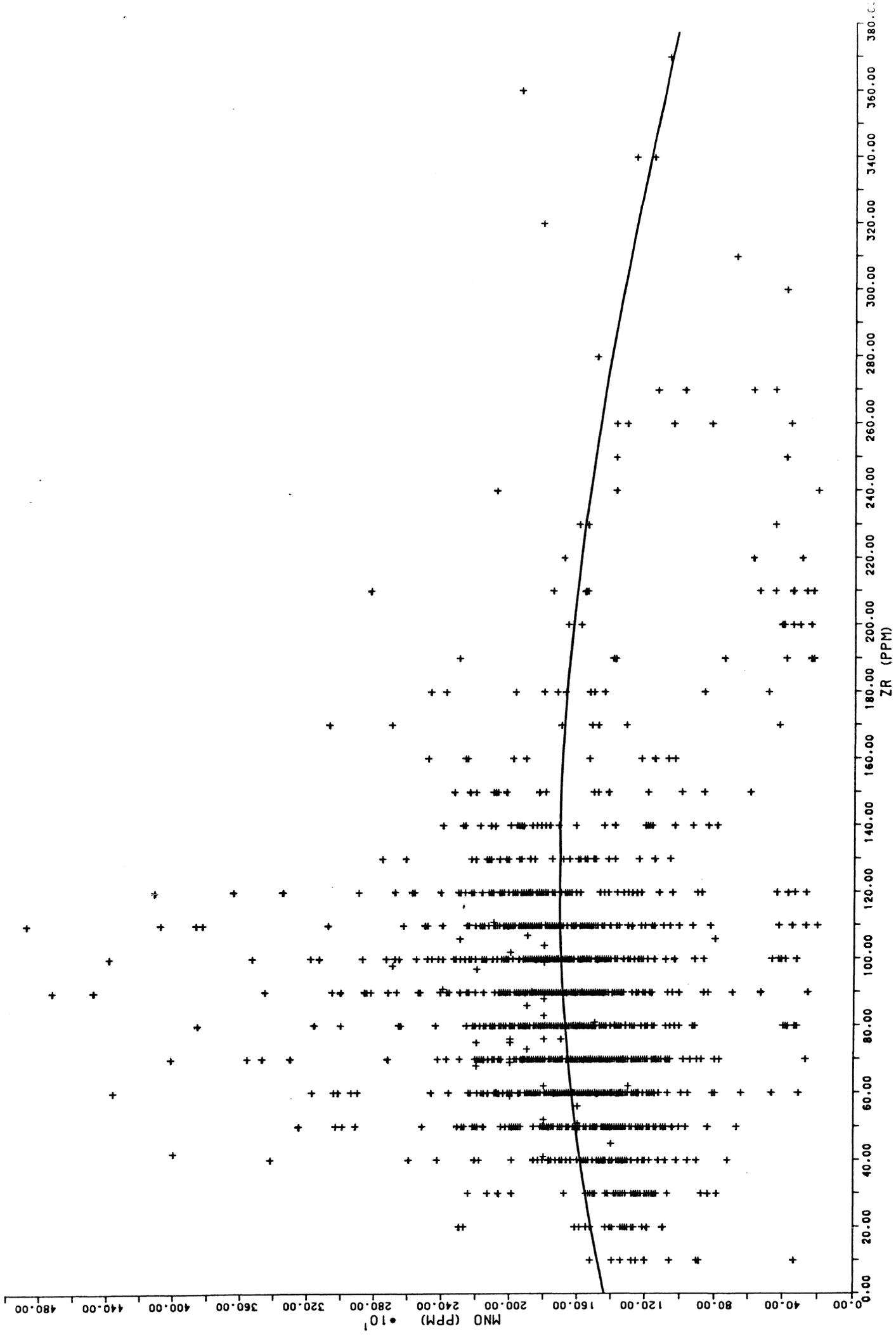


Fig 27

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LOKKEN

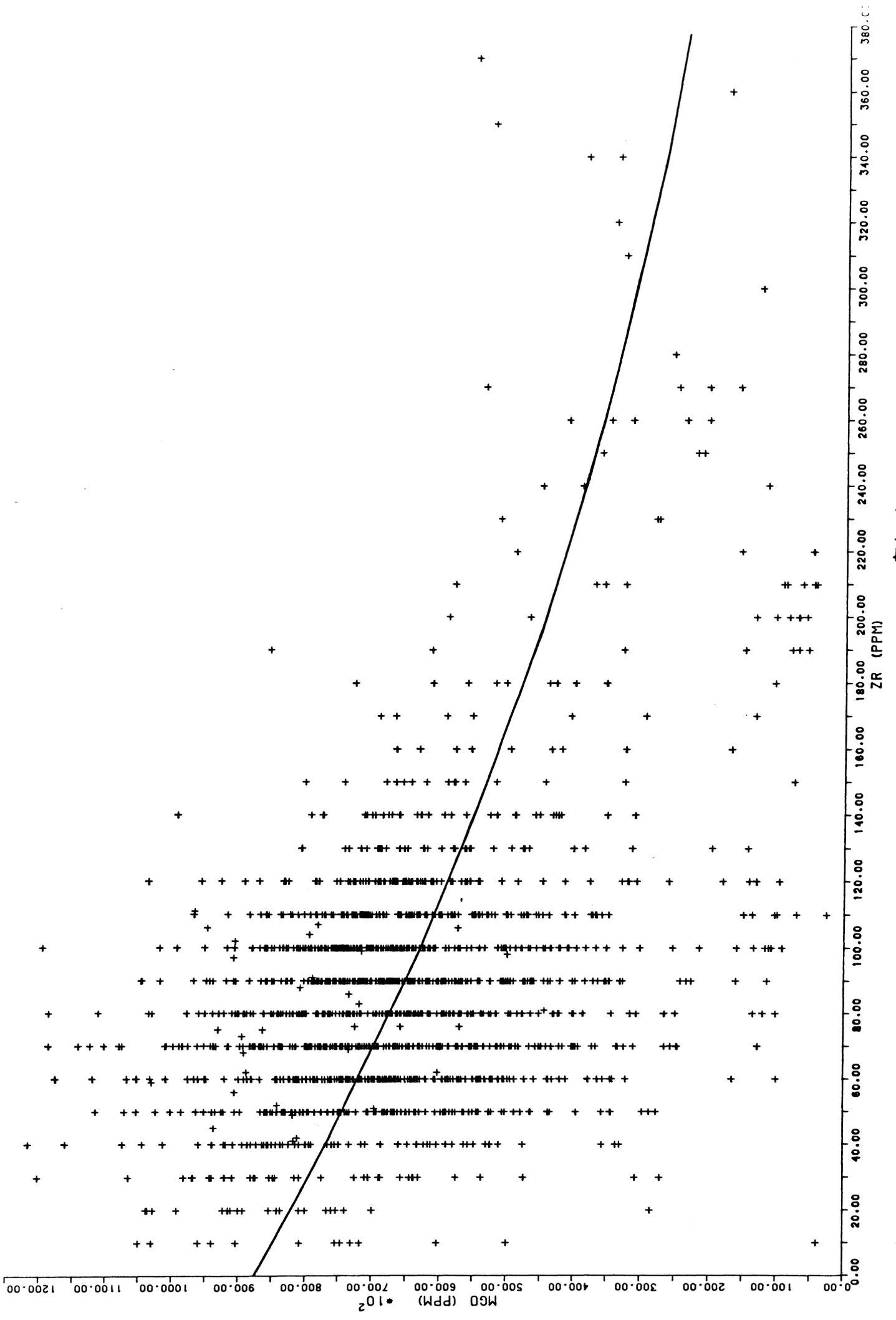
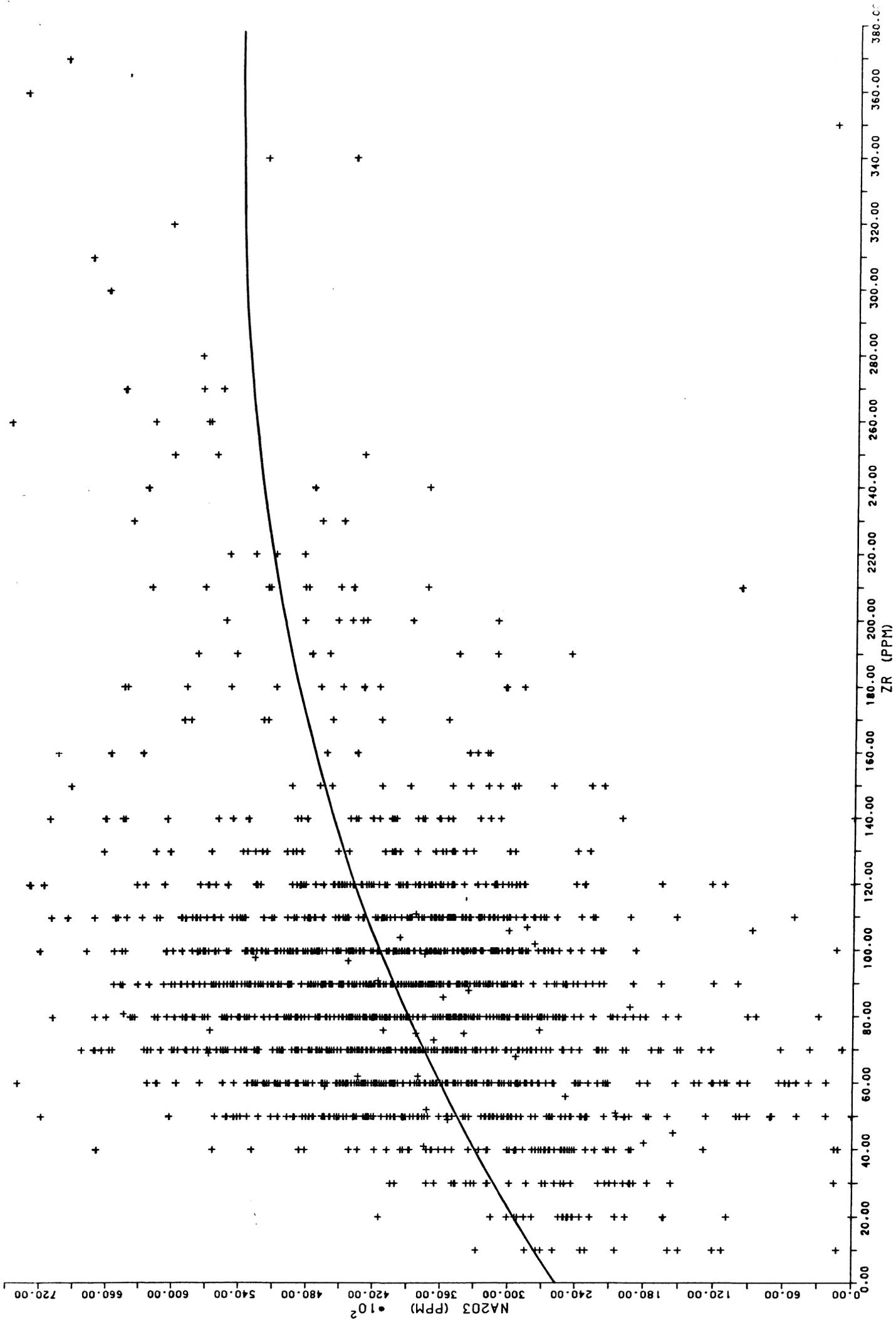


Fig 28

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Fig 29

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The Løkken area.

by Tor Grenne

### Introduction.

#### Regional setting and deformation.

The geology of the Løkken area (Fig. 1) has received a good deal of attention over the years on account of the presence of massive sulphide deposits. The first brief descriptions of the greenstones and the mineralizations were given by C.W. Carstens (1920, 1924, 1951), and more recently by Rutter et al. (1967) and Grenne et al. (1980). The geology of the sedimentary and volcanic rocks stratigraphically overlying the greenstones has been studied by Vogt (1945), Chadwick et al. (1962), Chaloupsky (1970), Bruton and Bockelie (1980) and Ryan et al. (1980).

At Løkken the greenstones are deformed in a fairly open, asymmetric synform trending approximately E-W, with near vertical dips along the strongly attenuated northern limb and more moderate, northerly dips in the little deformed southern parts. At least one earlier phase of deformation can be recognized with formation of overturned folds with strongly attenuated middle limbs and development of local shear-zones along favourable lithological units or boundaries. This is thought to be responsible also for the regional inversion of the greenstone sequence; younger sediments - conglomerates, metagreywackes, siltstones and shales occur structurally below the basaltic greenstone pile while the stratigraphically lower parts of the sequence are found within the core of the large synform structure. (Fig.1). In the southern-central areas a series of low-angled thrusts (Fig.1) with minor southerly movements cross-cut the early regional schistosity and in some places also apparently post-dates the late open folding. The greenstone complex has been further dissected by a series of faults, of which the most conspicuous are a set of ESE-WNW and SW-NE trending faults (Fig.1) which can be followed along the entire central and eastern part of the Løkken synform, south of its hinge zone. The

rocks are regionally metamorphosed in the lower greenschist facies, with formation of albite, epidote, chlorite, actinolite, sericite and locally stilpnomelane as characteristic minerals in the metabasalts and metagabbros.

The Løkken greenstones are stratigraphically overlain by the mainly sedimentary Lower Hovin, Upper Hovin and Horg groups. The sediments include a mainly volcanic-derived conglomerate or breccia considered by Vogt (1945) to be the basal conglomerate of the Lower Hovin Group. The overlying sequence of metagreywackes, siltstones, green and black shales, limestones, and calcareous sandstones, is characterized by marked facies changes. Fossils have given ages ranging from Caradoc, down to mid- or late Arenig for the oldest sediments. A variety of subvolcanic, volcanic and volcanoclastic rocks are also included in the thick sedimentary cover to the greenstones. Ranging from calc-alkaline andesites ('Høllonda porphyrites') at lower levels, to dacitic to rhyolitic tuffites and welded tuffs higher up, these rocks bear no resemblance to the underlying ophiolitic assemblage of tholeiitic greenstones and gabbros (see below). The whole volcanic-sedimentary sequence was interpreted by Roberts et al. (1984) as having formed in a marginal basin environment. Together with other ophiolite fragments in the western Trondheim district (Vassfjell, Grefstadfjell - see inset map, Fig.1), the Løkken greenstones were considered to represent phases of extensive crustal thinning and oceanic lithosphere accretion within the basin, with formation of the overlying conglomerates and breccias during subsequent intra-basinal movements or abortive displacement of the newly-formed oceanic crust in late Arenig times. All these greenstone sequences have generally been termed as equivalents to the thick and extensive Støren Group greenstones further SE (inset map, Fig. 1) (Vogt 1945, Chaloupsky 1970). The Støren Group sensu stricto, together with its substrate, the Gula Complex, upon which it was tectonically emplaced (Gale and Roberts 1974), was later considered to have been initially deformed, metamorphosed, uplifted and eroded in earliest Ordovician times (Furnes et al. 1980), following earlier suggestions by Vogt (1945). This prominent stratigraphic break was termed the Trondheim Disturbance

by Holtedahl (1920). The deformed Støren and Gula sequences were cut by trondhjemites of early to middle Ordovician age (Klingspor and Gee 1981), and as Tremadoc slates are found within the Gula (Vogt 1940), the early deformation of the Støren greenstones (and the Gula Complex) may be broadly coeval with the later stages of the Finnmarkian orogenic event (Sturt 1978), which corresponds to the Grampian deformation of the British Caledonides. The Lower Hovin, Upper Hovin and Horg Groups were unconformably deposited upon the trondhjemite-intruded Støren and Gula sequences and were deformed, metamorphosed and transported together with these previously deformed rocks as one nappe complex (the Trondheim Nappe Complex) during the later, Silurian, major orogenic event. The frequently used term 'Støren Nappe' for the Støren, Lower/Upper Hovin and Horg Groups, introduced by Gale and Roberts (1974) based on the assumption that these units were tectonically emplaced together on the Gula Complex, is thus somewhat misleading.

The traditionally accepted correlation of the Løkken, Grefstadfjell and Vassfjell ophiolite fragments with the Støren Group sensu stricto is presently somewhat ambiguous. Mapping in the Meldal area, some 10 km south of Løkken (Fig.1), led Ryan et al. (1980) to suggest that the thick greenstones in the Grefstadfjell area actually occur within the Lower Hovin Group. This was based on observations of apparently interfingering relationships between the fossiliferous, uppermost Arenig, Lower Hovin sediments and pillow lavas at the top of the Grefstadfjell lava pile. Ryan et al. thus inferred that the Grefstadfjell complex, together with the Løkken greenstones, are younger than the Støren Group and that the overlying breccias and conglomerates here are not the product of a tectonic disturbance as suggested by Vogt (1945). The situation at Løkken is similar to that in the Grefstadfjell area, inasmuch as the uppermost lavas interdigitate with Lower Hovin sediments. Here however, in view of the deformation style in the Løkken area, with early overturned tight to isoclinal folds with strongly attenuated middle limbs passing into imbricate structures, it is quite possible to interpret the interfingering relationships as a tectonic repetition of parts of the sequence.

The ambiguous nature of the apparently interfingering relationships between the greenstones and Lower Hovin sediments was noted also by Vogt (1945) and Carstens (1951) from the Hølanda area, some 15-20 km ENE of Løkken (see inset map, fig.XX). Additionally, although there is no obvious difference between the greenstones and the younger Lower Hovin sediments, either with respect to the deformational pattern or the metamorphic grade, it has been noted that relatively restricted zones within the Løkken ophiolite fragment exhibit a conspicuously strong deformational fabric that appears to be cut by obliquely intruding dykes of the Hølanda porphyrites of Lower Ordovician, probably Llanvirnian age (Grenne and Roberts 1981). It should also be noted that Vogt (1945) described fragments of crystalline marble and metamorphosed calciferous sandstones in the conglomerate resting on top of the greenstones in the area northwest of Løkken (along strike), while adjacent overlying Hølanda limestones are apparently unmetamorphosed. The question whether there is an important stratigraphic break between the greenstones and the younger Lower Hovin sediments, must therefore await further studies, and in the present author's opinion the mid-late Arenig age of the oldest recorded fossiliferous Lower Hovin sediments still must be considered as a minimum age.

#### The Løkken ophiolite fragment.

The Løkken greenstone sequence, as well as the neighbouring thick greenstones in the Western Trondheim district, does not contain the fully developed pseudostratigraphy of a typical ophiolite assemblage (Coleman 1977). Being in tectonic contact with their substrata or with unexposed bases (as at Løkken), and with eroded upper contacts with younger sediments (although the importance of this erosion is disputed - see above) the sequence are lacking the ultramafic plutonic parts as well as any evidence of possible overlying, pelagic sediments. The lowermost exposed parts of the sequence (Figs. 1 and 2) comprise a 1-2 km thick complex of various metagabbros with associated derivatives. Compositionally these

range from relatively mafic, through common hornblende gabbros into magnetite-bearing ferrogabbros. Highly differentiated, intermediate to plagiogranitic derivatives occur as small or locally larger (Fig.1) bodies within the uppermost parts of the gabbro complex. The gabbros are usually more or less isotropic, although banded varieties do occur especially in their lower parts, and they range from coarse pegmatitic types to microgabbros. The latter types are mostly found along the top of the plutons. The gabbros have intruded relatively high up in the sequence, generally into overlying pillow lavas. A thick complex of 100% sheeted basic dykes, which in the neighbouring ophiolite fragments can be found with decreasing dyke density downwards into gabbros and upwards into pillow lavas (Grenne 1980, Grenne et al. 1980, Ryan et al. 1980, Heim et al. in prep.), is mostly absent in the Løkken area; however it is partly preserved where the gabbros have not reached their highest levels, or possibly as inclusions within the higher parts of the plutonic complex (Fig.1). These dykes are subparallel and generally strike in a ESE-WNW direction. Some dykes extend down into the upper parts of the gabbros and are likely to be derived from the intruding gabbroic magma, while a few dykes cut through the whole plutonic complex and are obviously derived from deeper sources. Geochemical studies (see below), as well as field relationships, suggest that all these dykes are feeders to various parts of the overlying volcanic sequence, although a few dykes with distinctly different compositions are obviously not related to, and are younger than, the ophiolite complex.

The sheeted dykes (- through a zone of decreasing dyke density), and the intrusive gabbros, pass upwards into 0.5 to 1 km thick monotonous sequence of predominantly pillowed metabasalts. This lower part of the volcanic complex is characterized by relatively thick-rimmed, non-vesicular to only slightly vesicular pillows and abundant hyaloclastite breccias. The lower pillow lava member is overlain by a variably thick (near Løkken approximately 0.5 km) pile of vesicular, generally close-packed and thin-rimmed pillow metabasalts alternating with sheet-flows, locally with

interlayered jasper horizons. In the lower parts of this upper sequence, here termed the middle volcanic member, thick sheet flows often predominate over pillowed flows, suggesting very high flow rates of large volumes of fluid lava at that level, where also intermediate volcanic rocks occur locally.

The chemical composition (Table 1) of the various volcanic rocks of the ophiolite sequence, particularly with respect to the more stable elements (Grenne et al. 1980), is comparable to normal mid-ocean ridge tholeiites. Recent studies have revealed a tendency towards slightly more differentiated compositions in the lower volcanic member (the lower pillow lavas) as compared to the upper member. The middle part of the sequence, by contrast to the fairly uniform lower and upper members, is characterized by large diversities in the composition of the volcanic rocks, ranging from relatively primitive and to very differentiated (Table 1, column 2 and 3), and locally intermediate, flows. Also this middle volcanic unit, however, shares the MOR-tholeiite characteristics (with respect to for instance incompatible-element ratios) of the lower and upper members.

Within this middle part of the volcanic sequence, at least two of the known orebodies within the Løkken greenstones - the Løkken and the Høydal deposits - are found (Fig.1). Abundant breccias composed of angular fragments of metabasalts and jasper occur at the same general level and are interpreted to represent debris accumulations adjacent to steep escarpments on the sea-floor (Grenne et al. 1980), reflecting probably also an increased faulting activity at the time of their formation. Within the same stratigraphic interval, jasper horizons play a prominent role, and appear to be intimately associated with the stratiform orebodies; some of them extending laterally from the massive sulphides as a more distal expression of the hydrothermal activity which led to the sulphide formation. Slightly above the massive sulphides, or locally resting directly upon them, conspicuously extensive iron-rich banded sediments have precipitated. These horizons, which are called 'vasskis' in traditional Norwegian mining terminology (possibly derived from the German term 'weiss-kies',

meaning white sulphide as opposed to the yellowish Cu-bearing sulphides), and comprise alternating layers rich in very fine-grained pyrite and/or pyrrhotite, magnetite, iron-rich chlorite or stilpnomelane, and subordinate iron carbonates together with varying proportions of quartz (Sand, 1984). Sand (in press) interprets these horizons, with very low base metal values (Table 2) and  $\delta^{34}\text{S}$  between -20 and -25 ‰, to represent precipitation from hydrothermal, seawater-derived solutions. However, the underlying metalliferous massive sulphides of indisputable hydrothermal origin, by contrast, have distinctly different  $\delta^{34}\text{S}$  values (+1.5 to +5 ‰ - Grenne, in prep.); the latter values being comparable to those found in, for instance, the East Pacific Rise hydrothermal sulphides (Arnold and Sheppard 1981, Styrud et al. 1981, Kerridge et al. 1983). It is also noteworthy that the metabasalts directly underlying the 'vasskis' horizons often show evidence of a conspicuous sea-floor weathering, including strong oxidation of some of the basalts. This alteration is different from that of the hydrothermal feeder-zones to the massive orebodies in the area (see below). The question whether the 'vasskis' horizons have a hydrothermal origin (as stated by Sand, in press), or if other sea-floor, possibly weathering, processes were involved, is thus still a matter of dispute.

The massive sulphide occurrences in the Løkken area, among which only the Løkken mine is still operating (1986), contain predominantly pyrite with more or less chalcopyrite and sphalerite; pyrrhotite is abundant only in one of the deposits (Dragset, some 8 km WNW of Løkken). Galena, magnetite or hematite are local minor constituents, while tetrahedrite-tennantite and cobaltite are found only as accessories. The main gangue mineral is quartz, constituting 12-14% of the ore (Grenne et al. 1980). The ores display a massive to vaguely banded structure, or they may show irregular patches or bands enriched in chalcopyrite or sphalerite. The texture is very fine-grained, commonly with porous or colloform pyrite aggregates with gangue or base metal sulphides in the interstices. Several generations of sulphides can often be distinguished (Grenne and Vokes 1986). Average metal

contents of stratiform ore in three of the deposits (Løkken, Høydal and Dragset) are given in Table 2. The size of most of these massive orebodies can be estimated to less than 100.000 tonnes. The Løkken deposit, which was discovered in 1654 where the ore crops out in the western hillside of the valley at Løkken, is the outstanding exception, having originally more than 25 million tonnes of ore contained mainly in one large body. If the several separate orebodies in the Løkken mine were part of the same horizon of sulphide deposition, as suggested by Grenne et al. (1980) and confirmed by later work (R.Juhava, G. Grammeltvedt, pers.comm.), the orebody had a primary very elongate morphology (Fig.3); total length exceeds 4 km with a maximum width and thickness of ca. 400 and 60 metres, respectively. The shape was largely controlled by the sheet-like feeder-zone which underlies the central part of the stratiform sulphide body along its entire length. This zone obliquely cross-cuts the volcanic stratigraphy and is very well-defined down to more than 300 metres below the contemporaneous paleo sea-floor. Sulphide stockworks and disseminations constitute the most conspicuous parts of the feeder-zone, in a width of ca. 100 metres, increasing in density towards the most central parts and particularly towards the stratiform ore level. Different sulphide facies can be distinguished within the zone, commonly forming cross-cutting or composite veins, or veins cutting earlier disseminations (Grenne 1986 and in prep.). Hydrothermal alteration has strongly affected the chemical composition and mineralogy of the feeder-zone wall-rocks. The most conspicuous features are alteration to chlorite-albite-rich assemblages in the peripheral regions, while in the central zone a more advanced, pervasive, alteration has given chlorite ± quartz-rich rocks. Sericite-bearing assemblages appear in the altered volcanites close to the stratiform ore level. Representative analyses of various alteration rocks are listed in Table 1B. Feeder-zone relationships are largely similar to those at Løkken in the other ore occurrences in the Løkken area, like the Høydal deposit (Figs.1 and 5) although the feeder-zone is slightly more irregular and less well-defined here.

Although generally the stratiform sulphide bodies in the area are very proximal, lying immediately above their hydrothermal feeder-zones, parts of the deposits may have suffered penecontemporaneous slumping and were redeposited as adjacent, slightly more distal, breccias of sulphide ± metabasalt ± jasper or as finer-grained, laminated and partly graded sulphide sediments. A coarse variety of the former type is well exposed in the eastern mine in the Høydal deposit (Fig.5), where it constitutes a major part of the total stratiform sulphides. These breccias are considered as equivalents to the above-mentioned greenstone ± jasper talus breccias (Grenne 1981).

#### Excursion stops

The excursion localities are concentrated to the vicinity of Løkken and the area around the Høydal mine (Fig.1). Starting with the stratigraphic lower parts of the ophiolite pseudostratigraphy, the excursion will successively move to higher levels, until the overlying conglomerate is reached to the south in the area. Emphasis is put on the middle part of the volcanic sequence, including the massive sulphides, which are easily accessible and well exposed in the open-pits of the abandoned Høydal mine. Most of the localities are off the road, and stops 7 to 15 are along a 4 to 6 km walking traverse over the hill Høydalskammen. Stop no.8, 9 and 10 are alternative localities which may replace stops 1 to 4 on the western side of the Løkken valley.

Stop 1. Gabbro with dykes.

Locality: Ca. 300 m along a steep track off the road through Langenglia, ca. 300 m ESE of football ground.

Map-sheet M711/1521 III Løkken, NR 3620/0040.

The uppermost parts of the gabbro can be seen on small exposures on and near the track. The gabbro which is medium grained and

isotropic, is cut by several basic dykes trending ca. NW-SE, with fairly steep SW dips. The dykes range from half a metre in thickness to thin off-shoots a few centimetres across. Flow-banding is prominent along the fine-grained dyke margins, which were obviously chilled against an already cooled part of the gabbro. Angular bends in margins suggest that the dykes intruded along cracks and joints in the chilled gabbro. Irregular veins with epidote, and sometimes an alteration rim around it, often cut both gabbro and dykes. This type of veining is abundant in the lower parts of the ophiolite sequence and may be related to interactions between wall-rocks and solutions in the deep parts of hydrothermal systems associated with the intrusion and cooling of the gabbros. Some fifty metres to the south, dyke-intruded pillow lavas of the lower volcanic unit are exposed in large cliffs above the track.

#### Stop 2. Plagiogranite.

Locality: North-eastern shore of the lake Bjørnlivatnet, ca. 400 ESE from the road near the northwestern end of the lake.

Map-sheet M 711/1521 III Løkken, NR 3430/0075.

A characteristic light-coloured, medium grained plagiogranite is here exposed in the uppermost part of the gabbro or possibly at the contact to the pillow lavas above. The rock is composed primarily of albite, quartz and epidote; at this locality also magnetite is abundant. East-west striking basic dykes cut the plagiogranite with fine-grained chilled margins. The chemistry of these dykes demonstrates their relationship to overlying volcanites and hence that the plagiogranite is a part of the ophiolite. Numerous N-S oriented quartz veins occur in the plagiogranite at this locality; these veins also postdate and cut the basic dykes.

Ca. 100 m east of the locality, one can see a relatively dark, magnetite-bearing, somewhat fractionated gabbro with basic dykes,

whereas the first, relatively poor exposures southeast from the plagiogranite apparently show abundant basic dykes in pillow lava. A few, thin silicic dykes have the same general orientation as the basic ones in this area.

Stop 3. Pillow lavas of the lower volcanic member.

Locality:                   Northeastern shore of the lake Bjørnlivatnet,  
                              400-500 m SE of stop 2.  
                              Map-sheet M711/1521 III Løkken, NR 3460/0045.

Along the shore and in a cliff on the SW side of a small promontory there are several good exposures of the pillow lavas characteristic of the lower volcanic member. The pillows range from more than 2 m to small pillows a few centimetres across. At this locality the pillows have relatively regular, bun-shaped morphologies, the larger ones are slightly flattened. Inversion with steep northerly dip and way up to the south is clearly demonstrated. Radial and concentric cooling joints can be seen occasionally. Small spherulitic varioles are found especially along pillow margins, while vesicles are absent or scarce. A prominent and characteristic feature is the thick, originally glassy pillow rims surrounding the individual pillows. The basaltic glass is altered to mainly chlorite, with epidote along thin joints, but the original glassy nature is clearly shown by the very well-preserved conchoidal jointing, leaving a more than 2 cm thick shell of small sharp-edged and smoothly curved 'glass' shards around each pillow. The shards may be in situ, or glass fragments may have spalled off the pillow rims, forming thicker 'pockets' of hyaloclastite between pillows.

Stop 4. Sheeted dykes.

Locality: SE side of small hill-top, 350 NE of the dam of lake Bjørnlivatnet.

Map-sheet M711/1521 III Løkken, NR 3510/0065.

In this area basic dykes predominate, with only few screens of pillow lava preserved between dykes occasionally. The locality displays a section with 100% dykes, intruded subparallel, as multiple dykes, along earlier dyke margins, or with cross-cutting relationships (Fig.4). Dyke width ranges from more than one metre down to 10 cm, although thinner off-shoots can also be seen. Their margins are fine-grained and may show a vague flow-banding, while the interior parts pass into more medium grained metadolerite depending on dyke thickness. One set of dykes strike approximately WNW-ESE with southerly dips. A later generation intruded in a more E-W direction, while the latest dyke at this locality cuts the older ones with a SW-NE strike and moderate NW dip. The latter intruded along a fracture or minor fault with some 30 cm displacement of the early dyke contacts (see Fig.4). All these dykes have tholeiitic compositions which are compatible with their origin as a part of the ophiolite.

Stop 5. Distal part of the Løkken orebody.

Locality: Cliffs above old road, 80-100 m south of main road from Løkken to Bjørnli, just above old adit.

Map-sheet M 711/1521 III Løkken, NQ 3505/9975.

This locality is thought to be the place of discovery of the Løkken ore in 1954. Assuming that the separation of the ores in the Løkken mine into different bodies is due to a tectonic repetition of essentially one elongate lensoid ore layer (see introduction), this most distal part of the sulphide layer must originally have been 200 m or more from the feeder-zone, measured perpendicular to the feeder-zone/massive sulphide intersection line.

The sulphides are resting, in inverted position, on a sheet flow which can be seen to the north. This metabasalt is plagioclase phyric and generally, although variably, vesicular. Highly vesicular varieties with fairly large vesicles can be seen a few metres to the north, as well as some 100 m to the east, along strike. Transitions into irregular thin-rimmed pillow-like structures are found locally within the upper few metres of the generally massive flow. The flow-top surface, which is very well exposed, displays ropy to lobate pahoehoe structures, now oriented horizontally along strike. Shape and curvature of these structures may suggest a flow direction towards south (in the present inverted position), which is away from, and roughly at right angle to, the longitudinal axis of the proximal parts of the Løkken orebody.

The lowermost part of the ca. 90 cm thick distal ore horizon, resting directly on the pahoehoe flow-top, comprise 5-10 cm of finely laminated, fine-grained sulphides alternating with greenish bands and occasional jasper lenses. The top of this bed shows ripple-like structures oriented horizontally along strike, and it is overlain by a 40 cm thick unit of coarse clastic breccia ore. In addition to sulphides, this unit contains large and smaller fragments of fine-grained greenstone, minor jasper, and irregular chlorite-rich "flakes", in a sulphide matrix which shows a vague grading towards more sandy sulphide along the stratigraphic top. The upper 40 cm of the ore zone comprise thin, fine-grained sulphide (pyrite-chalcopyrite-sphalerite-pyrrhotite-magnetite) bands alternating with reddish to greenish fine-grained, finely laminated silicate-oxide sediments. Structures which can be interpreted as representing soft-sediment deformation are abundant.

A 10-15 m thick massive, plagioclase-phyric greenstone is concordantly overlying the sulphide horizon. The lower and upper contacts are fine-grained but apparently non-vesicular. A vague columnar jointing can be seen in the northern, stratigraphic lower parts. The greenstone may represent a subvolcanic sill or possibly a non-vesicular sheet-flow. To the south this is overlain by a new, ca. 70 cm thick, laminated sulphide (mainly

pyrite-chalcopyrite-sphalerite)-magnetite-silicate horizon with local thin jasper. Several of these sulphide layers exhibit a clear, normal graded bedding giving further evidence for inversion. A weak tectonic fabric can be seen along both the southern and northern ore horizon, striking ca. WSW-ENE with a more gentle NNW dip than the layering, and in the southern zone minor folds may be related to this fabric. The southern ore horizon is covered by a close-packed pillow lava with a fairly primitive basaltic composition (Table 1 A, column 3); this is exposed some 40 m to the west along strike.

#### Stop 6. Vasskis horizon.

Locality: Small exploration workings near old railway line, 5 m WSW of tunnel. East of lake Fagerlivatnet.  
Map sheet M 711/1521 III Løkken, NQ 3475/9965.

The locality shows a more than 1 m thick, typical vasskis horizon, striking WNW-ESE with  $45^{\circ}$  dip to the north. Very fine-grained Fe-sulphide (here pyrite) alternate with thick, dark, silicate-magnetite layers. The 3 pyrite layers here exposed are 1 to 3 cm thick and very regular, and display a very fine regular internal lamination. A similar fine lamination is seen also in the dark silicate-oxide interlayers. Contrary to the banded sulphides on stop no 5, these vasskis sulphide layers are nearly devoid of base metal sulphides. The horizon apparently occur 50-100 m stratigraphically above the massive ore level. Comparable vasskis layers are found also immediately or a few metres above the massive ore in the Løkken mine, so it is likely that there is more than one of these horizons, although they are confined to a very restricted stratigraphic interval above the massive sulphides.

Stop 7. Hematite-rich altered pillow lava.

Locality: 10 m above the track, 30-40 m east of small stream.  
Map-sheet M 711/1521 II Hølanda, NQ 3695/9905.

In a small outcrop one can see pillow lava or pillow breccia, more or less altered to hematite-rich, purplish rocks which grade into more normal, greyish-green metabasalt. Oxidation has partly occurred along a network of thin veins. This kind of alteration is common, down to a few tens of metres stratigraphically below vasskis horizons, through the whole area. It possibly reflects a period (or periods) of more pervasive weathering of the uppermost parts of the oceanic crust by oxidizing sea-water.

Stop 8. (Alternative stop). Pillow lava and hyaloclastite with dykes, lower volcanic member.

Locality: Below a cliff, 80 m south of the southern shore of the lake Styggjtjøna.  
Map-sheet M 711/1521 II Hølanda, NQ 3670/9980.

Similar to stop 3, this is an exposure typical of the lower part of the lava pile. It shows an irregular flow (?or several flows) comprising pillows, pillow fragments and much hyaloclastite material. Glassy pillow rims are highly jointed and appear to grade into a true hyaloclastite of altered glass shards generally a few millimetres to a centimetre across. The lava is strongly variolitic, and individual varioles often exhibit a characteristic radial fibrous texture.

An angular, 10 x 15 cm fragment of medium-grained doleritic greenstone is seen as an inclusion in the lava, with flow structure and chilling of the lava around it. One can also see several cross-cutting doleritic dykes, partly multiple with fine-grained, flow-banded chilled margins. The dykes are oriented roughly WNW-ESE with steep to moderate SSW dips. Local variations in the orientation of a dyke intruding along the middle of an earlier dyke, is clearly controlled by fractures in its precursor.

Stop 9 (Alternative stop). Gabbro with parallel dykes.

Locality: Large outcrop face and many small exposures half-way between the hills Garsengknippen and Svartåsen, 100 m E of a small lake.

Map-sheet M 711/1521 II Hølanda, NQ 3750/9980.

The southern, upper parts of the gabbro are intruded by numerous parallel NNW-SSE-striking, steeply WSW-dipping doleritic dykes. They cut the gabbro, which here is of the normal, medium-grained isotropic type with clear, fine-grained chilled margins, and occasionally with a weak flow-banding. Dyke thickness varies from 5 cm up to more than one metre. The orientation of these gabbro-related dykes is slightly different from the general WNW-ESE trend of early dykes in the lower volcanic member, which are apparently cut by the gabbros (see map, Fig.1).

Stop 10 (Alternative stop). Doleritic dykes in the lower part of the lava pile.

Locality: Several outcrops on the hill Koiåsen, 550 m N of the Høydal Mine.

Map sheet M 711/1521 II Hølanda, NQ 3775/9935.

Numerous doleritic dykes can be seen, with only subordinate pillow lava and hyaloclastite of the lower volcanic member found as screens between the dykes. Dyke margins are fine-grained, with occasional flow-banding. Multiple dykes are abundant, others have intruded along earlier chilled contacts or cross-cut earlier dykes. Dykes with a WNW-ESE trend apparently pre-date more NNW-SSE to NW-SE oriented ones (see also stop 9).

Stop 11. Greenstone ± jasper breccia.

Locality: A 15 m long N-S cliff, 300 m WNW of the western open-pit of the Høydal Mine.

Map-sheet M 711/1521 II Hølanda, NQ 3735/9885.

Greenstone breccias of this type, with or without jasper clasts, are characteristic of the middle volcanic unit. In the north, a few angular jasper fragments up to 20-30 cm across can be seen together with angular to slightly rounded clasts of fine-grained or doleritic metabasalt. Oxidation of fragments and matrix, comparable to that at stop 7, to reddish-brown, hematite-rich rocks can be seen locally. Further south the breccia is composed purely of metabasalt, comprising angular blocks a few centimetres to 20-30 cm across, generally loosely packed in a green, basaltic gravel matrix. A slight variation in the fragment to matrix ratio gives the impression of a very weak layering dipping steeply north. The weak schistosity seen in the matrix probably corresponds to the deformation fabric seen at stop 5, as well as in the breccias at stop 12 and 14 and in the wall-rocks of the Høydal ore; everywhere dipping more gently NNW than the bedding planes.

A poor exposure of a vasskis horizon can be seen in exploration workings some 30 m SE of the locality.

Stop 12. Hølanda porphyrite cutting through deformed greenstones.

Locality: Small exposures on the top of a small hill, 100 m E of stop 11.

Map-sheet M 711/1521 II Hølanda, NQ 3745/9880.

Bluish-grey magnetite-rich pillow lava (altered metabasalt) and greenstone breccia exhibit a pronounced deformational fabric with a schistose matrix and strongly deformed fragments. A NE-oriented dyke of Hølanda porphyrite (of lower Ordovician, probably Llanvirnian age) is cutting obliquely through the deformed greenstones, apparently without any significant deformation of the porphyrite. The thickness of the dyke is approximately 50 m. Near the margin, 1-2 cm tabular plagioclase phenocrysts are generally arranged subparallel to the somewhat irregular contact to the deformed greenstones; behind larger irregularities the orientation of the phenocrysts may also suggest turbulent flow along the dyke margin.

Stop 13 A. Massive sulphide deposit and related feeder-zone mineralization.

Locality: Høydal Mine, western open-pit, 2 km ESE of Løkken.  
Map-sheet M 711/1521 11 Hølonda, NQ 3765/9875.

The ore at Høydal was discovered in 1659. It was worked at intervals until 1911 on two separate orebodies, in underground workings and later in small open pits. The mine is small. Total production has been of the order of 100.000 tonnes averaging 45% S, 1.5% Cu and some zinc, contained in pyrite, chalcopyrite and sphalerite (Grenne et al. 1980). Galena is a minor constituent, but is definitely more abundant than in the Løkken deposit where also the Zn/Cu ratio is considerably lower (Table 2).

In the western open-pit, there appears to be two different levels of stratiform sulphides, separated by a 10 m thick lava (Fig.5). The lower horizon is seen in the western part of the pit, as finely laminated pyrite-chert overlying a jasper bed. To the east, along strike, apparently the same level comprises more massive or vaguely banded pyrite-quartz mineralization, however here the relationships to the upper ore horizon is somewhat unclear due to poor exposure. The upper ore horizon is exposed along the southern wall of the open-pit, as well as in the extreme west where the massive pyrite-sphalerite-chalcopyrite ore fingers out into metabasalt breccias. These are strongly albitized locally, but grade into recognizable greenstone (+ jasper) breccias both upwards and along strike. A few metres east along the south wall of the pit, one can see more normal greenstone breccias directly overlying the sulphides. Further east, however, the ore is overlain by a more than 5 m thick jasper, with local sulphide-jasper breccias along the contact.

The stratiform sulphides are underlain by a deep, fairly well-defined feeder-zone (although it is more irregular than the Løkken feeder-zone), comprising sulphide disseminations and veining (Grenne 1981 and in prep.). The zone can be followed continuously in drill-holes and exploration workings, more than 300

m into the stratigraphically underlying greenstones, trending SW-NE (Fig.5) with a gentle NW dip. The feeder-zone was partly worked in the western Høydal Mine, and is thus very well exposed in the northern wall of the open pit. Typically it contains relatively coarse-grained pyrite as networks of veins up to a few centimetres across or as individual thicker veins and irregular lenses, as well as disseminations. The veins sometimes follow primary volcanic structures in the wall-rocks, like pillow rims, pillow cooling joints etc. Vesicles are filled with pyrite and quartz. The feeder-zone is clearly cutting through the lower horizon of jasper and banded pyrite-chert, as well as the overlying intra-sulphide metabasalt, and the jasper is almost completely bleached with only a few small, red hematite-bearing patches preserved. Pyrite-quartz vein networks also cross-cut parts of the upper ore horizon, to which they are genetically related, as seen in the extreme west of the pit. In the north wall one can also see that the feeder-zone is actually separated into several, thinner and parallel, more strongly mineralized zones; the intersections between these and the bedding plunging to the WNW, similar to the plunge of the Løkken orebody.

The basaltic lavas in and around the feeder-zone are variably altered. Chlorite-albite rich assemblages predominate, with chlorite-quartz alteration only locally in the central parts. In the upper 30-50 m these rocks grade into albite-sericite and quartz-sericite-rich rocks, respectively (Table 1B). Also metabasalt breccias immediately overlying the stratiform sulphides are locally affected by this albite alteration.

Stop 13B. Sedimentary breccia of sulphide-jasper-metasalt.

Locality: Eastern Høydal Mine, 300 m E of stop 13A, and waste dumps below the mine.

Map-sheet M 711/1521 II Hølanda, NQ 3795/9875.

In small open pits (Fig.5) one can see a sedimentary breccia ore composed of sulphides similar to those found in the western Høydal

Mine, together with angular to rounded clasts of red jasper, greyish chert and variably altered metabasalt. The matrix is mainly sulphide, sometimes with some sand-sized jasper fragments, and the larger sulphide clasts are recognizable only where they are more fine-grained and massive than the matrix. The size of the clasts is variable; the largest, quite angular jasper blocks being more than 1 m across. Sorting or size grading is not observed in the deposit, although finer-grained banded sulphides more like those seen in the distal parts of the Løkken ore (stop 5), can occasionally be found on the waste dumps.

The breccia ore is both underlain and overlain by fairly thick jasper beds; these often exhibit a fine lamination more or less disturbed by soft-sediment deformation. Pillow lavas, which are found below the lower of these jasper horizons in the open pit, show no signs of feeder-zone mineralization or alteration. 20-30 m south of the mine, the thick metabasalt breccia overlying the sulphides and jaspers are exposed in a cliff; it can also be seen in blocks in the waste dumps below the mine.

Stop 14. Oxidized metabasalt-jasper breccia, at or close to the Høydal ore level, and overlying metabasalts and vasskis horizons.

Locality: A 120 m traverse from north to south, across a hill 450 m SSE of the small lake Gruvtjønnå, and 500 m ESE of the last stop.

Map-sheet M 711/1521 II Hølonde, NQ 3840/9865 to 3845/9855.

Starting at a small cliff down the hillside north of the peak, one sees a vesicular metabasalt just below (stratigraphically) the metabasalt-jasper breccia. The rock is oxidized (similar to that seen at stop 7) and is rich in hematite, particularly along and outwards from a network of 1-3 cm thick bluish-grey veins. The breccia overlying this altered metabasalt is exposed in a big block and a cliff some metres higher up. At this locality the breccia has suffered strong oxidation similar to the underlying

rocks, and the matrix is stained dark greyish by the high content of hematite. Also the metabasalt clasts are oxidized, although to a variable degree.

The contact between the breccia and the overlying metabasalt is exposed in the cliff to the south. The contact is sharp, with the oxidized breccia apparently being squeezed up between pillow-like structures in the base of the flow. The metabasalt shows no sign of strong oxidation, which thus must have taken place prior to the eruption of the basalt, while the breccia was exposed on the sea-floor. On several exposures at the top of the hill, the basaltic flow is developed as a slightly vesicular, close-packed and fairly thin-rimmed pillow lava. Pillow shapes confirm the inversion of the rocks. An unusually strong accentuation of the radial and concentric jointing of the pillows gives the rock a breccia-like appearance.

Overlying the pillow lava, on the south-eastern slope of the hill, is another metabasalt breccia, here composed of loosely packed bluish-grey to greenish-grey fragments in a more normal greenish matrix. The fragments were probably derived from the oxidized metabasalts lower down. The rock displays a marked tectonic fabric similar to that seen at stop 12. Two thin 'vasskis' horizons separated by a 3 m thick massive flow occur stratigraphically above the breccia. These are seen in small workings on the southern steep slope of the hill, and comprise centimetre-thick pyrite layers along with thin jasper and black magnetite-rich bands.

Stop 15. Greenstone-jasper conglomerate overlying the ophiolite sequence.

Locality: Just NE of the small hill Brandan on Høydalskammen, 400 m SSW of stop 14.

Map-sheet M 711/1521 II Hølanda, NQ 3830/9815.

On large hill-top exposures one can see the basal Lower Hovin greenstone-jasper conglomerate, here with a mixture of large angular to slightly rounded fragments, some of them more than one metre across. The clasts are mainly derived from the upper part of the underlying complex, with slightly vesicular, sometimes almost whole pillows, angular doleritic greenstone fragments, jasper and pinkt chert, and one can also see a block of banded jasper togheter with 'vasskis'. At this locality the conglomerate also contains a high proportion of angular, while felsite fragments, as well as blocks of calcite-rich, volcanite- and jasper-derived sediments. The very irregular structure of some thin green bands of siltstone and sandstone within the conglomerate may have been caused by a syn-depositional, soft-sediment deformation.

100 m to the south, the conglomerate contains a more than 15 m thick greenstone. Pillow structures suggest that it is situated in the normal inverted position, showing way up to the south. It is not clear whether this greenstone represents a basalt flow within the period of conglomerate deposition, or if it is a large slide-block in the conglomerate, although the latter is considered more likely. An E-W striking trondhjemite dyke cuts the conglomerate just S of the greenstone; such rocks have not been observed higher up in the Lower Hovin sedimentary sequence.

Table 1.

A: Representative analyses of volcanic rocks from the Løkken ophiolite fragment.

B: Representative analyses of altered volcanites in the feeder-zones to the Løkken and Høydal deposits. 1: Chlorite-quartz-sulphide rock, central part of the Løkken feeder-zone; 2: Chlorite-albite-epidote rock, peripheral part of the Løkken feeder-zone; 3: Quartz-sericite-pyrite rock, central upper part of the Høydal feeder-zone; 4: Albite-sericite-pyrite) rock, peripheral upper part of Høydal feeder-zone.

Major and trace elements by XRF (analysts B.Nilsen/G.Faye, NGU), except Na<sub>2</sub>O which is analysed by AAS (analyst I.Rømme, Geol.Inst.,NTH) or flame photometry (Table XX B, analysts B.I.Denstad/P.-R.Graff, NGU). Note that Fe<sub>2</sub>O<sub>3</sub> (tot) is total iron (including sulphides) calculated as Fe<sub>2</sub>O<sub>3</sub>.

| A.                                    | Lower volcanic member | Middle volcanic member |       | Upper volcanic member | B.    |       |       |       |
|---------------------------------------|-----------------------|------------------------|-------|-----------------------|-------|-------|-------|-------|
|                                       |                       |                        |       |                       | 1     | 2     | 3     | 4     |
| SiO <sub>2</sub> %                    | 46,46                 | 50,88                  | 45,49 | 46,00                 | 43,11 | 44,57 | 62,69 | 58,38 |
| Al <sub>2</sub> O <sub>3</sub> %      | 13,76                 | 13,16                  | 15,92 | 14,96                 | 13,36 | 15,81 | 9,72  | 15,61 |
| P <sub>2</sub> O <sub>5</sub> %       | 0,13                  | 0,34                   | 0,07  | 0,10                  | 0,11  | 0,10  | 0,11  | 0,14  |
| TiO <sub>2</sub> %                    | 1,67                  | 2,33                   | 1,09  | 1,26                  | 1,54  | 1,31  | 1,47  | 1,24  |
| Fe <sub>2</sub> O <sub>3</sub> (tot)% | 12,30                 | 11,42                  | 8,99  | 10,37                 | 24,11 | 12,77 | 13,67 | 9,31  |
| MnO%                                  | 0,20                  | 0,20                   | 0,17  | 0,16                  | 0,16  | 0,43  | <0,01 | <0,01 |
| MgO%                                  | 6,76                  | 3,45                   | 8,10  | 6,73                  | 8,50  | 10,14 | 0,66  | 0,33  |
| CaO%                                  | 11,53                 | 7,34                   | 12,92 | 9,59                  | 0,37  | 4,26  | 0,22  | 1,19  |
| Na <sub>2</sub> O%                    | 3,21                  | 6,03                   | 2,28  | 4,19                  | 0,30  | 3,28  | 0,35  | 6,98  |
| K <sub>2</sub> O%                     | 0,15                  | 0,19                   | 0,11  | 0,25                  | 0,07  | 0,63  | 2,31  | 1,02  |
| S%                                    | n.a.                  | n.a.                   | n.a.  | n.a.                  | 3,18  | 0,67  | 9,80  | 7,10  |
| Zr ppm                                | 119                   | 191                    | 74    | 78                    | 94    | 90    | 95    | 70    |
| Y ppm                                 | 37                    | 55                     | 23    | 27                    | 26    | 27    | 22    | 27    |
| Sr ppm                                | 216                   | 63                     | 192   | 134                   | 7     | 33    | 24    | 68    |
| Ba ppm                                | 23                    | 80                     | 15    | 48                    | 14    | 109   | 91    | 21    |
| Cr ppm                                | 166                   | 32                     | 562   | 274                   | 351   | 385   | 16    | <5    |
| Ni ppm                                | 49                    | 21                     | 234   | 106                   | 47    | 98    | 15    | 11    |
| Cu ppm                                | 84                    | 31                     | 101   | 45                    | 3200  | 51    | 158   | 40    |
| Zn ppm                                | 86                    | 114                    | 103   | 95                    | 73    | 333   | 107   | 268   |

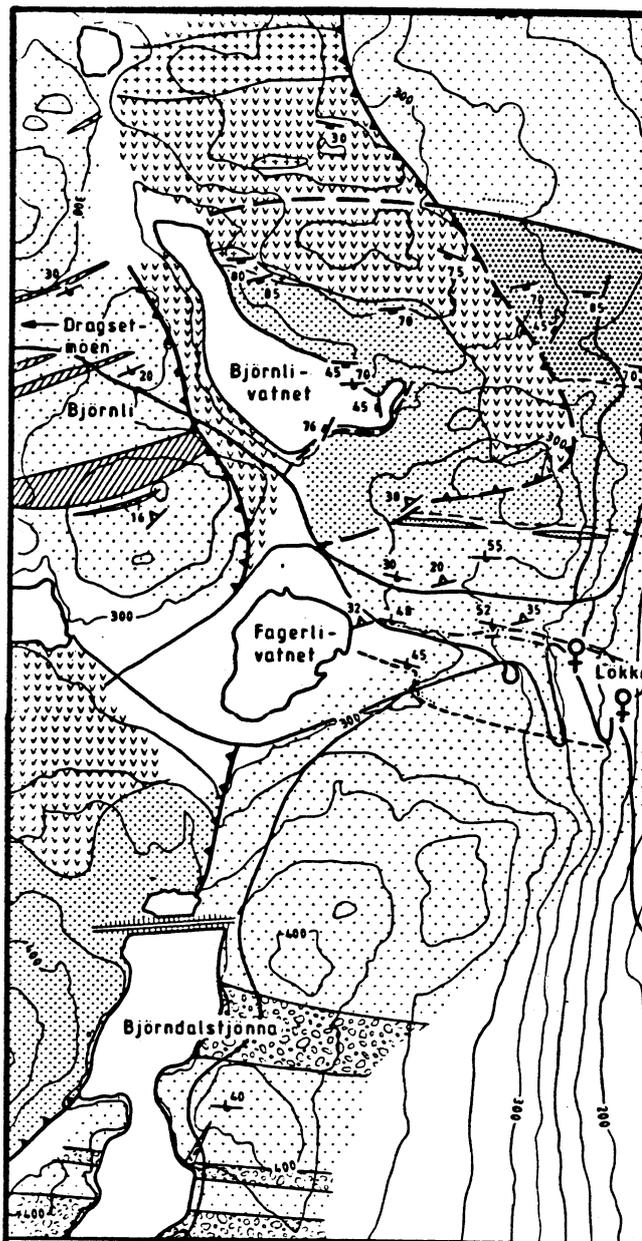
Table 2.

Mean compositions of massive, stratiform sulphide ores and 'vasskis' sulphides from the Løkken area. Løkken Mine data are on a continuous mill head sample (1982 production). Høydal data are based on 63 representative samples, and the 'vasskis' figures are average of 11 samples of sulphide layers from 'vasskis' horizons in various parts of the Løkken area. Dragset data (19 samples) from McQueen (1985). Analyses by AAS, except Au, As, Sb and Se, which are done by instrumental neutron activation (16 selected samples from Høydal). Vasskis Au is analysed by fire assay-AAS.

|    | Løkken  | Høydal  | Dragset | Vasskis |
|----|---------|---------|---------|---------|
| Cu | 2,2%    | 1,7%    | 2.2%    | 220 ppm |
| Zn | 2,4%    | 7.1%    | 2.7%    | 450 ppm |
| Pb | 330 ppm | 840 ppm | 100 ppm | 170 ppm |
| Ag | 18 ppm  | 36 ppm  | 18 ppm  | 1 ppm   |
| Co | 450 ppm | 250 ppm | 210 ppm | 30 ppm  |
| Ni | 30 ppm  | 40 ppm  | 50 ppm  | 120 ppm |
| Cd | 70 ppm  | 210 ppm | 90 ppm  | 2 ppm   |
| Mn | 190 ppm | 120 ppm | 170 ppm | 530 ppm |
| Mo | 50 ppm  | 20 ppm  | n.a.    | n.a.    |
| Au | 200 ppb | 300 ppb | n.a.    | <20 ppb |
| As | 330 ppm | 440 ppm | n.a.    | n.a.    |
| Sb | 5 ppm   | 11 ppm  | n.a.    | n.a.    |
| Se | 70 ppm  | 120 ppm | n.a.    | n.a.    |

Figure captions.

- Fig.1. Geological map of the Løkken-Høydal area, with excursion stops indicated. Contour interval 25 m.
- Fig.2. Schematic stratigraphic column of the Løkken ophiolite fragment. Vertical scale is only approximate, and thickness of individual units is exaggerated.
- Fig.3. Vertical longitudinal, and cross-sections of the Løkken massive sulphide deposit. (From Grenne et al. 1980).
- Fig.4. Sketch from stop 4, showing multiple metadolerite dykes.
- Fig.5. Geological map of the Høydal Mine area. Stippled boundaries are inferred from drill-hole data. Contour interval 2 m.



-  Andesitic porphyrite dyke ('Holonda porphyrite')
-  Trondhjemite dyke
-  Metagreywackes and siltstones
-  Greenstone conglomerate
-  'Vasskis' horizon
-  Jasper horizon / Bedded Fe-Cu-Zn sulphides
-  Breccia of metabasalt ± jasper ± sulphides
-  Intermediate to silicic metavolcanites
-  Alternating pillow metabasalts / sheet flows
-  Metabasalts, predominantly pillowed
-  Sheeted dykes with screens of metabasalt
-  Plagiogranites
-  Metagabbros

0

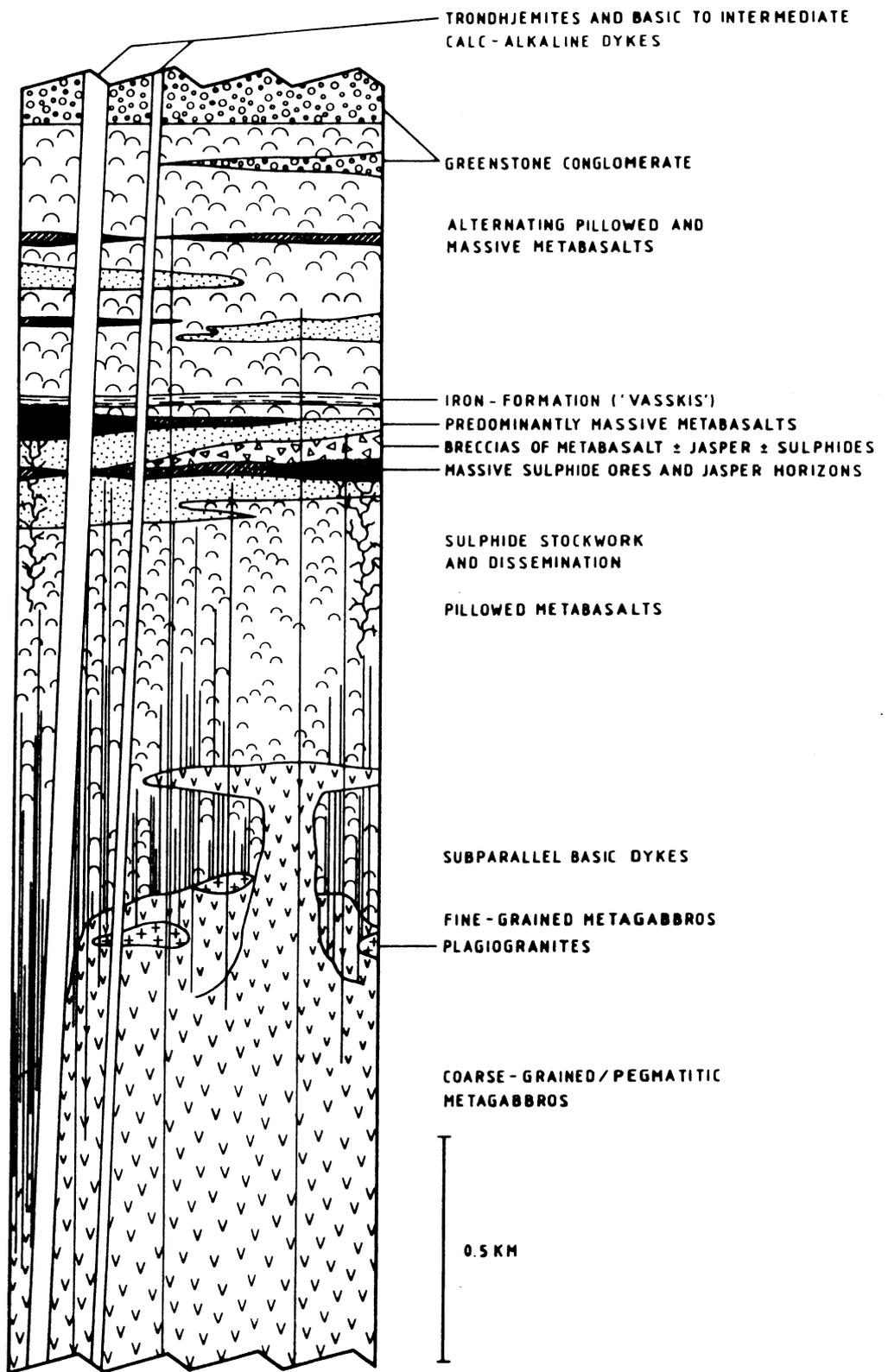


Fig. 2

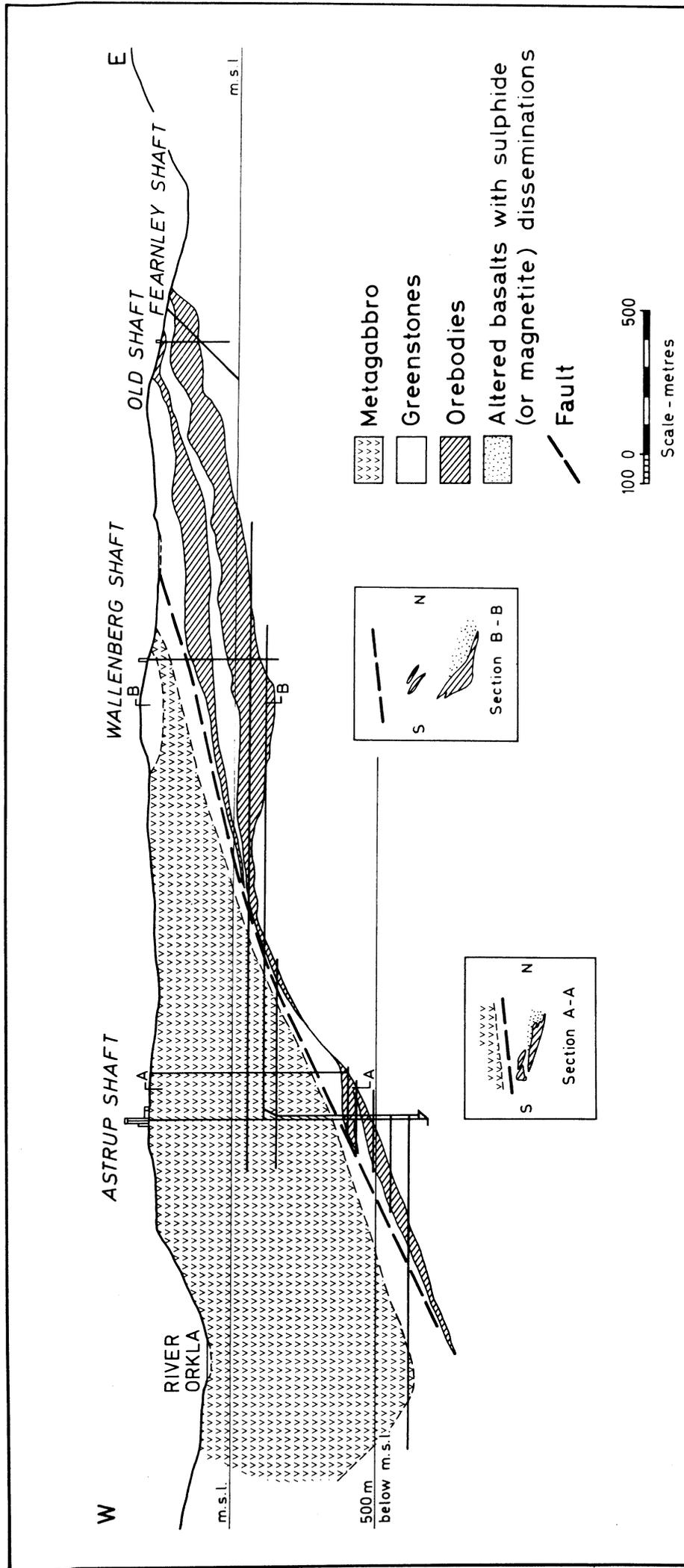


Fig 3

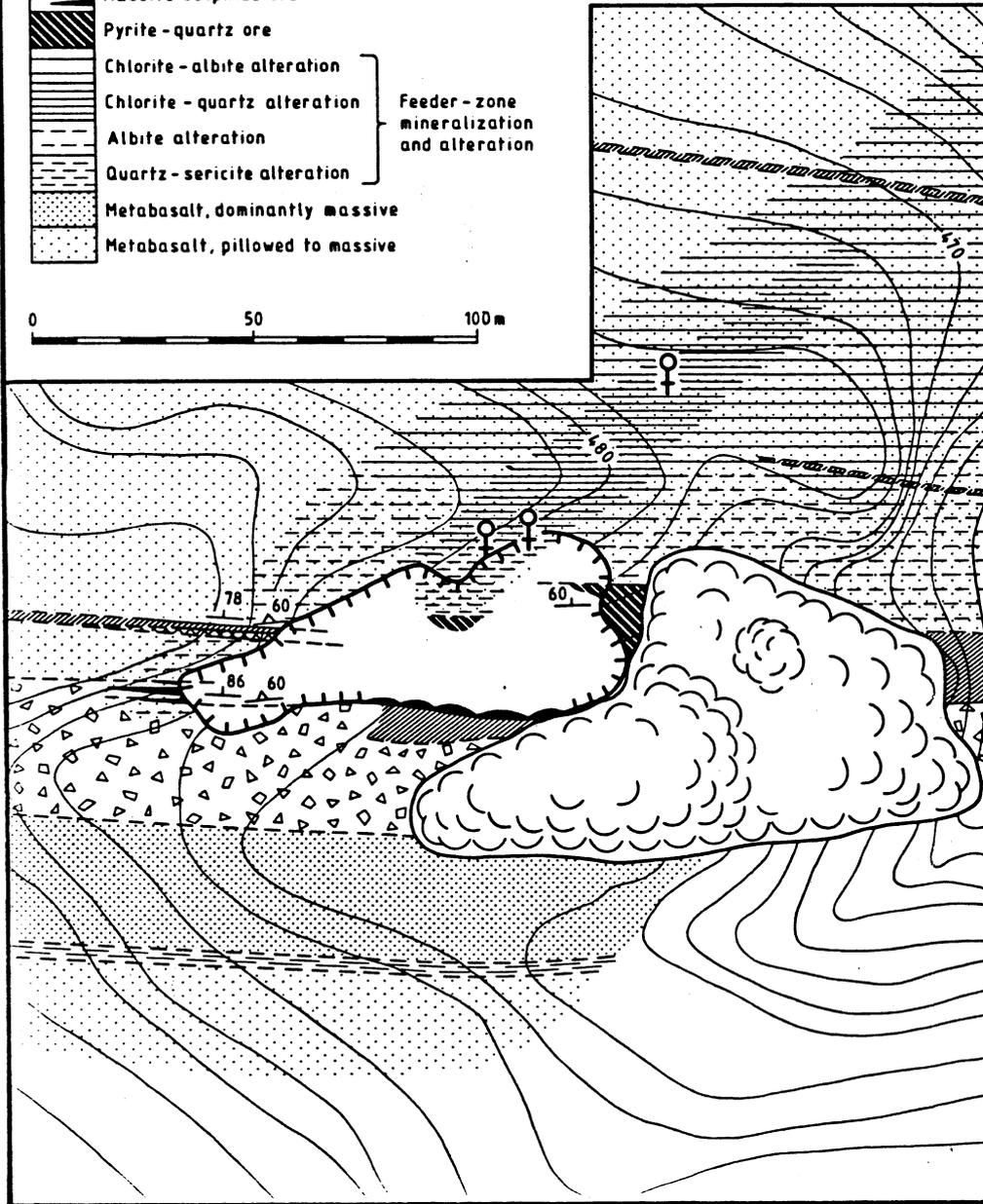
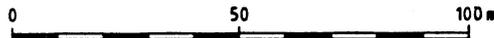


**LEGEND**

-  Iron-formation ('vasskis')
-  Breccia of metabasalt ± jasper
-  Breccia of sulphide ± jasper ± metabasalt
-  Jasper horizon
-  Banded pyrite-bearing chert
-  Massive sulphide ore
-  Pyrite-quartz ore
-  Chlorite-albite alteration
-  Chlorite-quartz alteration
-  Albite alteration
-  Quartz-sericite alteration
-  Metabasalt, dominantly massive
-  Metabasalt, pillowed to massive

Feeder-zone mineralization and alteration

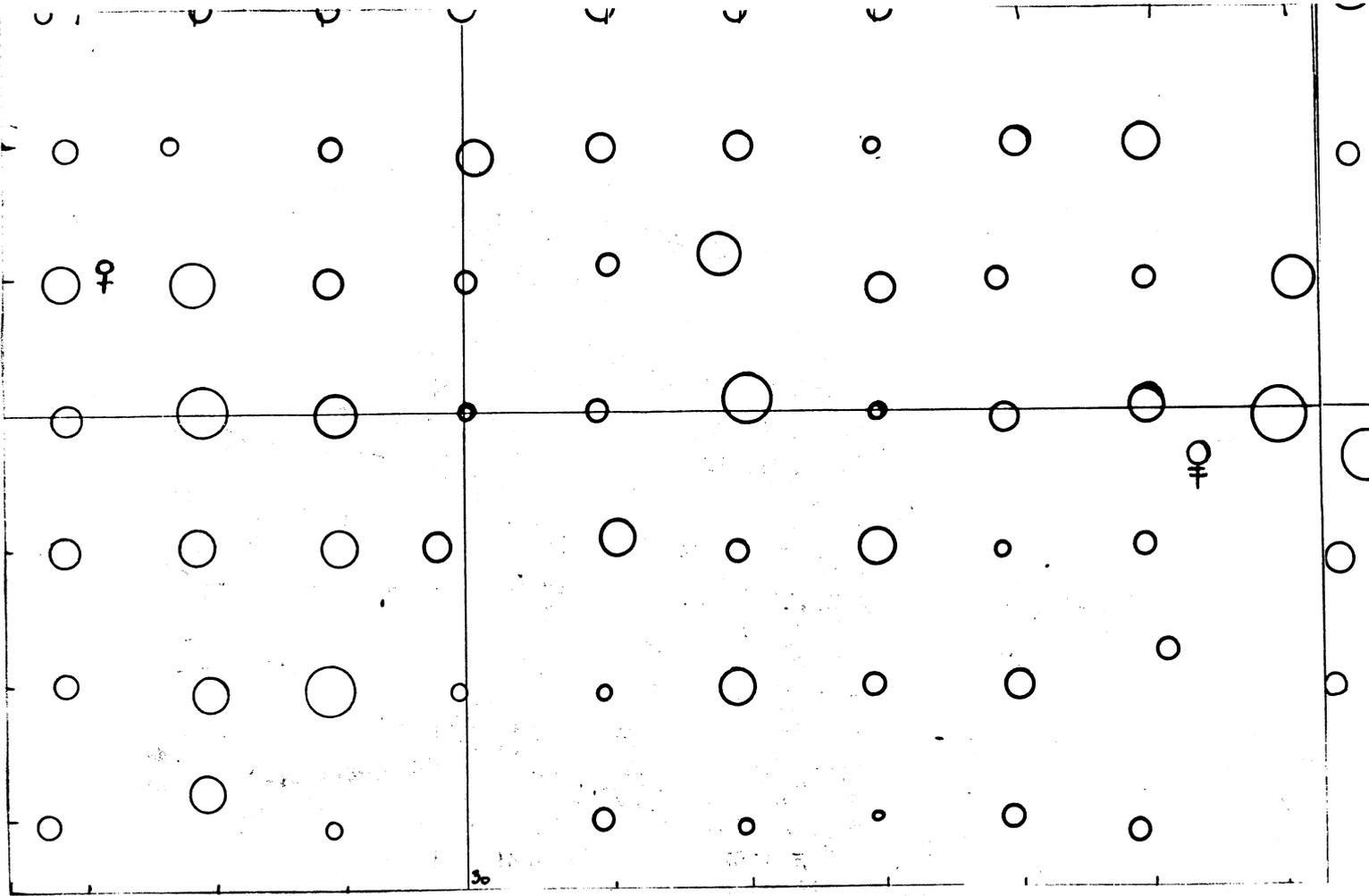
-  60 Strike and dip of layering (inverted)
-  45 Strike and dip of regional schistosity
-  Mine openings
-  Exploration workings
-  Waste dumps





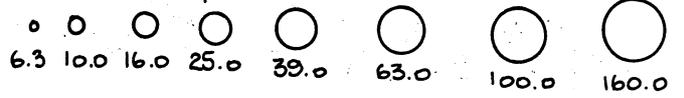
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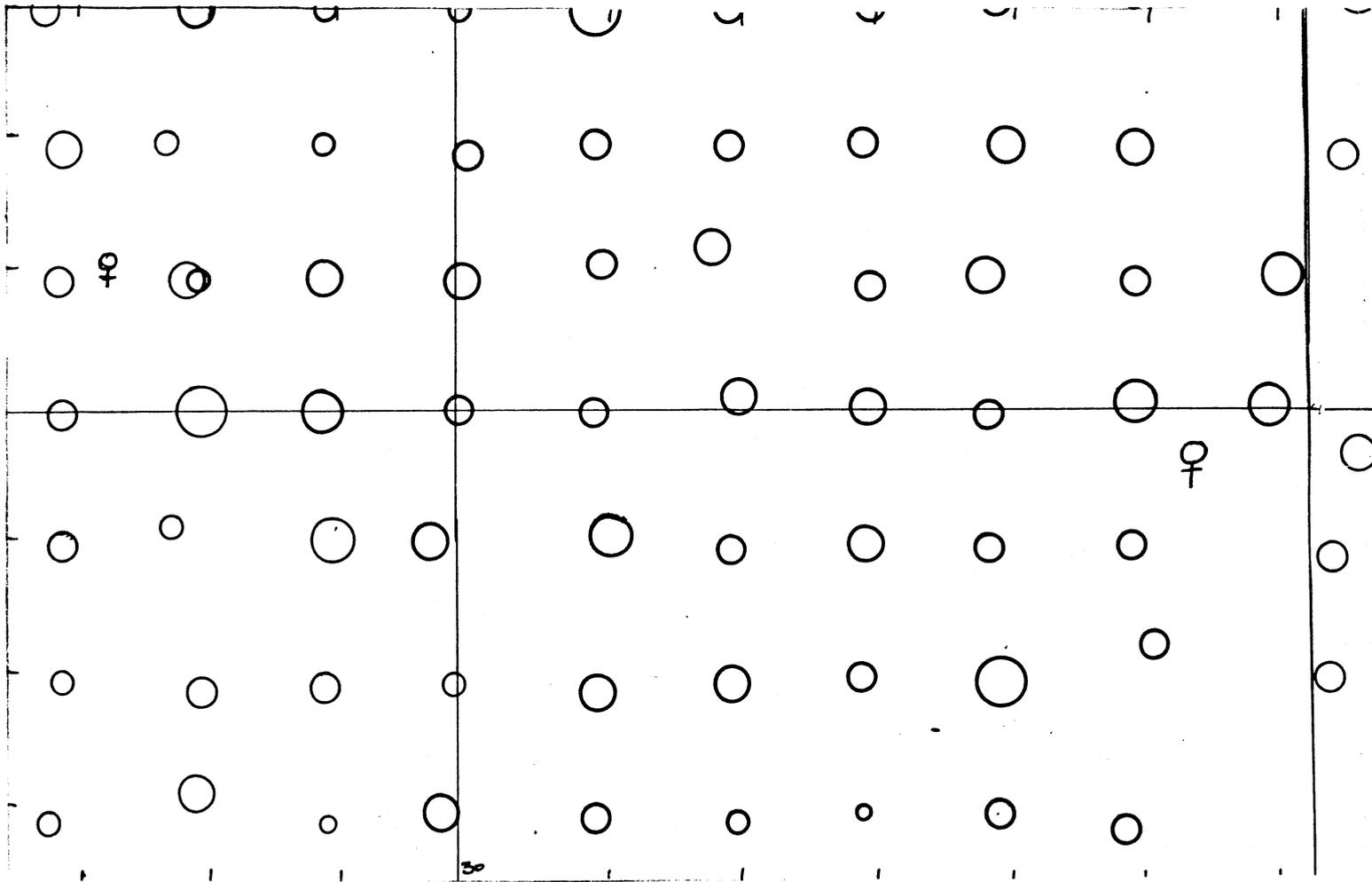
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2. Zn jordprøver
3. Geofysiske bakkemålinger 1928 - 1968
4. Geofysiske bakkemålinger etter 1968
5. Magnetisk totalfelt, helikoptermålinger Dighem 1981
- 5b EM-anomalier HEM og bakkemålinger
6. Geologisk kart
7. Lithogeokjemiske profiler
8. Symbolkart CU
- 9 " Ni
10. " Cr
11. " MnO
12. " As
13. " Cl
14. " Zr
15. Sammenstilt kart Zr/F2g (Ni,Cr)/F2a(Ti,V)/S9(MgO/Cr)
- 16 Symbolkart S2 CaO/Cr
- 17 " S4 Mn/V
- 18 " S5 Mn/Fe
- 19 " S6 Fe/Ti
- 20 " S9 MgO/Cr
- 21 " F3g (S,Cu,(Zn))
- 22 " F3a (Cu,Zn)
- 23 " F3a<sup>X</sup> (Cu, Zn,S)
- 24 Sammenstilt kart F3g,F3a,F3a<sup>X</sup>
- 25 Symbolkart F9a (S,(Fe))
- 26 " F10g (Zn)
- 27 Sammenstilt kart F9a,F10g og Cu - Zn faktor
- 28 Symbolkart F11a (Mn)
- 29 " F1g (Fe,V,Ti,Mn)
- 30 " F2a (V,Ti,Fe)
- 31 " F2g (Cr,Ni)
- 32 Anomalikart 1
- 33 Anomaliekart 2
- 34 Sammenstilt kart Cr,Ni,Zr,MgO/Cr
- 35 Lithogeokjemisk tolkningskart
- 36 Oversikt EM - 37 målinger 1985



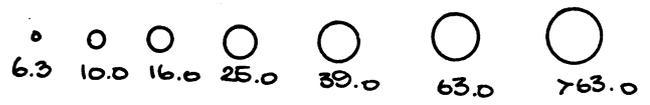
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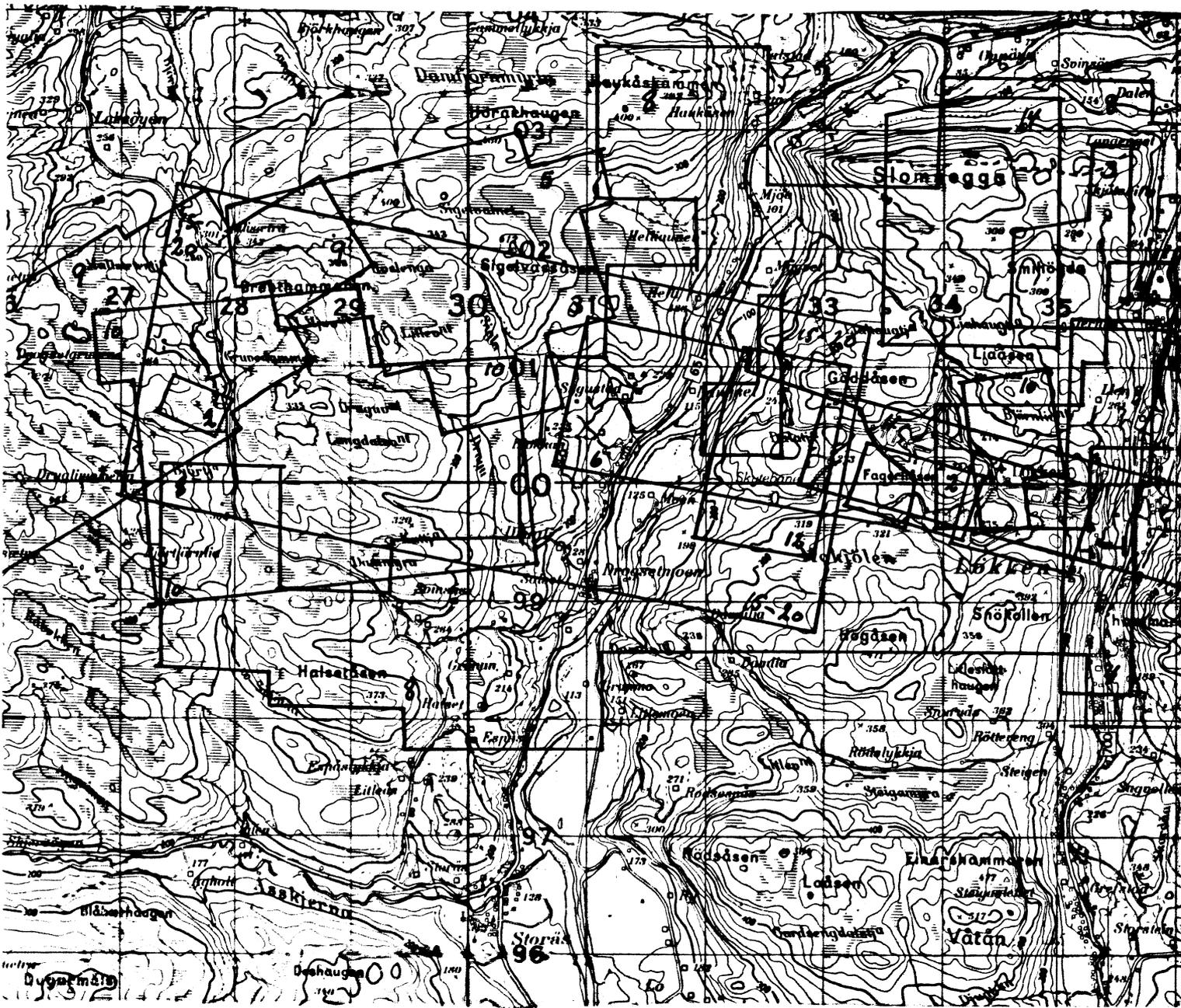
Soil samples

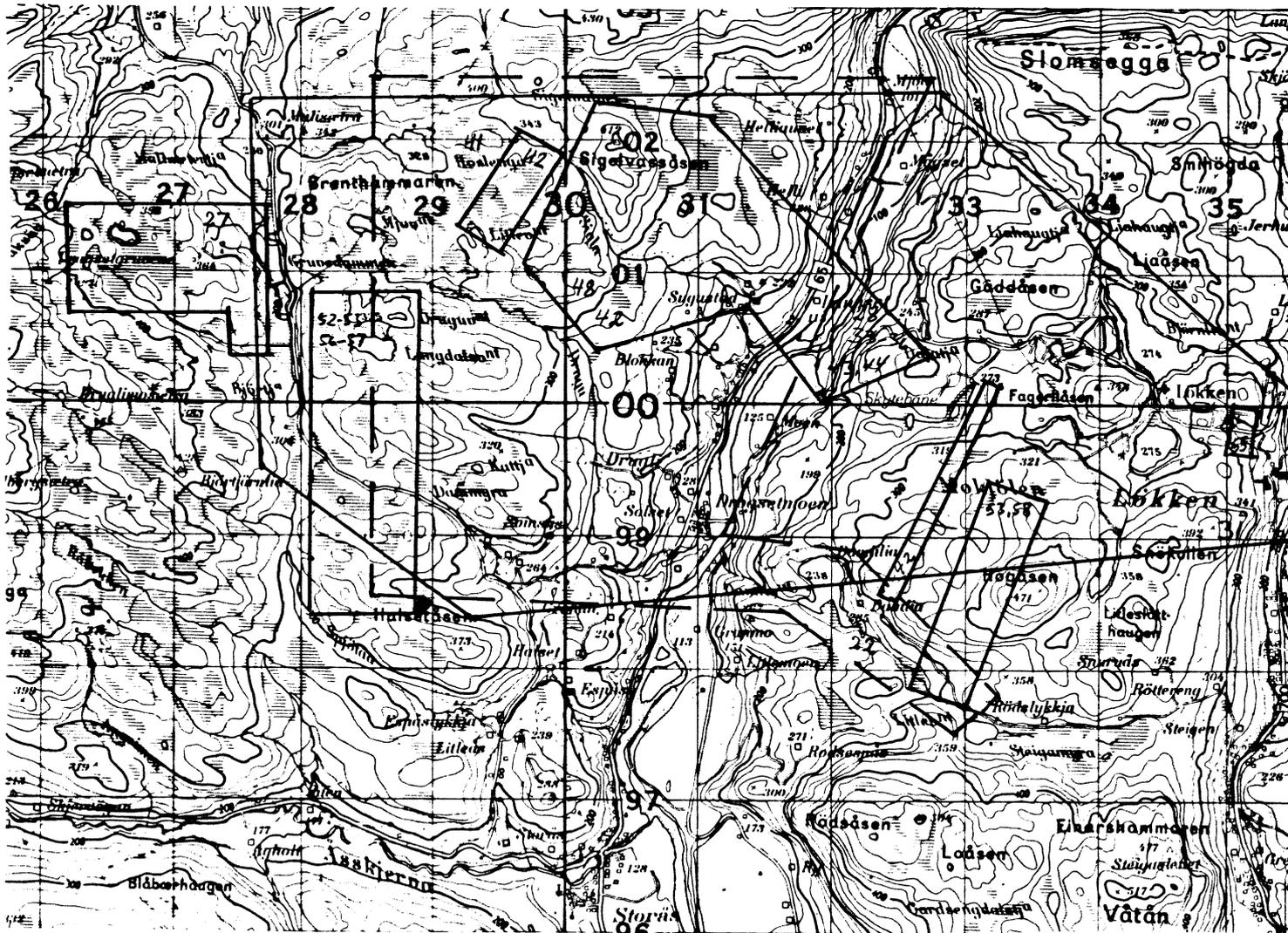


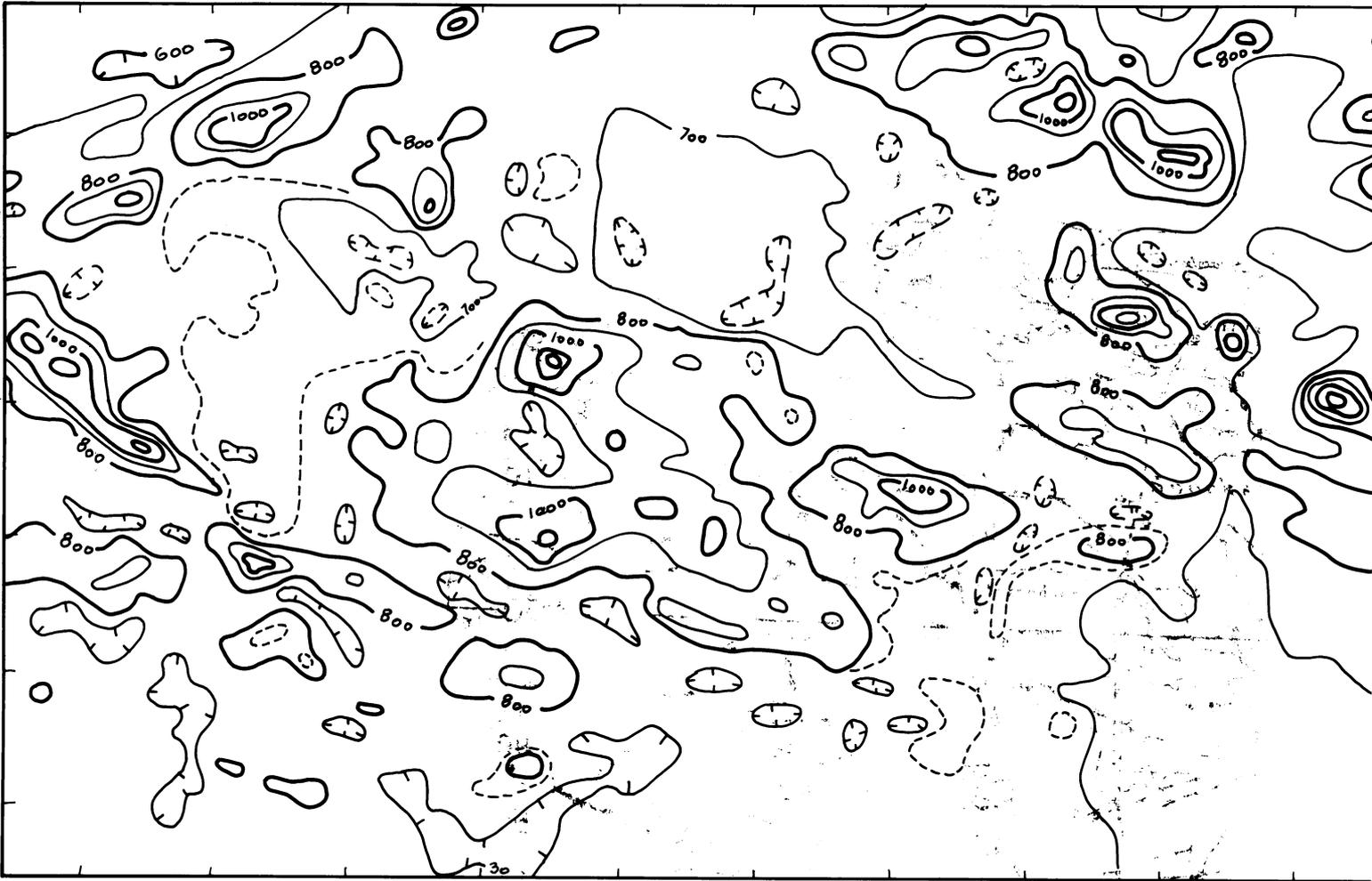


Zn  
soil samples





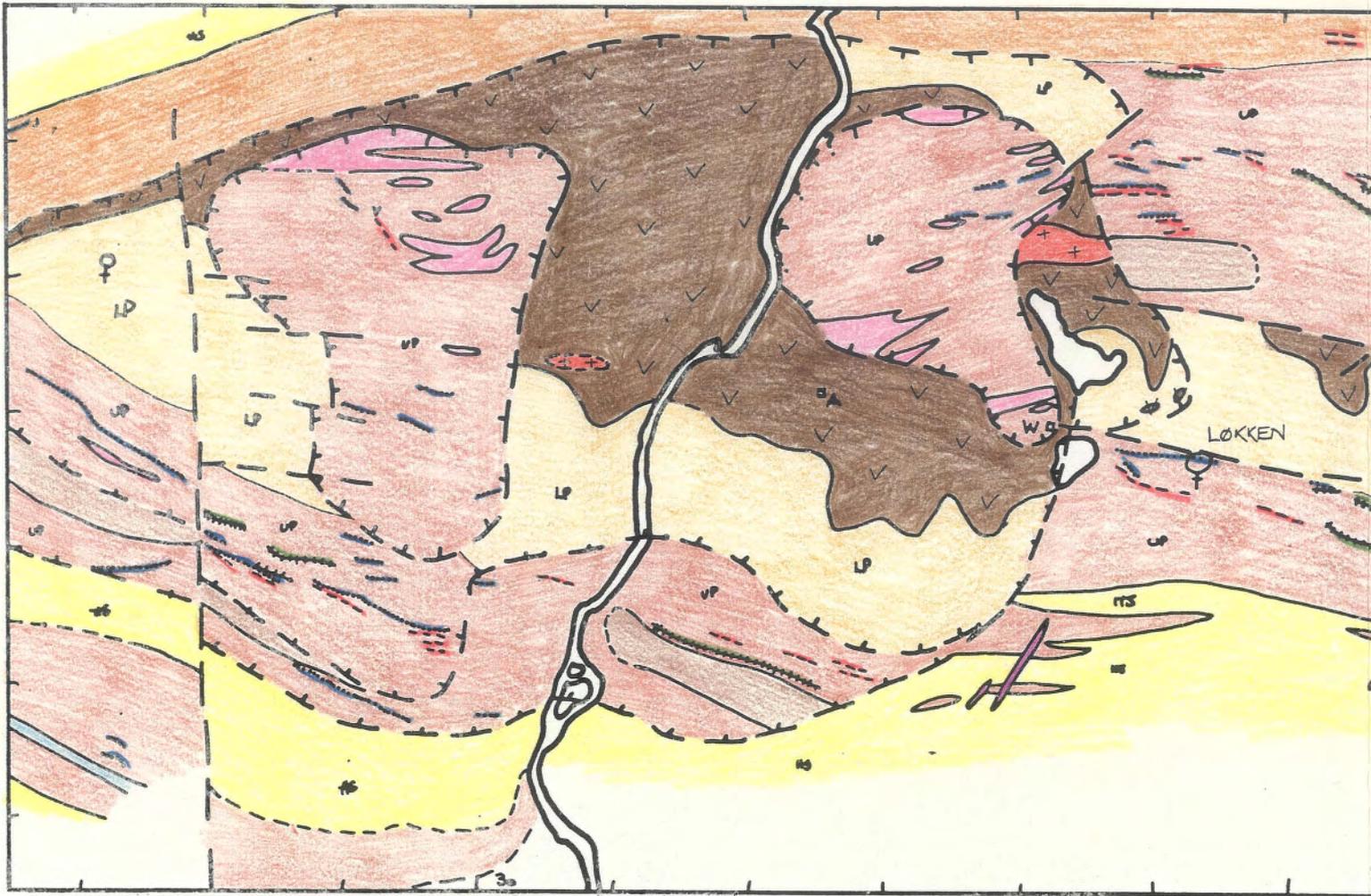




Isometric lines

- 200  $\gamma$
- 100  $\gamma$
- - 50  $\gamma$
- ⊖ magnetic depression

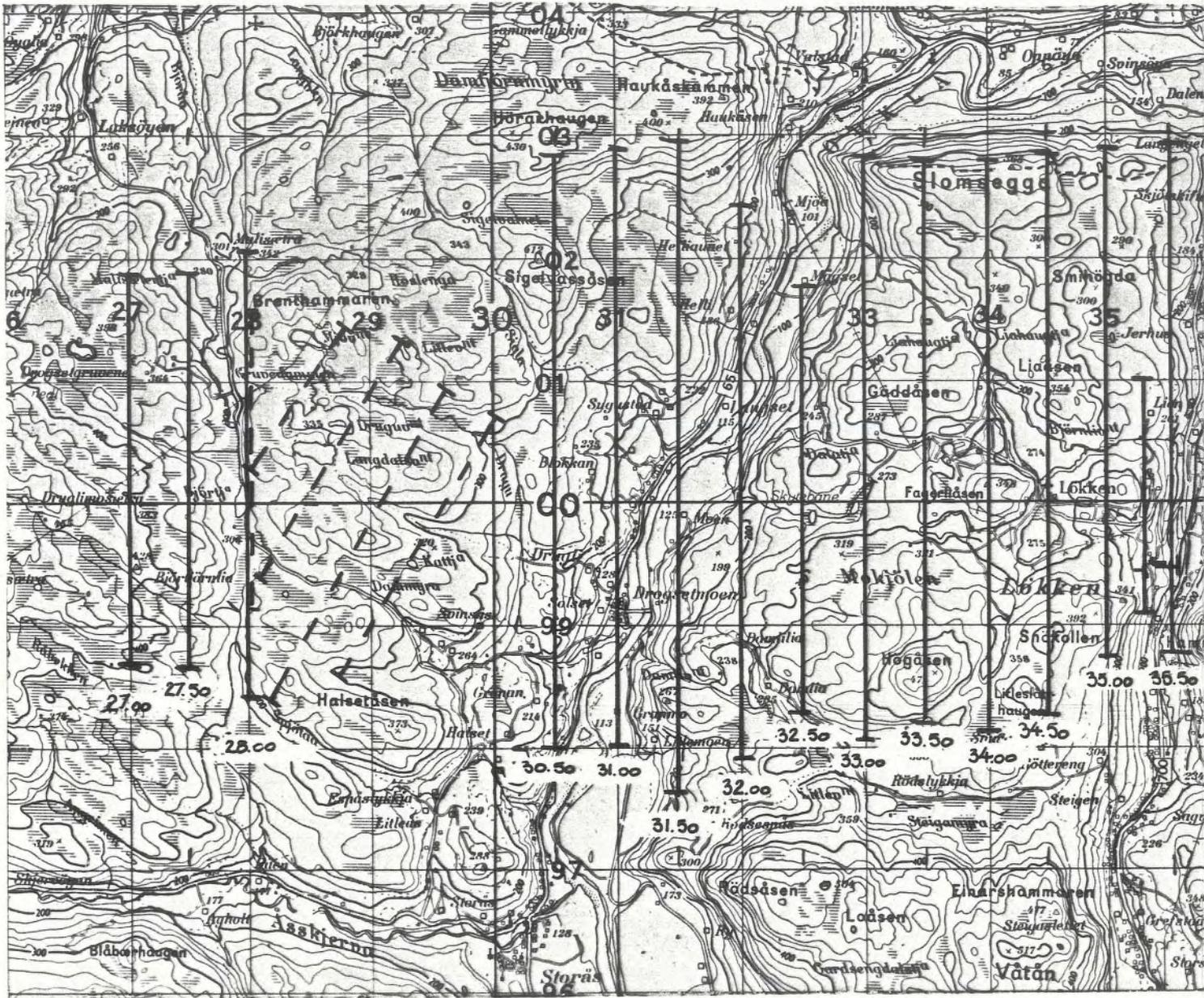




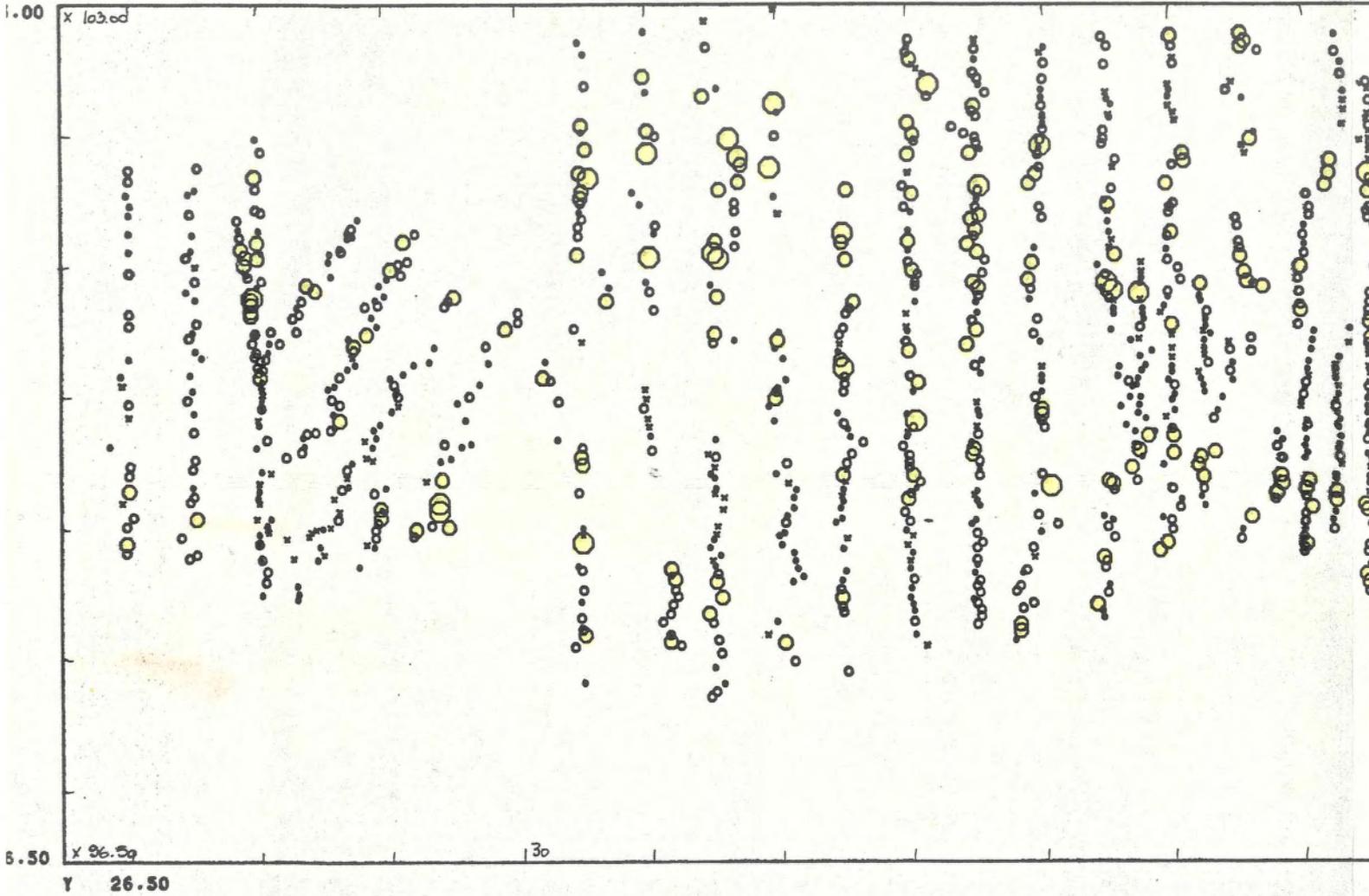
## LEGEND

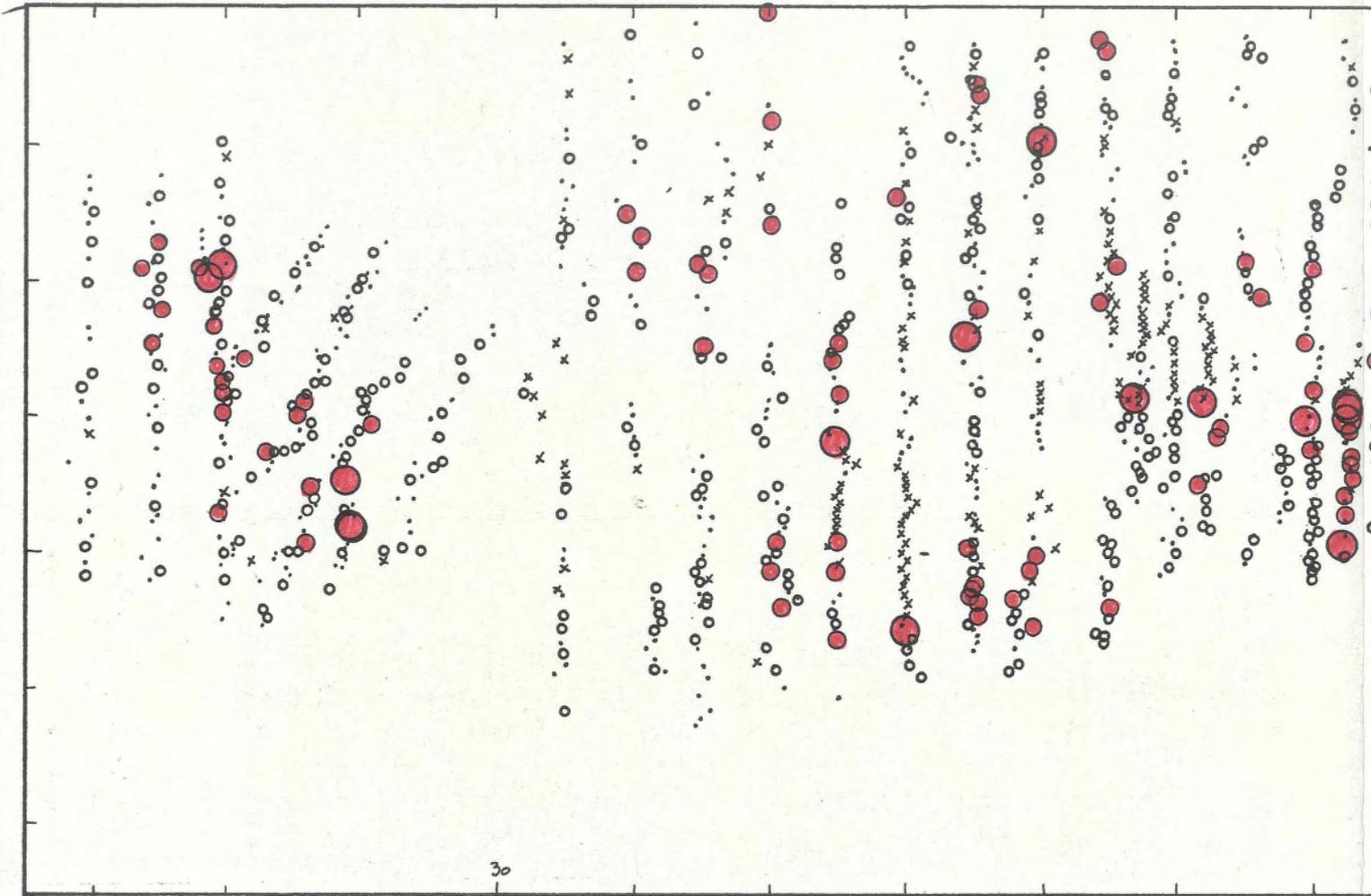
- Porphyrite dyke
- Undifferentiated sediments (Hovin group)
- Limestone
- Undifferentiated greenstones
- Vasskis
- Jasper
- Greenstone breccia

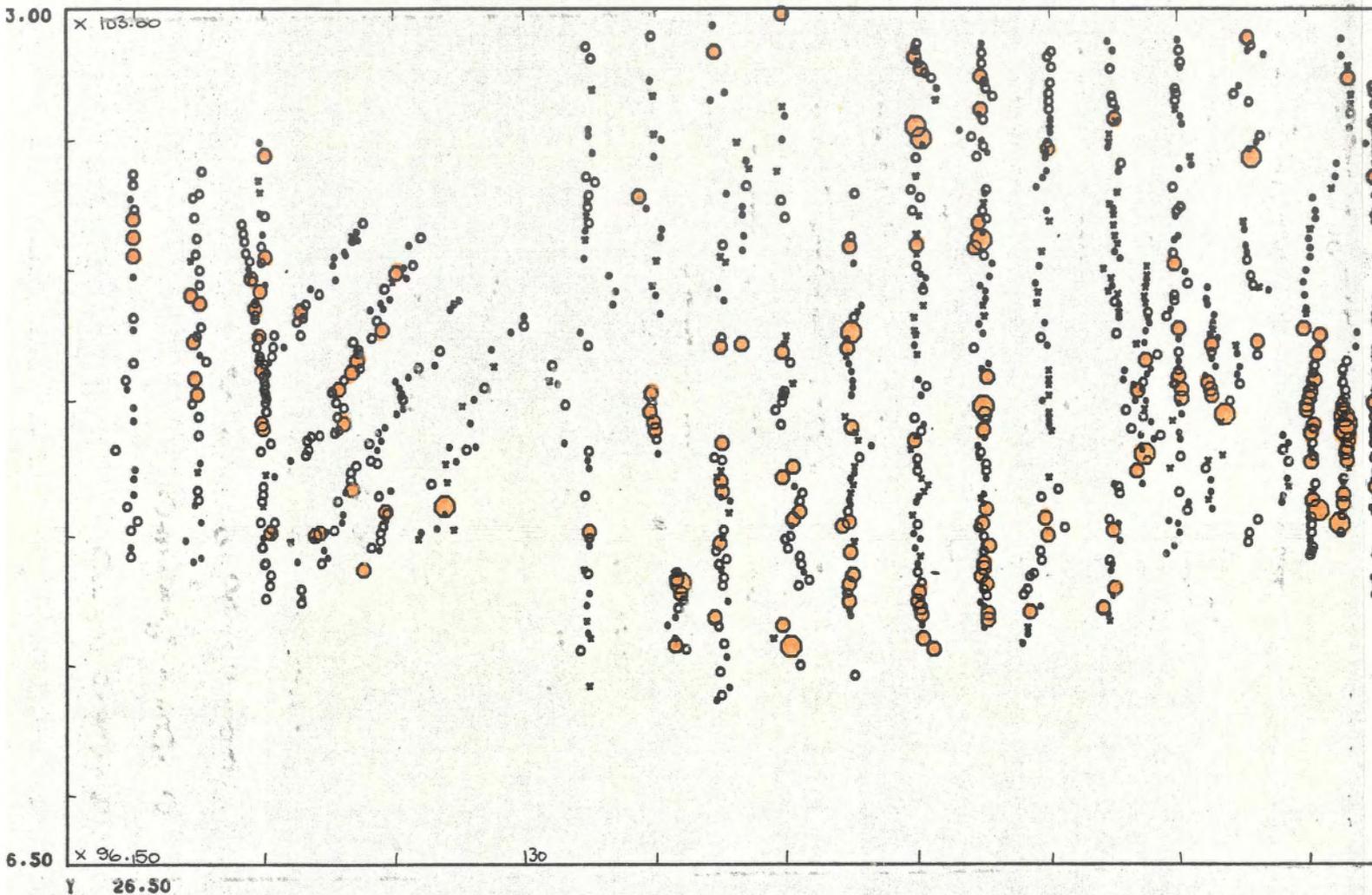
- Acid metavulcanite
- UP Upper pillow lava
- Thick coarse grain
- LP Lower pillowlava
- VV Metagabbro
- + + Plagiogranite





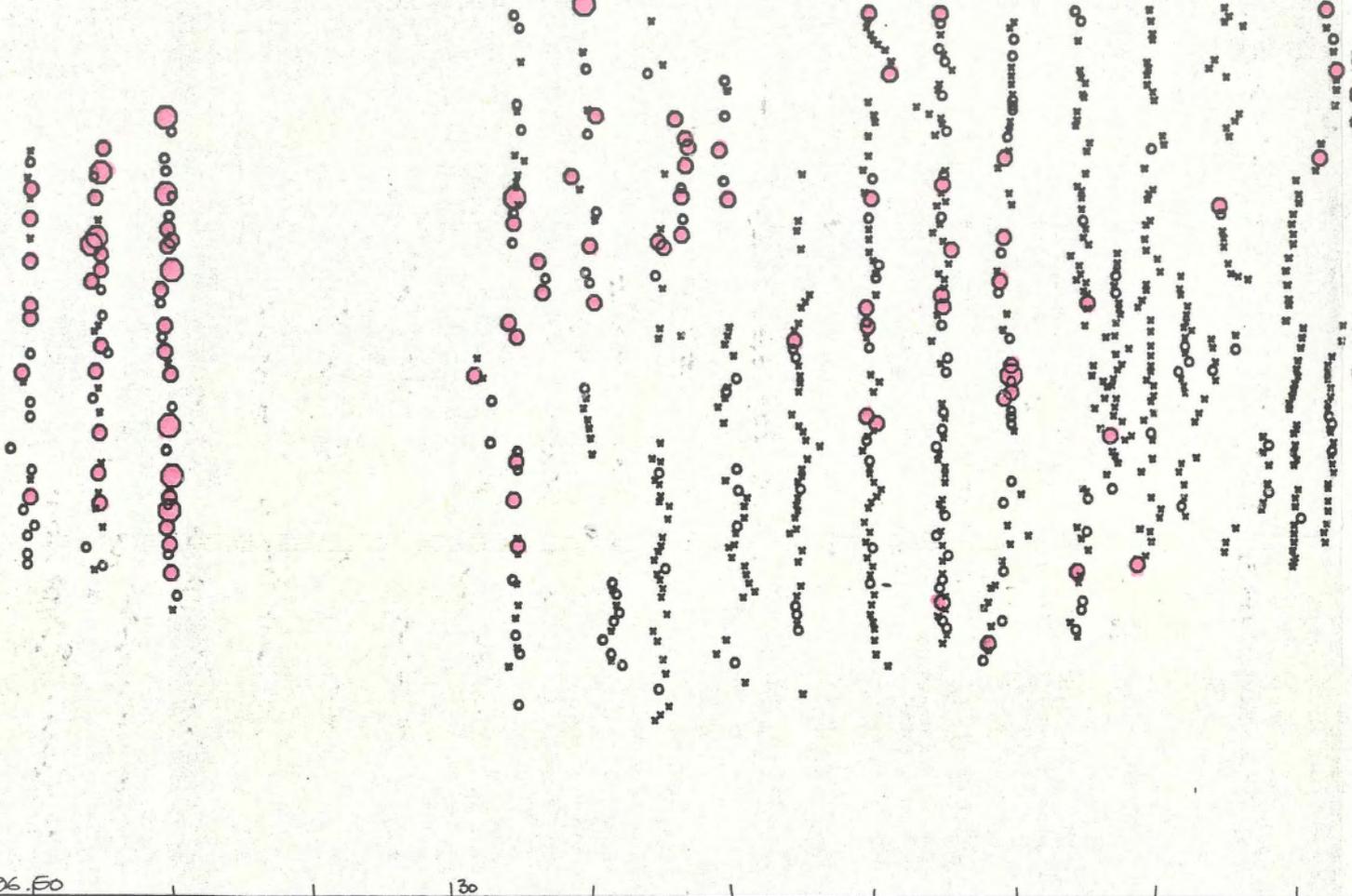






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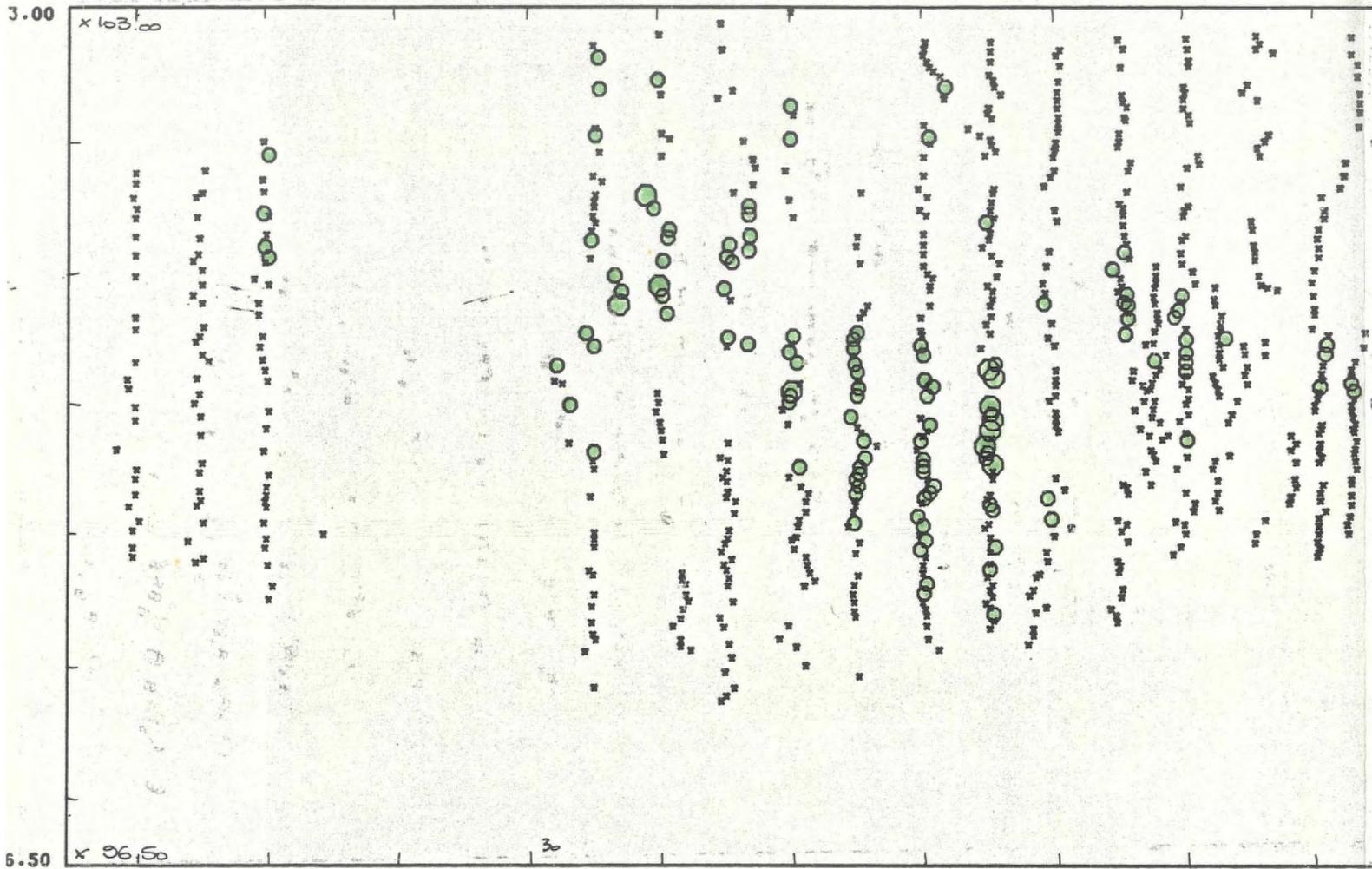
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Y 26.50

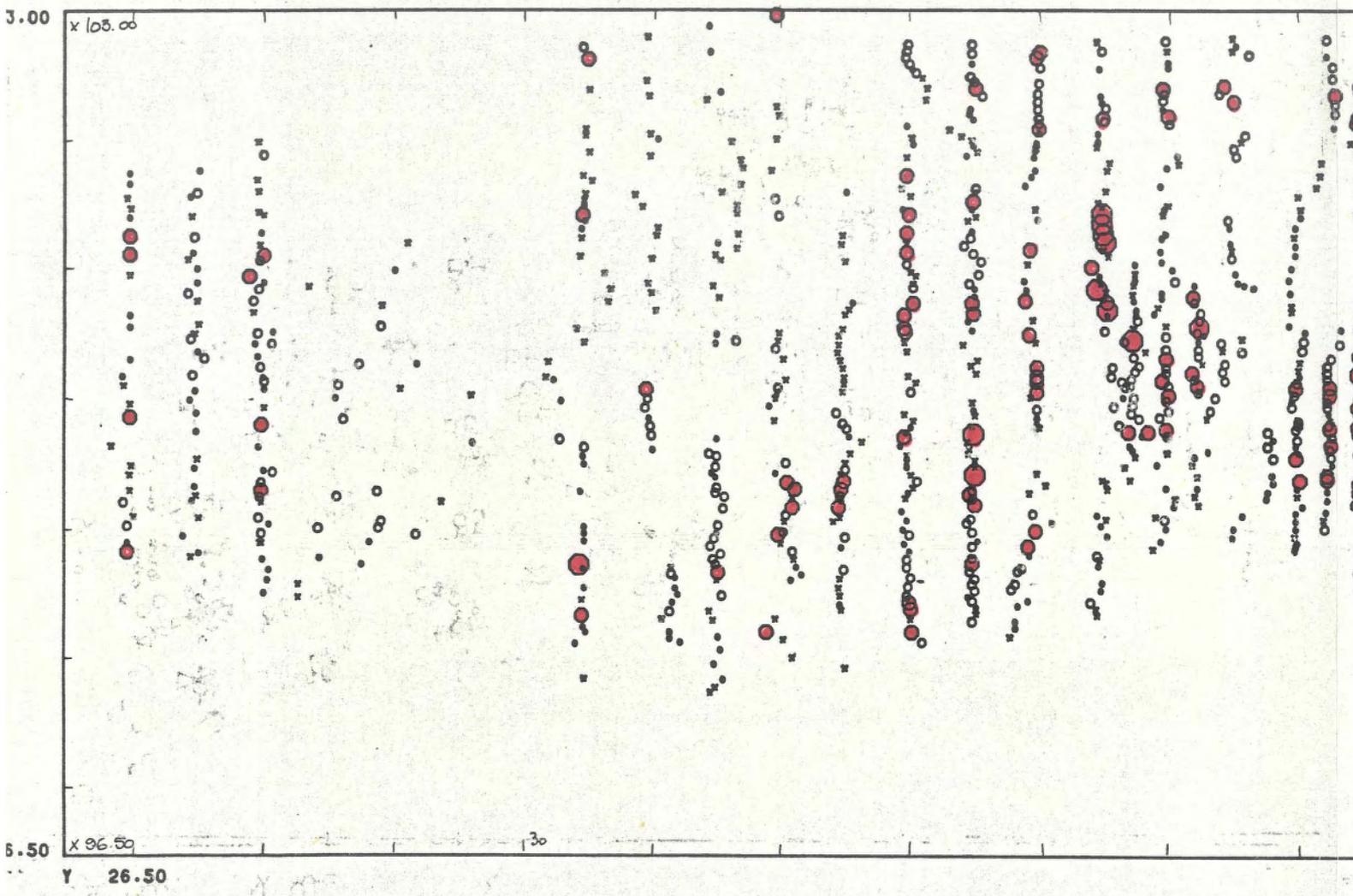
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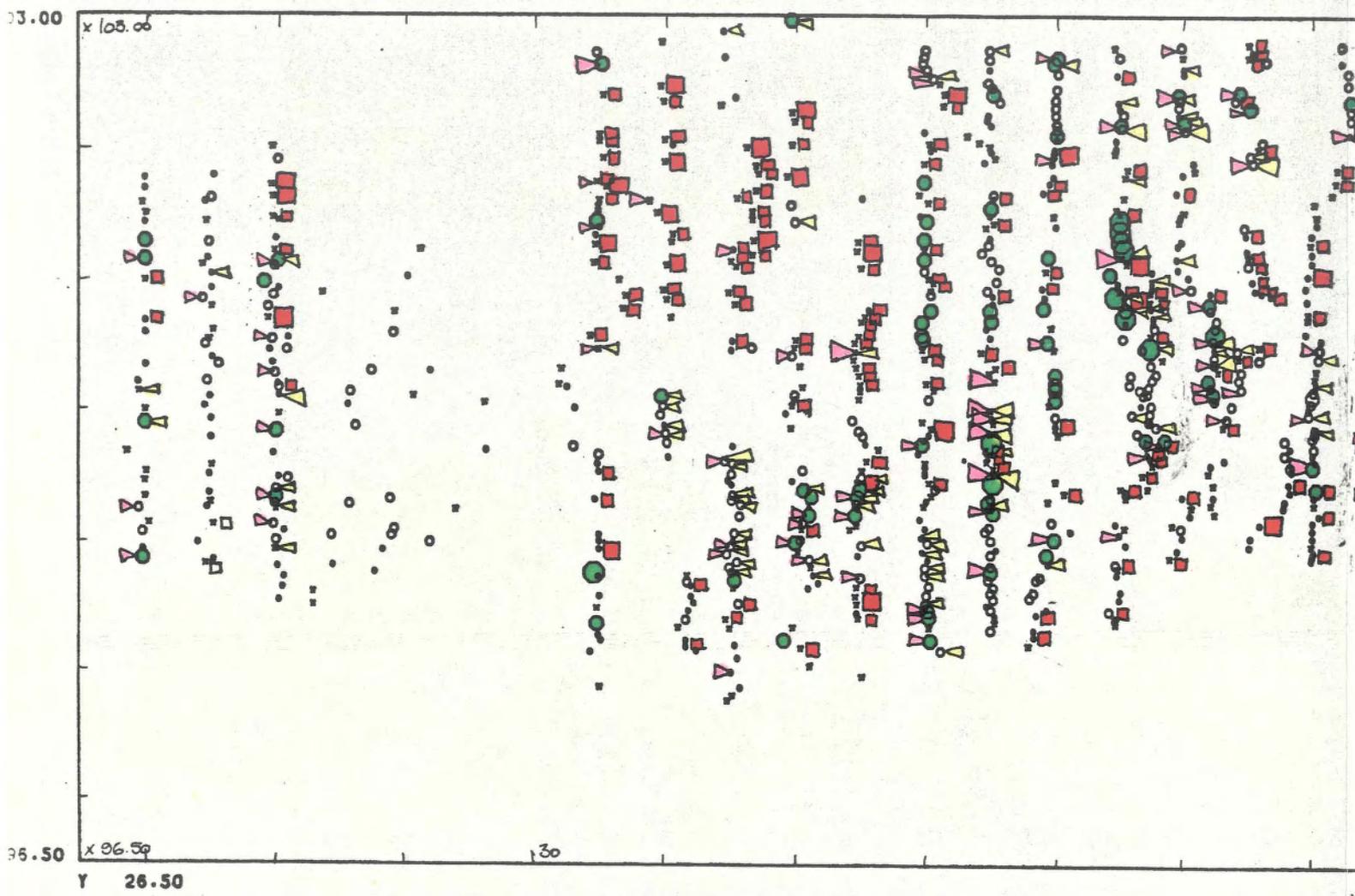


26.50

3

1950



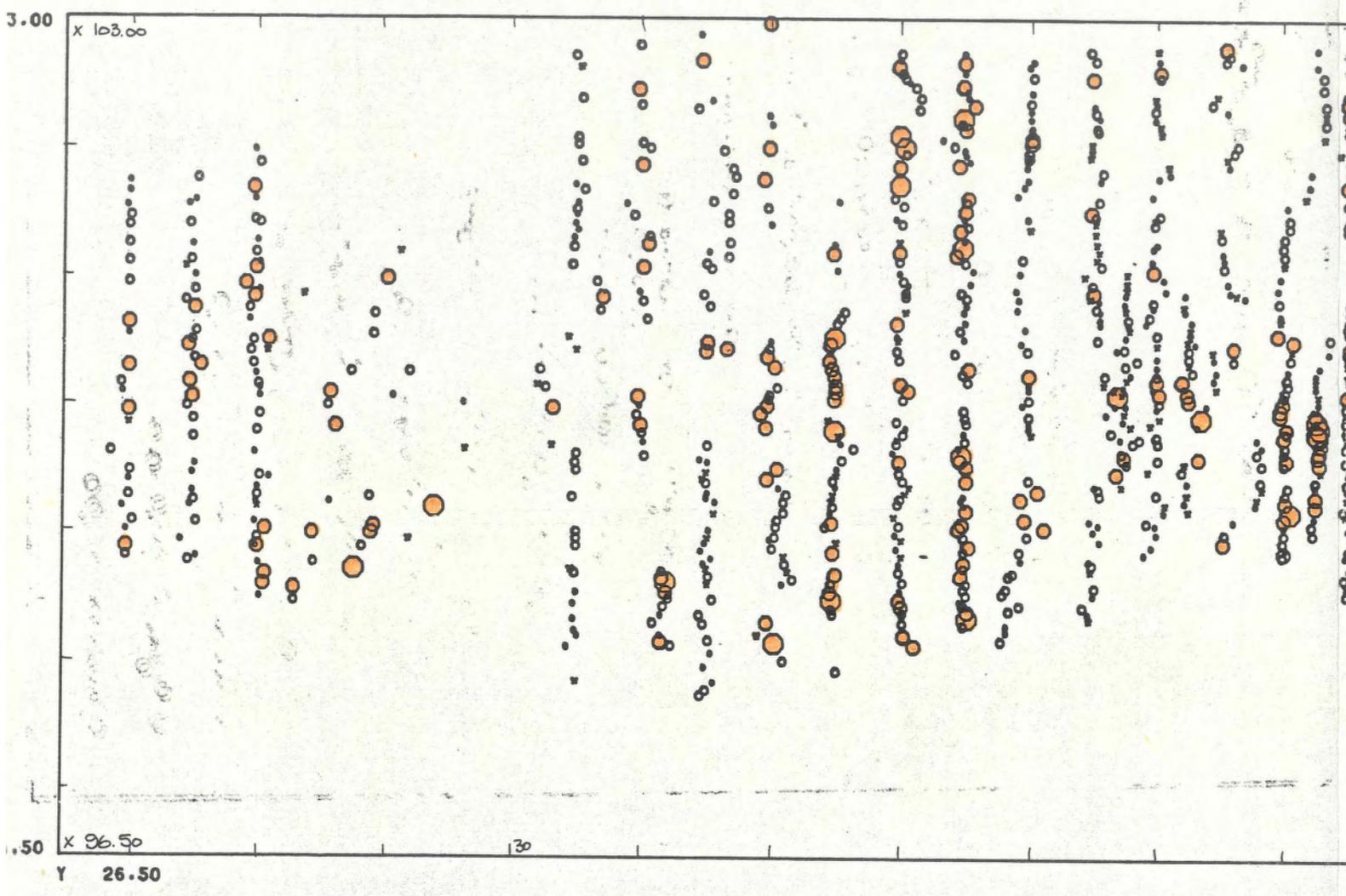


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- F2g (Ni, Cr)
- ▾ F2a (Ti, V)
- ▿ MgO/Cr

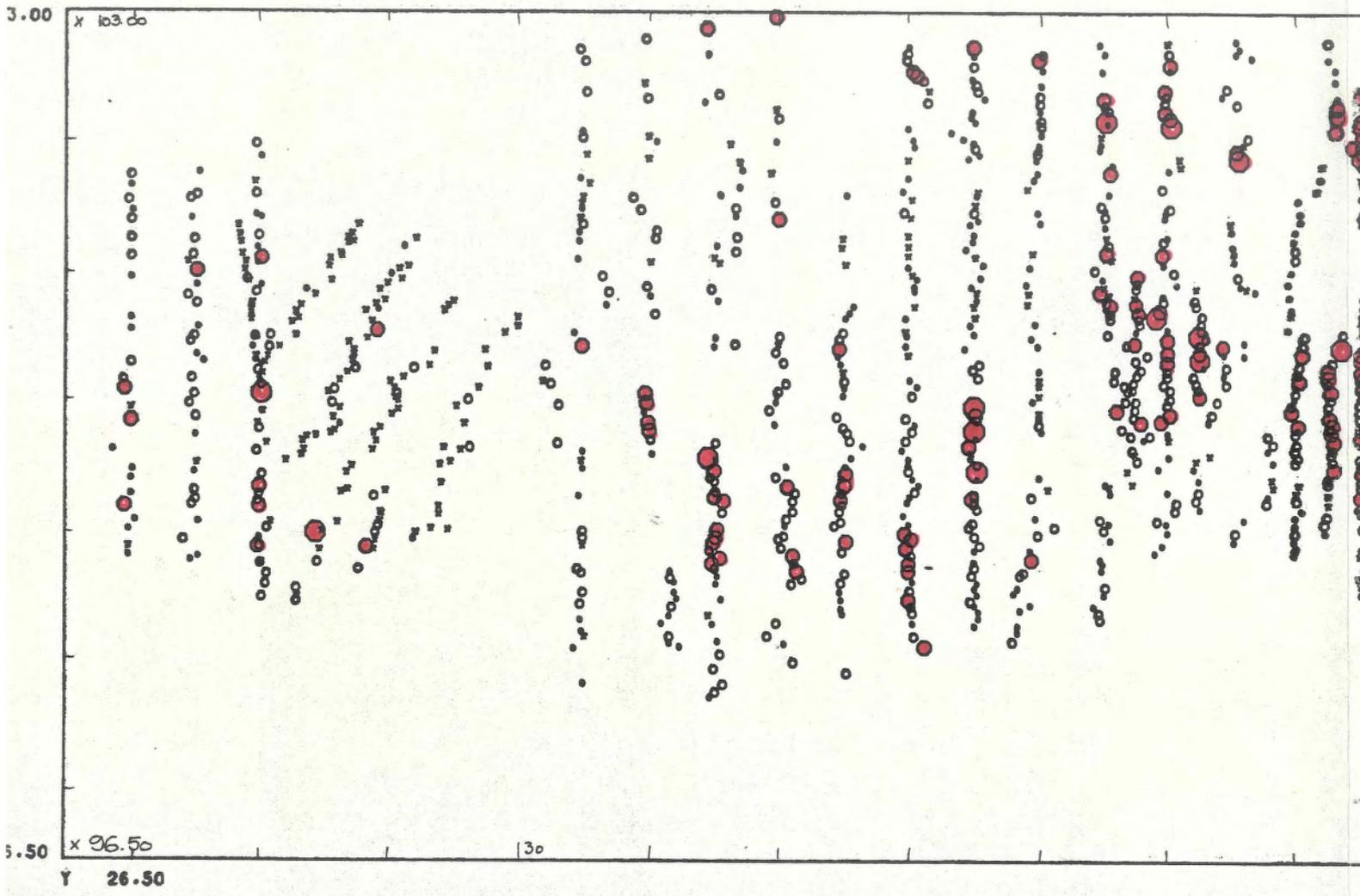


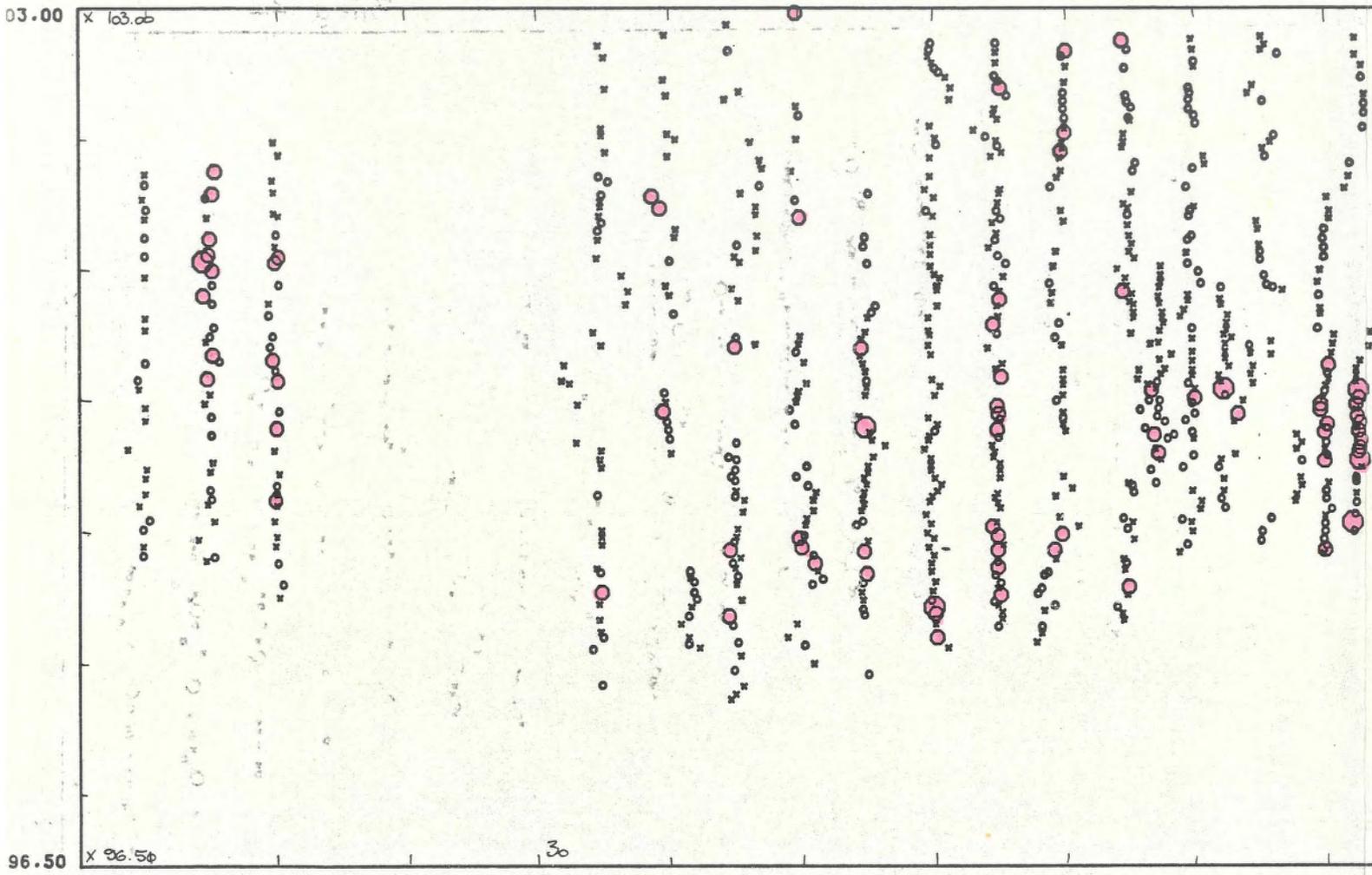


21 2415









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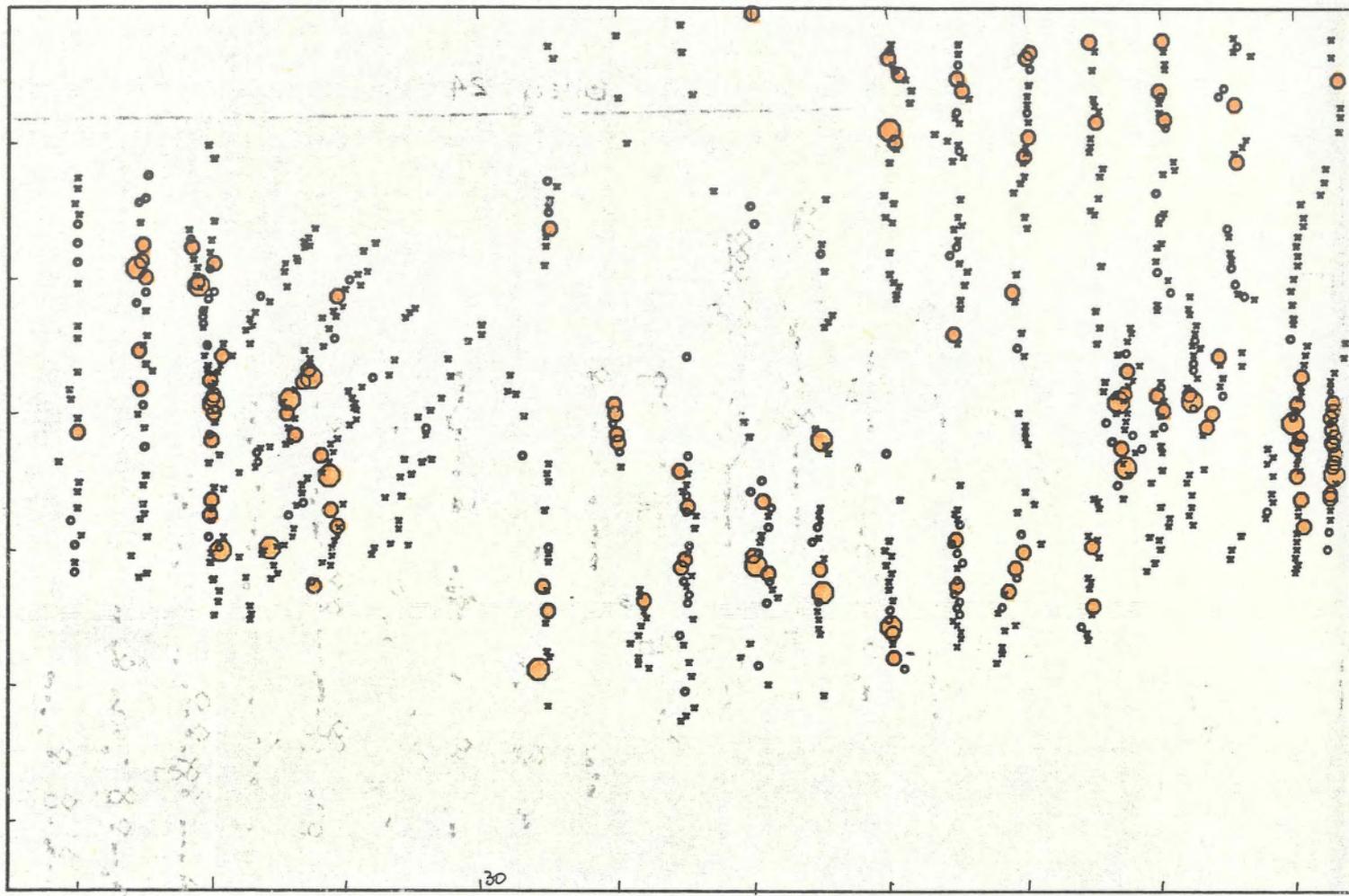
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 100  
 100



13.00

6.50



Y 26.50

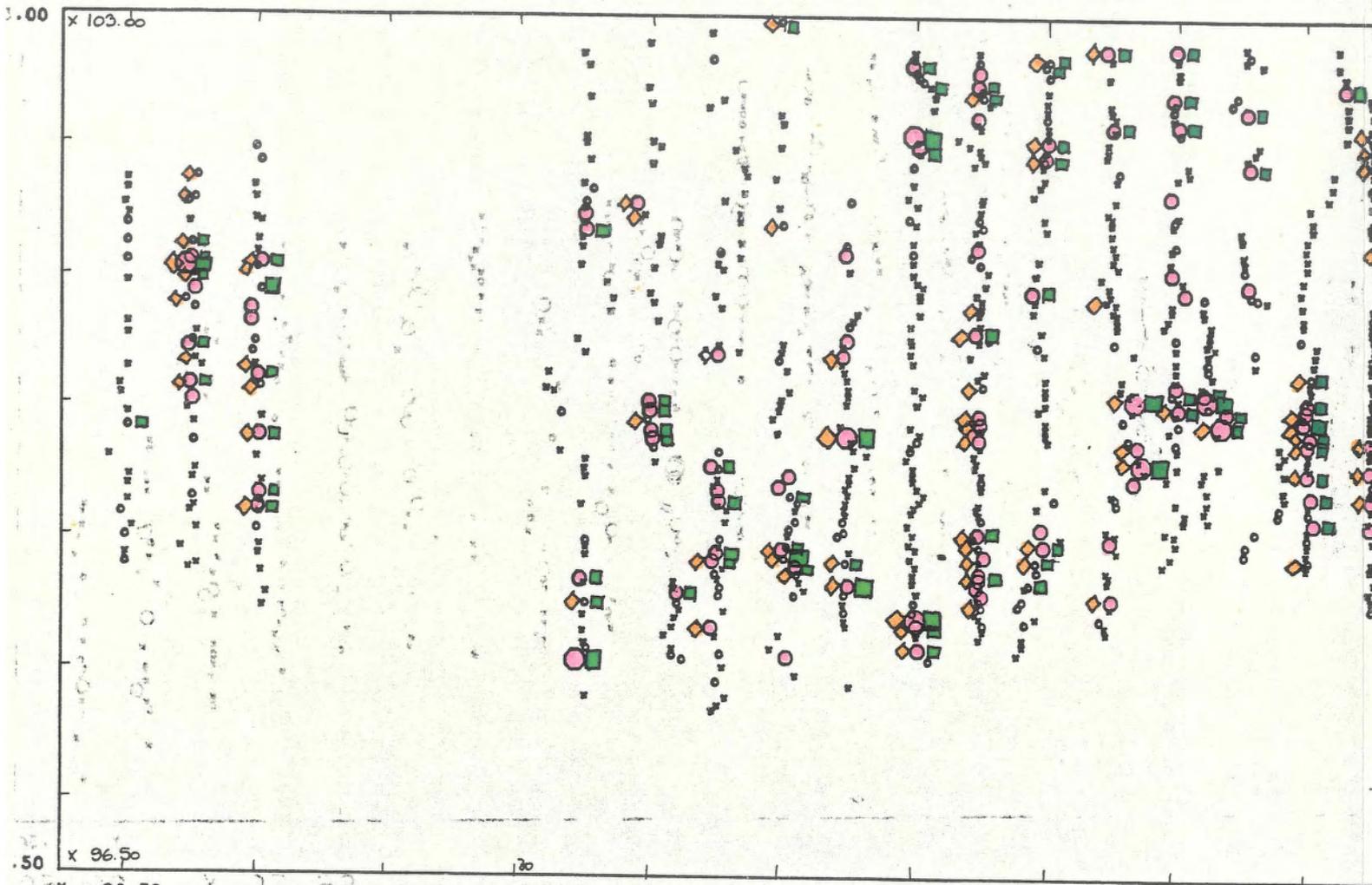
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08.80

0.00

25 0015



50 x 96.50

26.50 Y 30 89

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- F3a\* grønnstein (Cu, Zn, S)
- ◆ F3g (Cu, S)

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 15.0-00.0  
 00.0

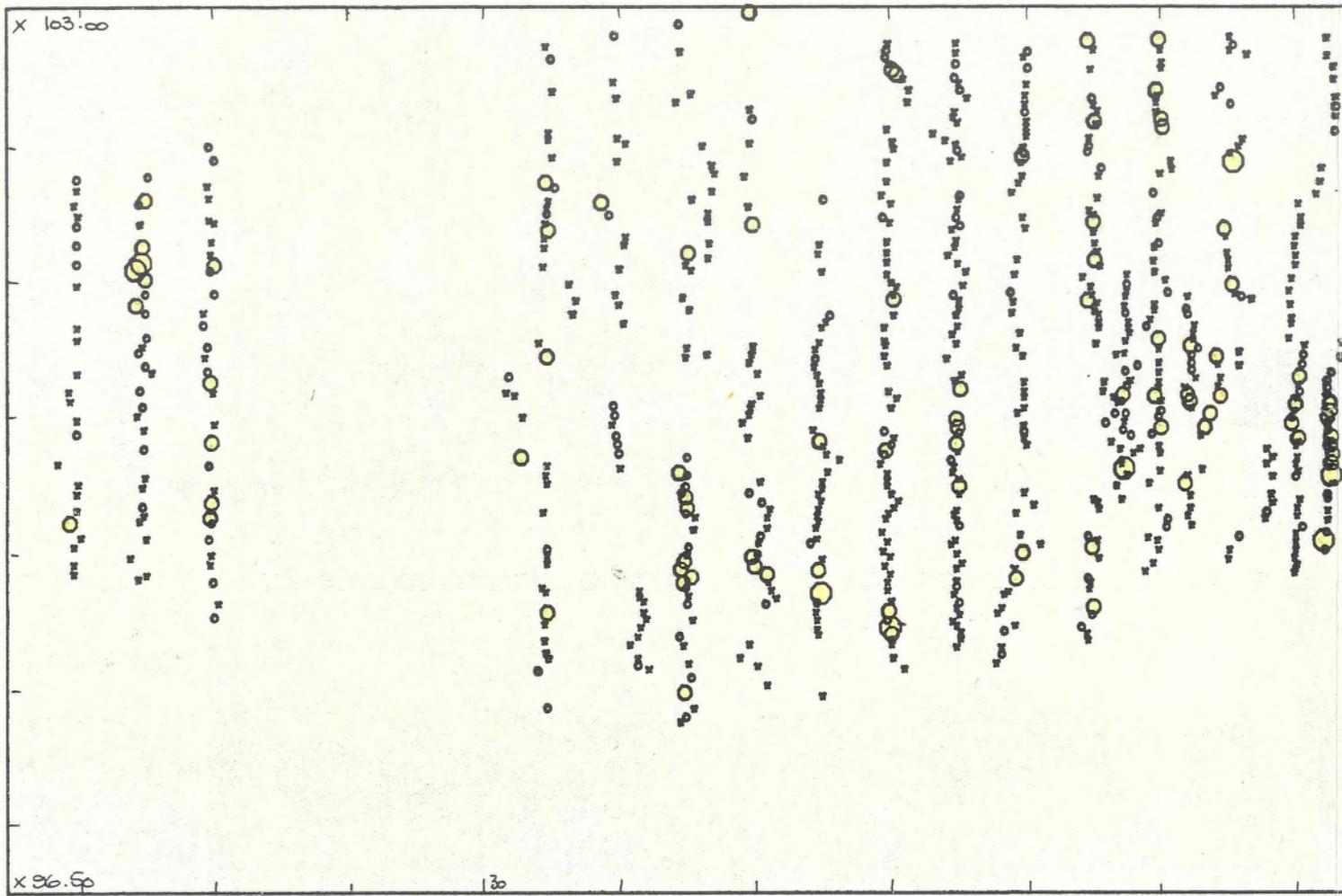
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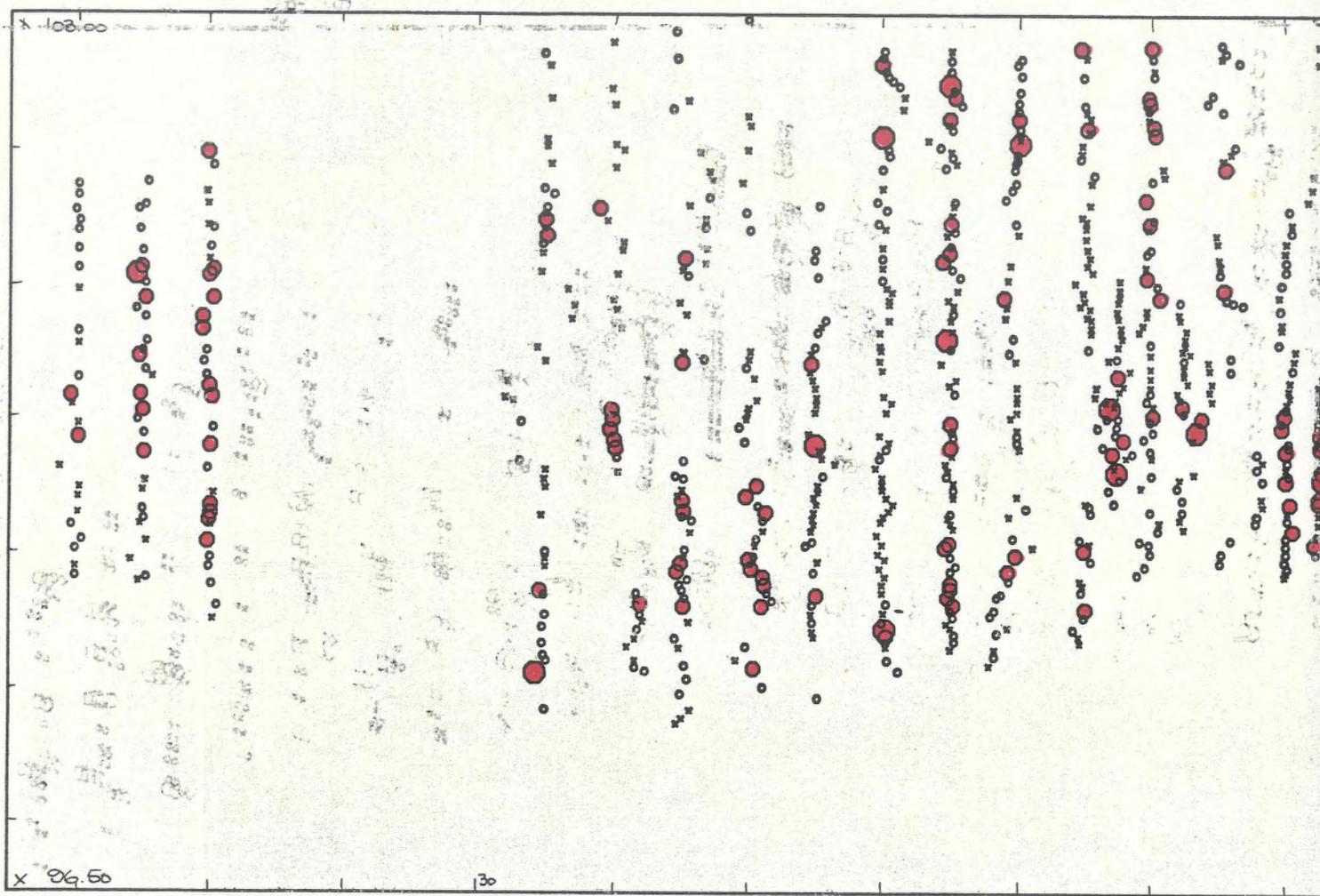
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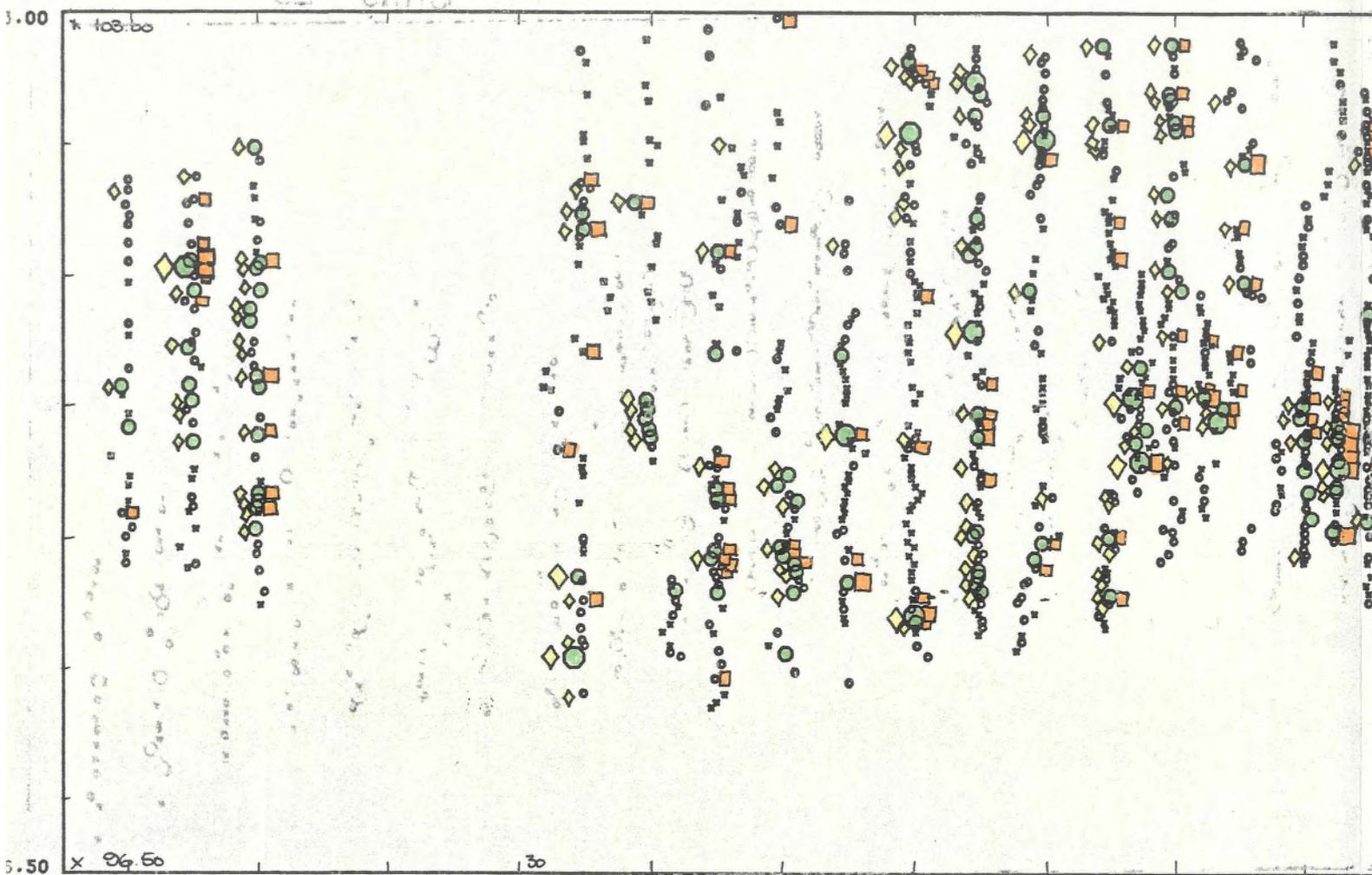
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Y 26.50

130

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82 011-5



- F10g
- F9a
- ◆ Cu-Zn factor

Y 26.50

X 29.50

30

02 20 X 29 20

ENVA SIM

1000

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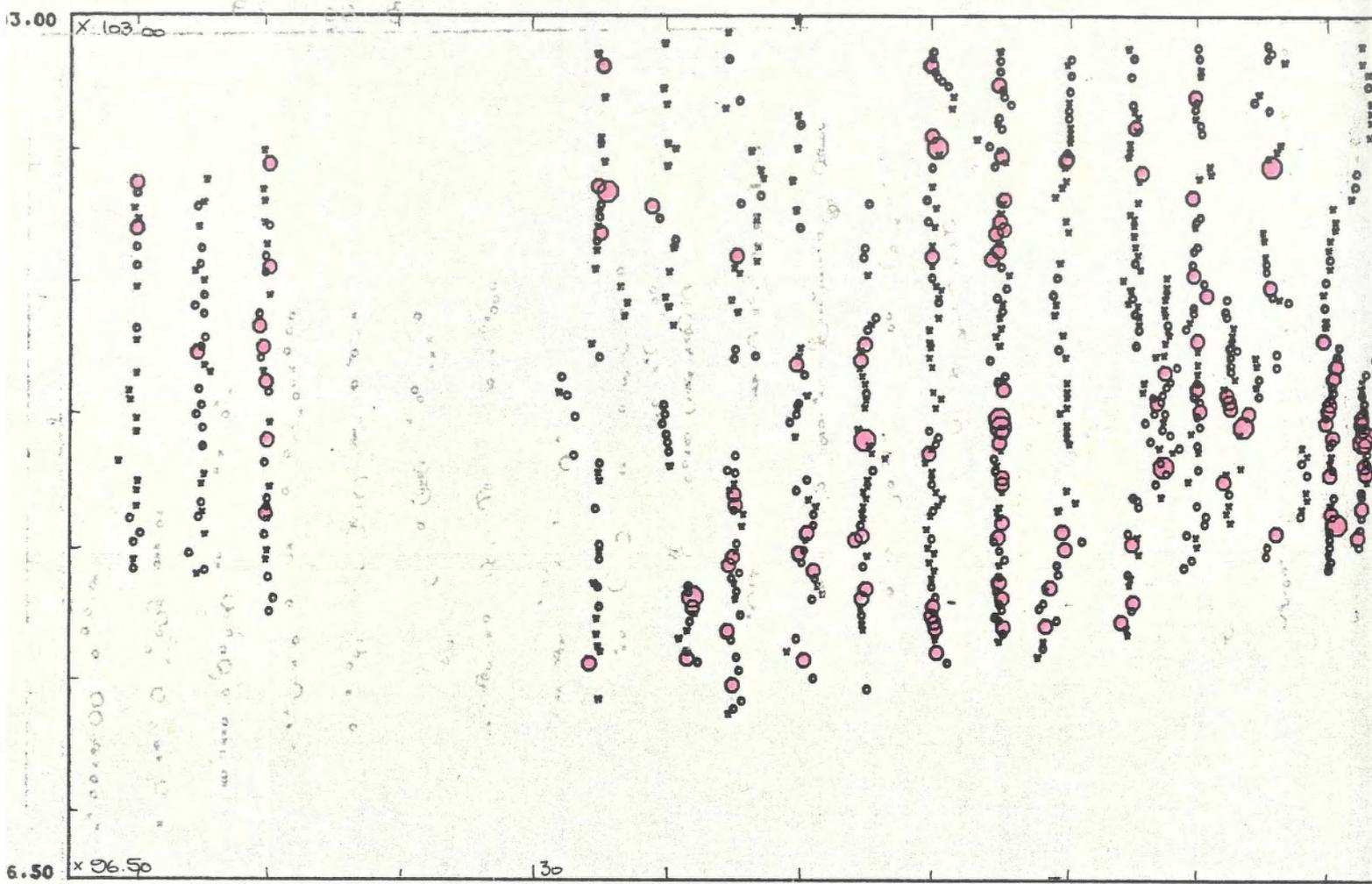
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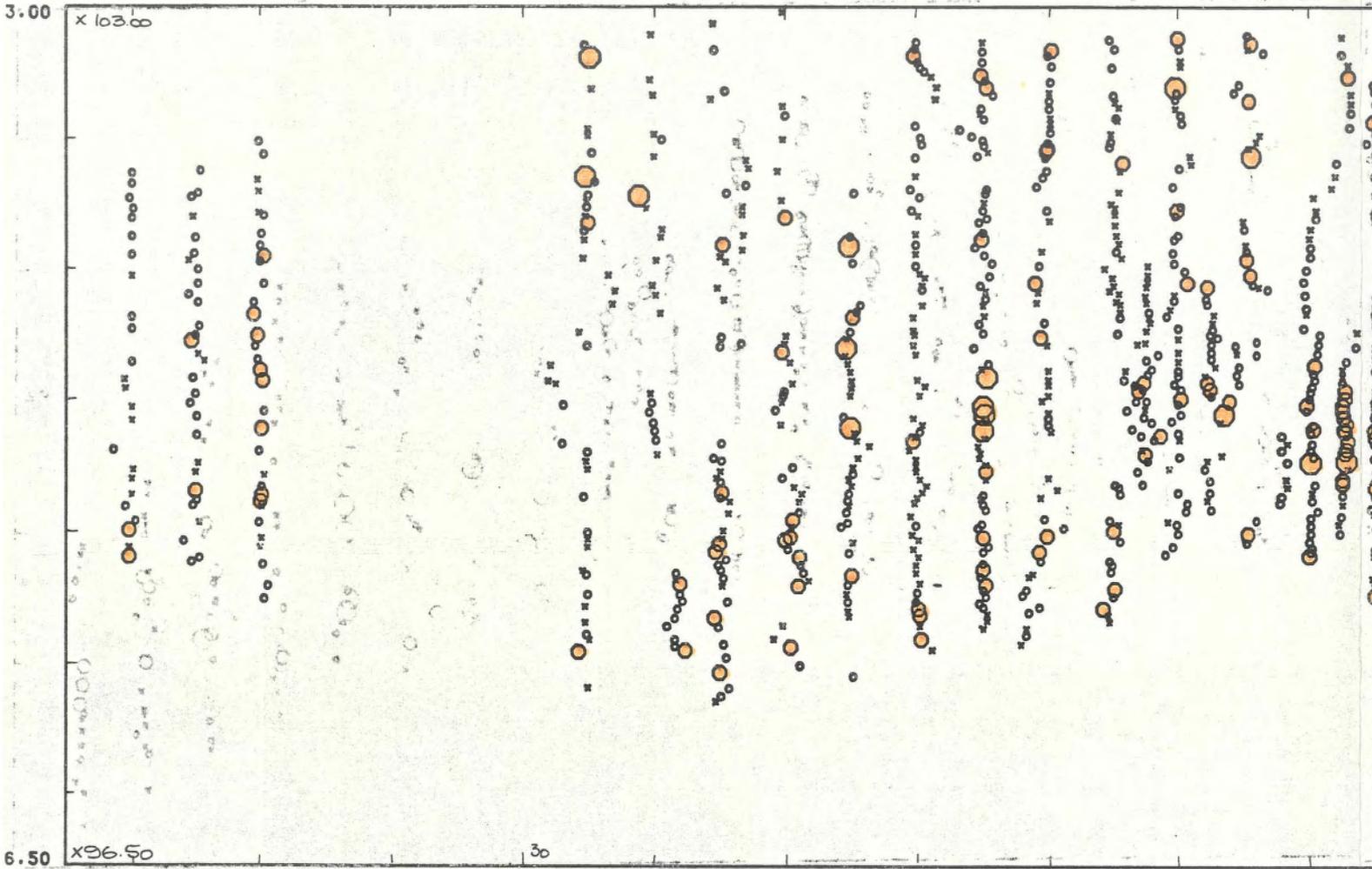
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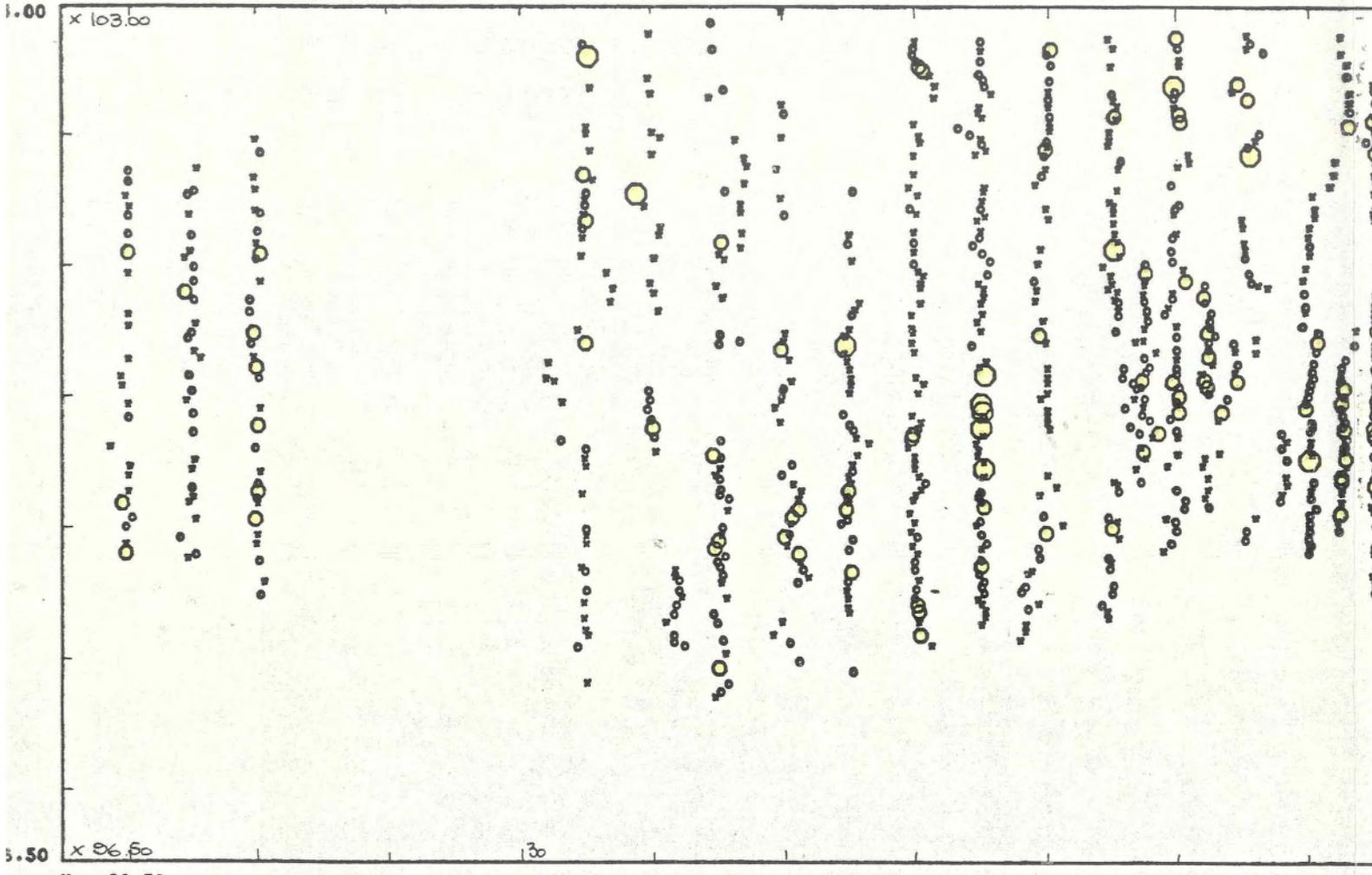
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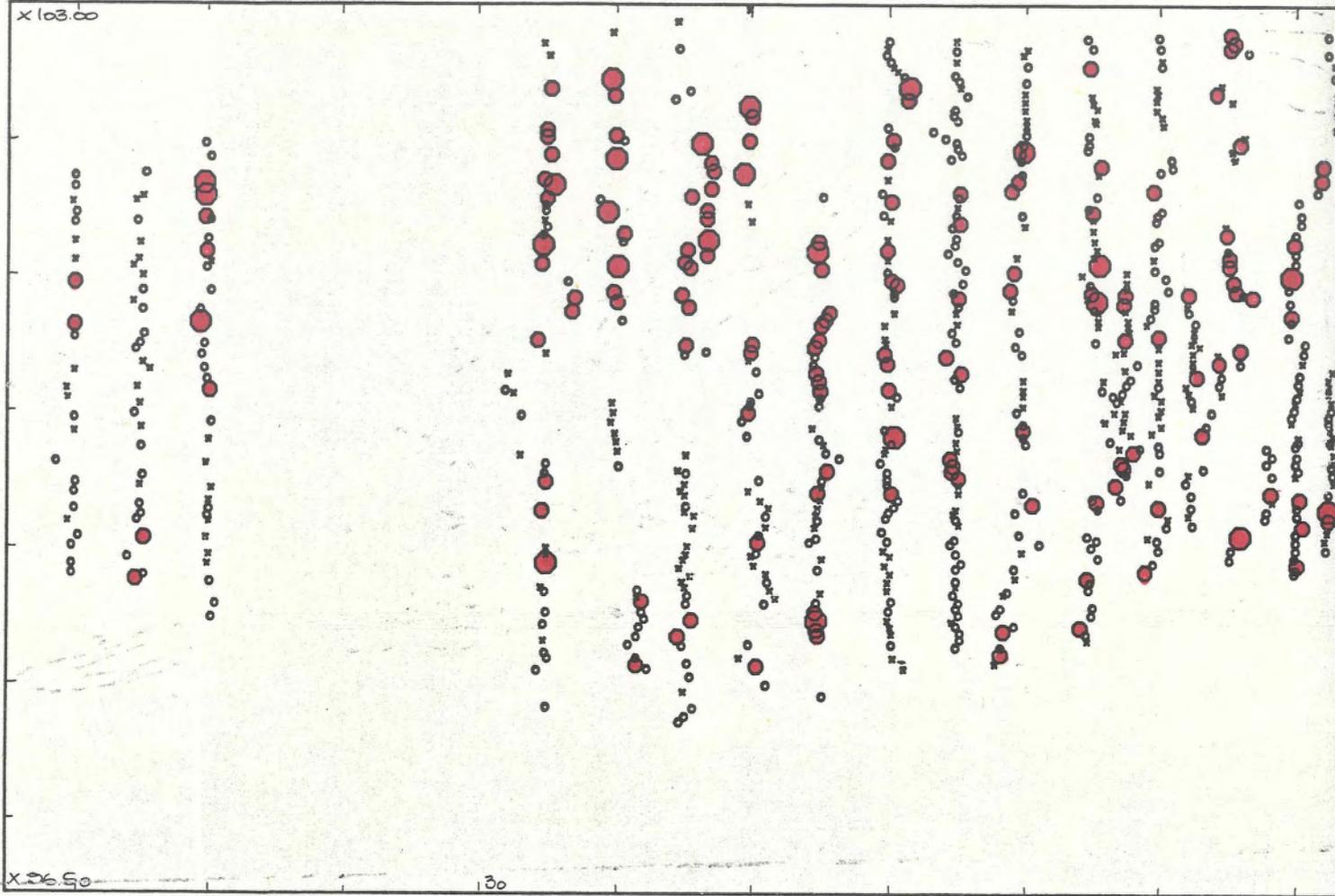
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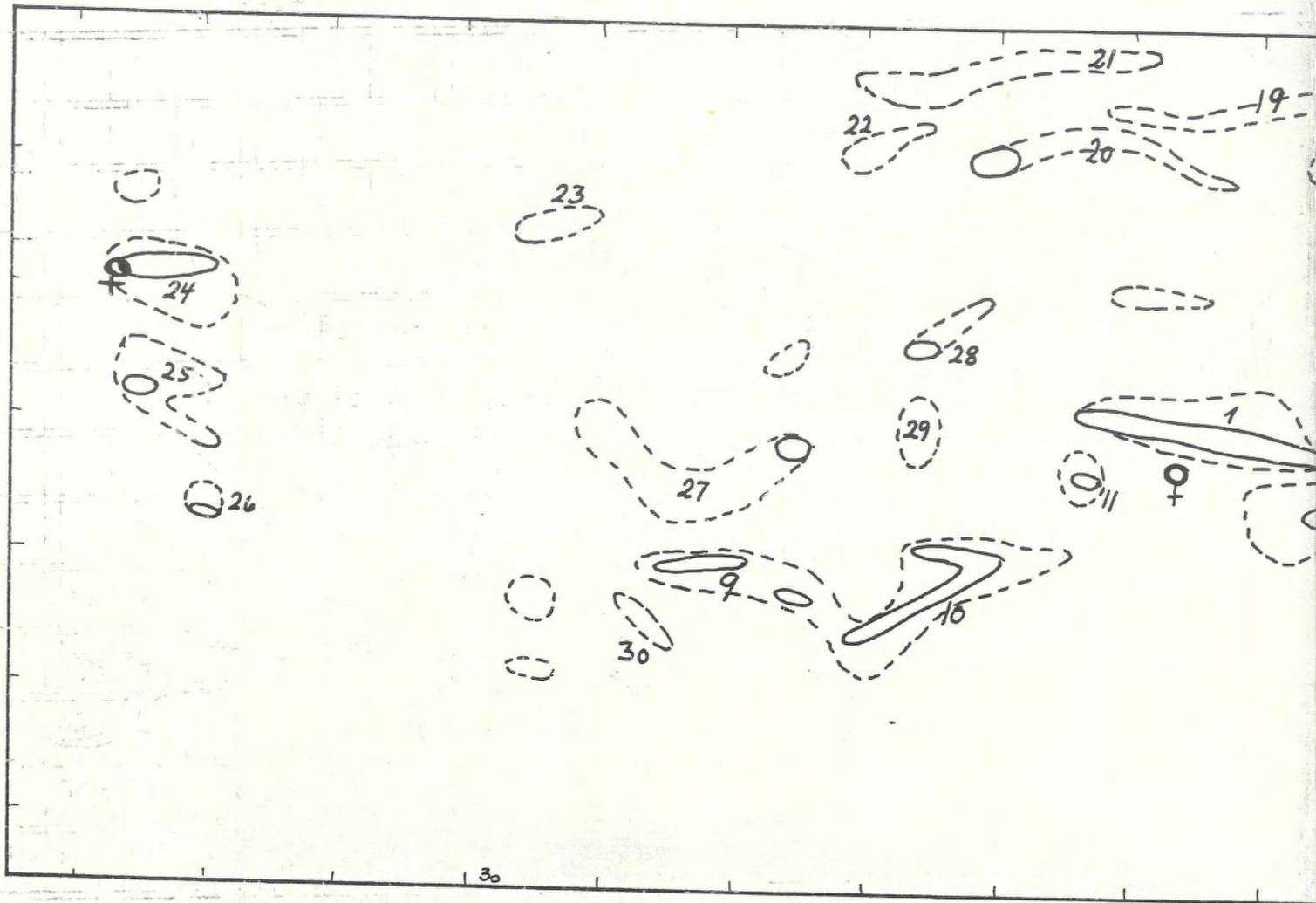
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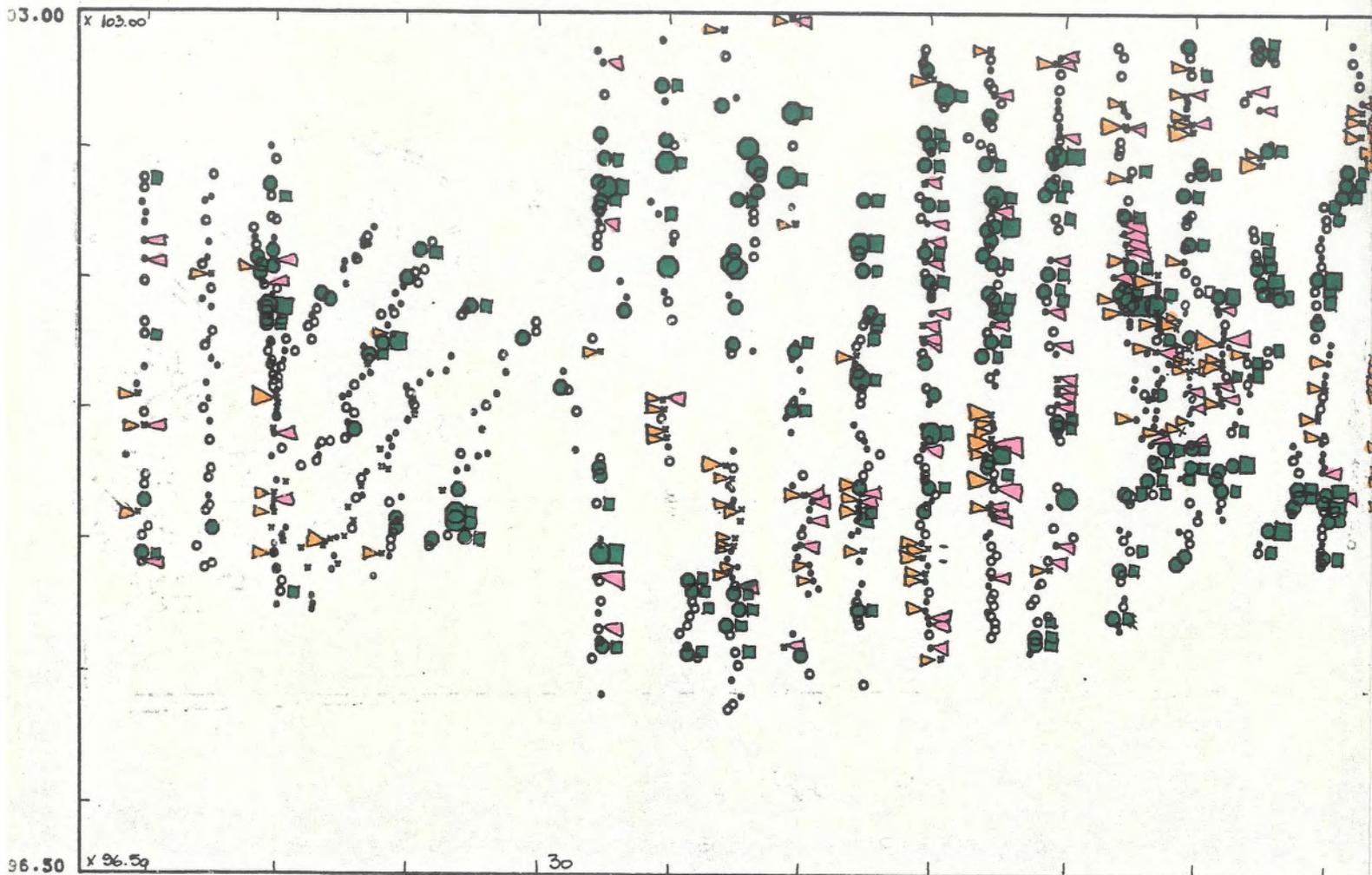
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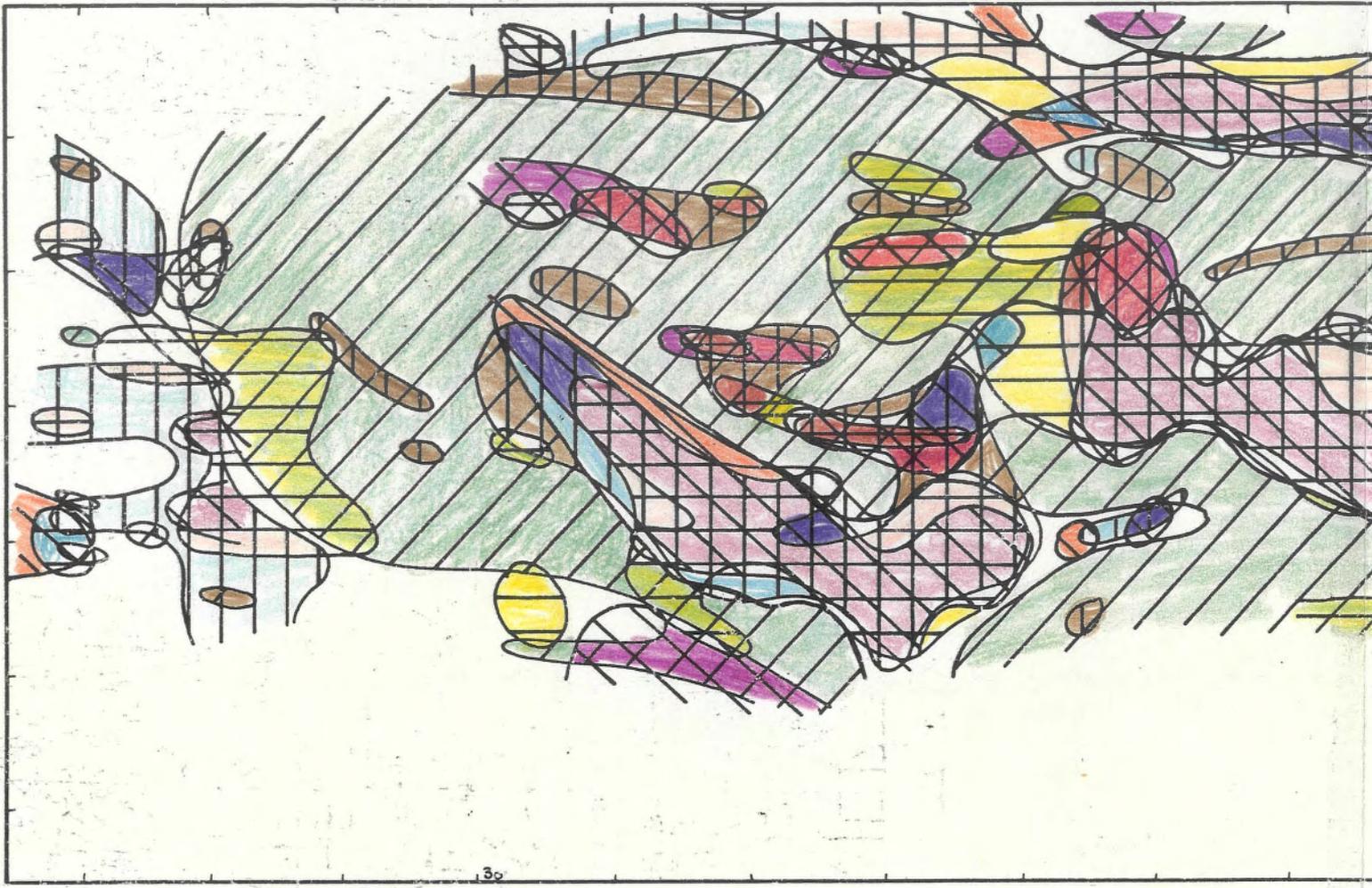
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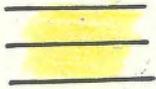
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S9 (MgO/Cr)



F2a (Ti, V, Fe)



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