Bergvesenet
Postboks 3021, 7002 Trondheim

Rapportarkivet

Bergvesenet rapport nr	Intern Journal nr	Internt arkiv nr	Rapport lokalisering	Gradering
BV 751	670/83 FB	T & F 608	Trondheim	Fortrolig
Kommer fra ..arkiv	**Ekstern rapport nr**	**Oversendt fra**	**Fortrolig pga**	**Fortrolig fra dato:**
Troms & Finnmark	Sydv 1427			

Tittel
Regional geologisk kartlegging Kautokeino

Forfatter	Dato	Bedrift
Olsen, Karl Inge	20.06 1983	Sydvaranger A/S

Kommune	Fylke	Bergdistrikt	1: 50 000 kartblad	1: 250 000 kartblad
Kautokeino	Finnmark	Troms og Finnmark	18321 18332 19324	

Fagområde	Dokument type	Forekomster
Geologi		
Råstofftype	**Emneord**	

Sammendrag
En beskrivelse av bergartene gis, og en tolkning av de tektoniske prosessene foretas.

Et vedlegg beskriver kjemi med en foreløpig tolkning. Noen foreløpige aldersdateringer antyder en del om aldersforhold mellom bergartsenheter.

Arbeidsutgaver av tre kartblad i 1 : 50.000 er sammenstilt.

Hovedkonklusjon:
Et arkeisk grønnstensbelte gjennomskjæres av en tidlig proterozoisk riftsone.

Nr 608.

ASPRO PROSPEKTERING

GAMLE RINGERIKS VEI 14 POSTB. 83 1321 STABEKK

EIELD AV AKTIESELSKABET SYDVARANGER

Jnr. 670/83 FB 14/11-83.

(02) 53 08 34

Telex 72 987 aspro n

INTERN RAPPORT.

DATO: 20.6.1983	RAPPORT NR: 1427	KARTBLAD 1832 I, 1833 II, 1932 IV	Antall sider 10, —"— bilag

SAKSBEARBEIDER Geolog Karl Inge Olsen

RAPPORT VEDRØRENDE:

REGIONAL GEOLOGISK KARTLEGGING I KAUTOKEINO.

FORDELING

OSLO:

KIRKENES:

ANDRE:

RESYMÉ:

En beskrivelse av bergartene gis og en tolkning av de tektoniske prosessene foretas.

Et vedlegg beskriver kjemi med en foreløpig tolkning. Noen foreløpige aldersdateringer antyder en del om aldersforhold mellom bergartsenheter.

Arbeidsutgaver av tre kartblad i 1 : 50 000 er sammenstillet.

Hovedkonklusjon:

Et arkeisk grønnstensbelte gjennomskjæres av en tidlig proterozoisk riftsone.

KOMMENTAR:

KONFIDENSIELT

KIO/rf

INNLEDNING

Kartleggingen 1982 ble konsentrert om Kautokeino-kartbladet og et begrenset område ved Bahasavdujavri på kartblad Lavvoaivi og Siebe. I det sistnevnte området gikk kartleggingen parallelt med de geofysiske undersøkelser som ble utført, da feltet har vist seg å bestå av bergartstyper som er potensielle bærere av massive Ni-holdige kisforekomster, og mulige assosierte gull-konsentrasjoner. De siste kan eventuelt være knyttet genetisk til de ultrabasiske bergarter, eller til vulkanogene exhalative forekomster.

I tillegg ble en del spredt kartlegging og oppsjekking utført på kartbl. Siebe.

Kartbl. Kautokeino -Lavvoaivi - Siebe er sammenstillet og tegnet og foreligger som arbeidsutgaver.

Sommeren -83 vil gå med til mer i detalj å undersøke området ved Bahasavdujavri m.h.t. stratigrafi, og å differensiere mer mellom ulike bergartstyper. Fullføring og oppsjekking av Kautokeino, Lavvoaivi og Siebe kartbladene med prioritering av det siste, skal føre til at disse foreligger som foreløpige utgaver vinter -83/84.

Addjit og Urdutoaivi vil ventelig ikke kunne påbegynnes før sommeren -84.

Total kjemi på grønnstener og assosierte granitter og gneiser er så å si fullført(se vedlegg). Sammen med geologien og strukturgeologiske studier har dette gitt en modell for dannelseshistorien av bergartene i Kautokeino.

Jeg vil i denne rapporten presentere de konklusjoner jeg har kommet til og hvilke kriterier de er basert på.

ANALYTISK ARBEID

Ca. 65 prøver av grønnstenene og 12 prøver av gneiser fra gneisdomen er det gjort totalkjemi på, inkludert REE-analyser på 35 grønnstener og 5 gneiser utført med INAA på Geologisk Museum, Tøyen.

Dataene er behandlet, og en foreløpig tolkning er foretatt (se vedlagte manuskript).

Dessuten er noen indikasjoner om aldersforhold oppnådd på grunnlag av Rb-Sr isotop kjemi, som ble gjort på noen vulkanitter og granitter/gneiser.

REGIONALT.

Kautokeino granitt-/grønnstensterreng danner en naturlig del av det karelske basement kompleks som strekker seg som en bred NV-SØ gående sone fra Onega-Ladoga sjøene gjennom Sovjet og Finland (se fig. 1a). Denne sonen er karakterisert ved assosiasjonen granitt/gneis - grønnstensbelter, og er arkeisk i alder. Grønnstenene består ofte av en komatiitt-tholeiitt serie som spesielt utgjør grønnstensserier også andre steder i verden; Superior Province, Canada. Barberton, S.-Afrika; Pilbara - og Yilgarn Blocks, Australia.

Granitt- grønnstenssonen danner basement for yngre grønnstens- sedimentserier (jatulian) som er spesielt utviklet N for Onegasjøen. Disse seriene er avsatt i forbindelse med "rifting", innsynkning og bassengdannelse i en NV-SØ -lig sone fra Onegasjøen til Finnmark. Denne riftsonen er forblitt en svakhetssone helt opp til nyere tid, og dype NV-gående forkastningssoner strekker seg inn i Finnmark og er antaklig blitt reaktivert helt opp til nyere tid. Disse forkastningssonene, e.g. Kantalahti i bruddsone kan tydes på satelittbilder. Tre kjente karbonatitt, Sokli, Kovdor, Turjanniemi (de to sistnevnte i Sovjet) ligger på denne bruddsonen.

KAUTOKEINO

En foreløpig tolkning av geologien er gjort for kartblad Kautokeino - Siebe - Lavvoaivi og et "samlekart" for Baharavdujavri - Bælljas området er laget (fig. 2).

Grønnstenene i Kautokeino er begrenset av granitt-/gneissterreng i øst og vest. Gneisdomen i øst skiller dem fra Karasjok grønnstensbelte.

I grønnstensseriene kan påvises både lavaer og tuffitter (basaltiske). Vulkanittene alternerer med ulike typer terrigene sedimenter, fra metapelitter til metasandstener og kvartsitter.

Bergartstyper, petrografi, stratigrafi

Homogen amfibolitt. Denne opptrer i store deler av lagrekken, men særlig i nær tilknytning til kvartsitt-/fuksittglimmerskifre og sandstener/glimmergneiser. Den er middels til grovkrystallin, moderat- til sterkt foliert.

Min.: hbl + plag $\pm$ cpx $\pm$ bio + ores.

Hbl kan opptre porfyroblastisk og lokalt utgjøre hele bergarten (hornblenditt). Mineralparageneser er helt og holdent metamorfe. Teksturen, imidlertid, kan reflektere en delvis relikt magmatisk tekstur.

Som oftest er bergarten likekornet middelskornet amfibolitt med hbl : pl = 1 : 1.

Bergarten kan tolkes som en metagabbro, metamorfosert til øvre amfibolitt facies. Om alle variantene av den, i tilfellet, reflekterer ett stadium eller flere stadier av intrusjoner, kan ikke fastslås med sikkerhet. Det ser ut til at de grovkrystalline og/eller porfyroblastiske variantene kan representere et sent stadium og være syn- til sentektoniske intrusjoner, mens de middelskornete er pre- til tidlig tektoniske (sills?).

Lagdelte- /båndete amfibolitter, kan være representert i 2, kanskje 3 nivåer i lagserien (Baharavdujavri-serien, Avzzejavri-serien, Caskias-serien) og er klart vulkansk/sedimentært dannet; metatuffitter iblandet mer eller mindre terrigent materiale. Disse veksler med pelittiske og psammittiske bergarter og grafittskifere. De kan være meget grovkrystalline med store porfyroblaster i en finkkornet matriks. Porfyroblastene kan være Al-silikat, gnt og/eller hbl. Matriks er pl + qz ± bio ± musk.

Parageneser:
1. Al-silikat + bio + qz + fsp.
2. Gnt + hbl + bio + qz + plag.
3. Gnt + bio + qz + fsp
4. Hbl + cord (?) + bio + qz + fsp.
5. Hbl + bio + qz + fsp.
6. Bio + qz + fsp.
7. Hbl + qz + plag.
8. Qz + plag.

Den store variasjonen i mineral-assosiasjoner reflekterer en sammensetning gradvis fra rent vulkansk (tuffittisk) til pelittisk/psammittisk. Paragenese nr. 8 veksler oftest som 5 til 10 cm tykke bånd med hbl-rike bånd av samme tykkelse (par. 7) Båndingen kan også være representert ved alle de andre paragenesene ovenfor.

Fin- til middelskornete homogene amfibolitter.
Disse er tolket som metavulkanitter og opptrer gjennom store deler av terrenget. De er som regel sterkt folierte med hbl-nåler som danner planstrukturene. De kan også være nokså massive til tross for amfibolittfacies metamorfose. Komatiitter og metabasalter vil komme inn under denne gruppen, og opprinnelige primære teksturer vil delvis gjenspeiles i den metamorfe teksturen. Komatiittene kan inneholde ol-fenokrystaller som gir den grønne bergarten et brunspettet utseende. Fenokrystallene er mer eller mindre foliert. Ol er åpenbart metamorft dannet, idet de kan inneslutte halvveis metamorft dannet tremolitt nål-aggregater. Imidlertid kan opptreden til ol gjenspeile en

opprinnelig magmatisk porfyrisk dannelse som senere har fått påvekst av ol under metamorfosen.

Parageneser :

- Basalter: plag + hbl ± bio + qz ± ore
- Basaltiske komatiitter: hbl ± plag + ore
- Ultrabasiske komatiitter: hbl + ore ± ol ± klor ± serp.

Ol kan bære serp ± klor omvandlet, med en karakteristisk mineralogisk sonering:

Kloritt (ytterst) —> serp —> ol.

Stripete amfibolitter. Disse er sterkt folierte med tynne, hvite lameller som veksler med lag av vanlig amfibolitt (middelskornet). Bergarten er assosiert med understliggende amfibolittserie med komatiitter (ol-porfyriske). De stripete amfibolittene kan være av tuffittisk opprinnelse. Stripene kan også skyldes en liten grad av anatekse.

Parageneser :

1. Plag + hbl ± bio ± qz ± ore
2. plag + hbl + gnt ± bio ± qz
3. plag + hbl + cpx ± bio ± qz
4. Cpx + plag ± bio ± qz

De hvite lamellene består ofte av paragenese nr. 4. Ba. kan være impregnert med magnetkis og inneholder da bare cpx + plag + qz i tillegg til kis.

Metasandstener /-pelitter. Dette er en meget inhomogen og lateralt varierende sedimentlagrekke, og består av qz + fsp ± biotitt skifere (metasandstener), feltspatiske kvartsitter, rene kvartsitter, glimmerskifere/-gneiser og konglomerater.

Bergartsserien opptrer stratigrafisk over den underste amfibolittserien (Baharavdujavri serien).

Kvartsitt : Kryss-sjikt er ofte forekommende.
Ba. inneholder ofte noe feltspatkorn.

Metasandsten, arkose : Kvartsitt kan gå over i sandsten som regel inneholdene varierende mengde biotitt. Rene qz- bioskifere forekommer også.

Glimmerskifere : Disse er Mu- klor- bioskifere. Klor og mu kan i noen tilfeller være sekundære nedbrytningsprodukter etter gnt. og/eller cordieritt, som utgjør en del av Cordieritt gneiser.

Migmatittiske glimmergneiser	:	Granittisk materiale veksler med qz + mu + sill ± cord aggregater. De siste kan opptre som opptil 5 cm store kule- eller linseformede inneslutninger i granittisk grunnmasse.
Konglomerat	:	Disse kan ha kvartsitt-, sandstens- eller granittboller spredt i en pelittisk matriks. Bollene kan være 1/2-5 cm store. Sedimentet har antaklig sammensetning som en gråvakke og dannet som en turbidittavsetning. Gradert lagning og en 1/2-1 m tykke kryss-sjikt er observert med sten-, grus- og pelittisk materiale godt sammenblandet.

Rekkefølgen i lagserien er, nedenfra:

Metagråvakker/konglomerater —> metasandstener
—> metapelitter —> metasandstener (glimmergneiser)
—> feltspatiske kvartsitter/kvartsitter.

Parageneser:
1. qz ± fsp
2. qz + fsp
3. qz + fsp + bio
4. qz + fsp + bio + Al-silikat (sill)
5. qz + fsp + bio + gnt
6. qz + fsp + bio + cord ± klor ± musk
7. qz + bio + musk + sill ± cord + granitt

Kvartsitt/qz- fuksitt- skifere/-gneiser (Masi-serien)

Denne serien ser jeg på som liggende øverst i bergserien. Kvartsitten er alltid nesten ren kvartsitt, men kan veksle med grønne fuksittskifere og går lateralt og vertikalt (opp) over i disse. Tilsynelatende blir serien mer glimmerrik når en beveger seg sydover i feltet mot finskegrensen. Lagrekken SØ for Kautokeino er:

Urene kvartsitter (100 m) —> sandsten + fuksittgneiser
—> fuksittskifere/-gneiser.

En del av terrenget er metamorfosert i lavere- til midlere grønnskiferfacies, og en kort beskrivelse av bergartene her følger.

Metadiabas/-gabbro, er massive, middels til grovkrystalline med magmatiske teksturer.

Parageneser : Hbl + plag ± bio ± qz ± cpx

Hornblende kan delvis være magmatisk dannet, men kjemien er modifisert ved avkjøling, og svak metamorfe. Dette sees ved soneringen som tydelig framtrer, med en fargeløs indre kjerne og en grønnfarging langs kanten av krystallene; d.v.s. : pargasitt (kjerne) → hastingsitt/aktinolitt (kant).

Disse bergartene kan være umetamorfe ekvivalenter til de homogene amfibolittene beskrevet ovenfor. De to bergartene kan opptre i nær assosiasjon og må i disse tilfeller ha blitt dannet til forskjellig tidspunkt. Diabasene og gabbroene har, på samme måten som de homogene amfibolittene, intrudert i forskjellige stadier, antaklig i tilknytning til utviklingen av ulike svakhetssoner gjennom hvilke de intruderte. De fleste intruderte i ulike stadier under dannelsen av vulkanittene (N-S -lig retning) som lagerganger, og er foldet sammen med disse. En del følger også sprekke-forkastningsretninger i NV-SE og NØ-SV -lige soner, hvorav de første kan være dannet samtidig eller etter de som intruderte i N-S -lig retning. Diabas/gabbro som følger NØ-SV soner ser ut til å være klart sen- til posttektoniske (Kautokeino elv svakhetssone).

Metavulkanitter. Metabasalter er identifisert ved karakteristisk magmatisk basaltisk tekstur og andre vulkanske strukturer (putestrukturer, blærerom, flytestrukturer). Teksturen er fin- til middelskrystallin.

Metatuffitter er finkornete laminerte grønne bergarter. Bergarten kan ha metamorft dannet små akt.- nåler spredt i en finkornet kloritt- akt- ab matriks.

Metasedimenter. Grafittskifere og leirskifere (grå og grågrønne), laminerte, opptrer vekselvis med tuffittene eller danner en egen sekvens i lagrekken. Øverst i lagserien opptrer disse vekselvis med metasandstener som den nederste del av en mektig sedimentserie (Caravarri-serien), som består av en mektig sandstensserie på toppen. Caravarri-serien har delvis primær sedimentær kontakt diskordant på eldre bergarter, og delvis tektonisk kontakt til andre bergarter. Primær sedimentær kontakt er observert ved Gæsjavri, og kan markere en primær høyt liggende bassengmargin, hvor erosjon og grov, klastisk sedimentasjon (debrisavsetn.) fant sted. Vestover får leirskifere og finere sedimenter en mer dominerende rolle, og markerer mer fjerntliggende miljø fra bassengkanten.

Albitt- karbonat omvandling

Metavulkanitter (amfibolitter el. grønnstener) kan være mer eller mindre omvandlet ved karbonatisering, og blir lyse rødaktig med en matriks av sukkerliknende konsistens. Opprinnelige strukturer/teksturer kan være bevart (foliasjon, laminasjon, porfyroblast relikter).

Mineralogien er monoton:

Qz + ab + karb. + hem.

Karbonatiseringen/albittiseringen har foregått i forbindelse med gjennomtrengende karbonatrike løsninger under høyt trykk som har hatt en eksplosjonsartet utvikling og forårsaket breksjering av sidebergart. Årer med karb + hem + qz gjennomtrenger på denne måten bergarten. Denne prosessen foregikk i forbindelse med bevegelser langs N-S gående forkastningssoner.

Omvandlingen foregikk også ved mer mekaniske breksjeringer, spesielt med NV-SØ gående forkasningssoner, hvor mindre karbonat var involvert. Breksjene kan da utvikles så langt at de får et utseende av konglomerat. Både kvartsitt og vulkanitter blir berørt. Spesielt den siste kan være svært oppmalt og består da av boller av ab-karb. i en finkornet qz- ab- karb. matriks. De er som regel opptil 10 m mektige soner og er ikke blitt tektonisert vesentlig siden. De går gradvis over i sterkt tektoniserte/breksjerte albittiserte vulkanitter eller oppsprukken breksjert kvartsitt.

Retrogradering

En tektonisk episode med dannelse av intense skjærsoner har ført til delvis mylonittisering og forskifring med påfølgende nedbrydning av høyere grads metamorfe parageneser.

Retogradering:
- hbl ⟶ akt ⟶ kloritt/biotitt
- bio ⟶ kloritt
- cord ⟶ kloritt + +
- fsp ⟶ musk + +

Slike retrograde skjærsoner er spesielt utviklet N for Mierson og i syd ved finskegrensen øst for Gædgejavri. Ellers gir denne tektoniske begivenhet seg bare uttrykk i utvikling av "parting" og sekundær kløv. i alle typer bergarter uten at noen betydelig retrogradering har funnet sted. Skjæresonene med påfølgende forskifring kan sees på som en kompresjonsfase i motsetning til fasen med karbonatisering, som mer sannsynlig har foregått under en tensjonsfase hvor CO_2 rike gasser fritt har kunnet passere opp gjennom svakhetssonene.

Tektonikk

Foldestilen er beskrevet i fjordårets rapport. Som allerede antydet, kan ulike typer tektonikk identifiseres:

1. Duktil foldetektonikk
2. Stiv tektonikk på blokker ⇒ forkastninger/horisontale bevegelser
   a) Kompresjon
   b) Tensjon.

I de høyere metamorfe bergarter kan 3 foldefaser skilles ut:

1. Isoklinale skjærfolder : Oppr. NNØ-SSV
2. Tette bøyningsfolder : Ø-V
3. Lineasjoner/Stengelighet: SSV

De lavmetamorfe bergarter er foldet i åpne- til tette bøyningsfolder rund en N-S -lig foldeakse. Disse er igjen foldet rundt en E-V -lig foldeakse som bare sees på en regional skala, og forårsaker dom- og depresjonsformede strukturer.

Stiv tektonikk under tensjonsregimer har forårsaket brekseringer og karbonatiseringer langs N-S gående og NV-SØ gående forkastningssoner, hovedsaklig synlig i de høymetamorfe områdene (kvartsitt, gl.sk./-gneiss, amfibolitt). Gjennomgående planstrukturer i nærheten av slike områder, og forkastningsplan viser dette.

Intrusjon av diabaser har foregått langs de samme soner og er derfor blitt utsatt for den samme karbonatiseringsprosess.

Stiv tektonikk under kompresjon har hatt betydning bare lokalt (som før beskrevet) men foregikk hovedsaklig i N-S -lig retning, eller fulgt tidligere svakhetssoner dannet under tensjonsregimer. Denne fasen har vært gunstig for intrusjon av diabas- lagerganger i de lav metamorfe vulkanittene.

En siste tensjonsfase har forårsaket bare små bevegelser og utvikling av NØ-SV -lige forkastninger med hovedsaklig vertikale bevegelser. Diabaser og gabbroganger har intrudert langs disse sonene. En del observasjoner kan tyde på at jo mer mot nord disse er orientert (NNØ), dess senere er de. Kautokeino-elva renner langs hovedsaklig en slik forkastningssone.

Foldingen av de lav-metamorfe vulkanittene/sedimentene kan korreleres i tid med stiv tektonikk under kompresjon i den høy-metamorfe bergartsserien (basement). Skjærbevegelser kan ikke identifiseres i samme grad i den lavmetamorfe bergartsserien, mens den siste tensjonsfasen er like mye utviklet i alle typer bergartsterreng (også i Caravarri-serien).

Reaktivering av tidligere svakhetssoner kan ha forårsaket at disse også har utviklet seg inn i den lavmetamorfe bergartsserien, som, om enn i mindre grad, også har utviklet karbonat breksjesoner.

Konklusjon: Bergarter, tektonikk.

En del ting gjør det sannsynlig at to bergartsserier dannet til helt forskjellig tid må være tilstede. Jeg vil postulere at hovedsaklig metamorfosegraden er

nok til å skille mellom disse to bergartsserier.
En oppsummering av en del observasjoner kan vise dette:

1. Foldestilen er mye mer komplisert i den høymetamorfe delen.
2. Alle foldefaser i denne serien blir overprintet av planstrukturer parallelle med deformasjonsstrukturene i den lavmetamorfe serien.
3. Forkastningstektonikk, N-S og NV-SØ, som i vesentlig grad bare har berørt den høymetamorfe delen, og forårsaket intense breksjeringer og karbonatiseringsprosesser.
4. En sen forkastningstektonikk, NØ-SV, kan identifiseres i begge serier.
5. Skjæresoner forårsaker mylonittisering og forskifring med påfølgende retrogradering av høyere metamorf mineralogi.
6. Antatte tidligere massive diabas-/gabbro intrusjoner opptrer nært ved homogene, sterkt folierte middels- til grovkryst. amfibolitter.

Min hypotese er, at den første stive tensjonsfasen opptrer under dannelsen av en rift langs en N-S -lig spredningsakse med bevegelser langs NV-SØ -lige transforme forkastninger, og innsynkning langs N-S gående soner.
Ved disse bevegelser foregikk karbonatiseringer og breksjeringer av det eldre basement. En rekke svakhetssoner utvikles parallelt med spredningsaksen med påfølgende karbonatisering. Samtidig skjer innsynkning og bassengdannelse med vulkanisme og sedimentasjon.

KJEMI

Hoved- og sporelementer på vulkanittene og gneiser er behandlet i vedlegget.
Gjennomsnittssammensetninger av grønnstensbeltet er sammenliknet med liknende i Finland i tabellen. Den viser likheten mellom disse, når det gjelder den eldste grønnstensserien i Kautokeino. Spesielt er MgO innholdet karakteristisk og viser innslaget fra bergarter med komatiitisk sammensetning. Feltrelasjoner tyder på at disse bergarter er virkelige komatiitter (putestrukturer og mulige spinifex teksturer er observert).

Høyeste MgO -innhold som er analysert på slike bergarter i Kautokeino er 30 w %.
Det vanligste ligger omkr. 22-24 w % MgO (Perid. kom.).
Ellers er basaltiske komatiiter vanlig, med MgO ~ 12-16 w %.

Ingen av disse bergarter ser ut til å representere noen differensiasjonsserier, men er heller produkter av forskjellig grad av oppsmeltning i mantelen.

Resten av grønnstenene er tholeiittisk i sammensetning, og er mer produkter av ulike grader av differensiasjon, delvis fra opprinnelig komatiitiske smelter.

REE skal jeg ikke komme noe særlig inn på her, bare nevne at de kan vise grønnstensserier som egentlig hører til samme differensiasjonsserie, og at det på den måten kan være mulig å korrelere mellom områder. Spesielt kan f.eks. bergartsserien N for Mieron og den på Bællasvarri og sydover ikke utelukkes å høre til samme serien.

REE på de "yngre vulkanittene" viser et annet mønster. En del av basaltene her er mye sterkere fraksjonerte på de lette REE. Diabasene og noen av basaltene er derimot mer utarmet på sporelementer generelt for samme MgO -innhold enn noen av bergartene fra den "eldre serien".

Kjemien på "den eldre serien" viser trekk som er meget karakteristisk for arkeiske grønnstensbelter. Komatiiter er observert også i proterozoiske grønnstener (Canada), men hører mer med til sjeldenhetene, og disse har aldri så høye MgO -innhold som de i Kautokeino.

Aldersdateringer

- Sekundære aldre på amfibolitter gir ca. 1900 my. Denne viser antaklig alder på deformasjonen av den yngre serien (skjærbevegelser i amfibolittene).
- Primære aldre på amfibolitter er meget usikre, men indikasjoner tyder på 3.0 by.
- Gneisene viser en usikker alder på 2.4 by. (Metamorfosealder).
- Postektoniske granitter intrusiver gir 1700 my.
  Disse er påvirket svært lite av tektoniske begivenheter, og gir en nedre grense for grønnstensbelte dannelsen.

Både kjemien og radiogene isotoper og aldersforhold på gneisene (i gneisdomen) kan tyde på at i hvert fall en stor del av disse er dannet ved oppsmelting av en del av grønnstensserien som finnes (Kautokeino og Karasjok), og intrudert i disse.

Stabekk, 20. juni 1983

Karl Inge Olsen

GJENNOMSNITTSKJEMI
GRØNNSTENER.

	Kautokeino $n = 57$		Finland $n = 40$		Kautokeino yngre belte $n = 11$	
	w%	2SD	w%	2SD	w%	2SD
SiO_2	50.3	7.4	48.3	10.5	50.1	2.8
Al_2O_3	11.4	6.4	11.6	7.4	13.4	1.8
TiO_2	1.2	0.9	1.1	0.9	1.8	1.2
FeO	13.1	4.0	12.1	4.5	14.9	2.1
MgO	11.3	13.3	12.4	16.0	6.7	3.2
CaO	9.8	5.0	9.6	6.4	8.1	2.7
Na_2O	2.1	2.0	1.6	2.1	3.5	1.2
K_2O	0.6	0.5	0.4	1.2	0.6	0.5

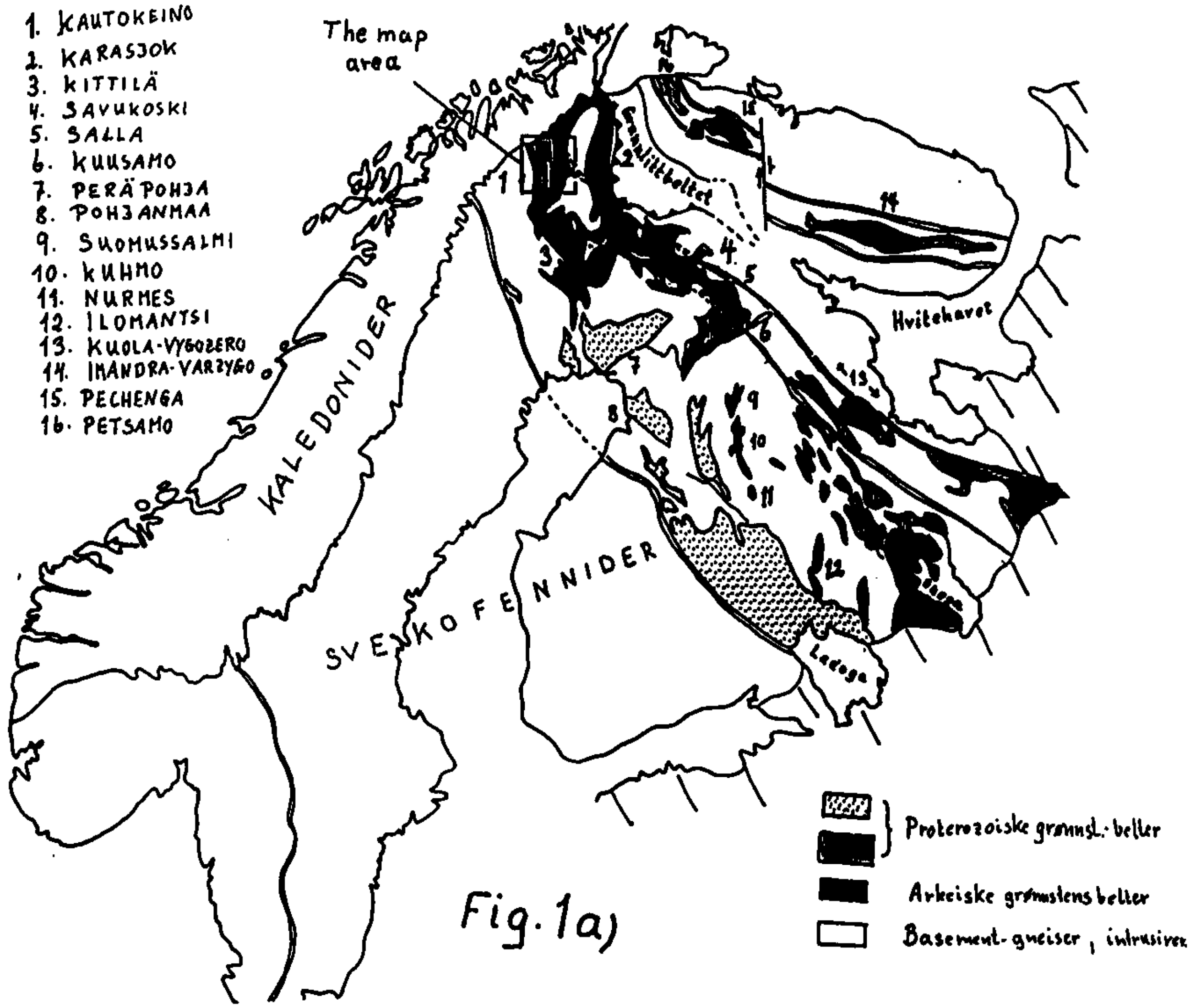

1. KAUTOKEINO
2. KARASJOK
3. KITTILÄ
4. SAVUKOSKI
5. SALLA
6. KUUSAMO
7. PERÄPOHJA
8. POHJANMAA
9. SUOMUSSALMI
10. KUHMO
11. NURMES
12. ILOMANTSI
13. KUOLA-VYGOZERO
14. IMANDRA-VARZYGO
15. PECHENGA
16. PETSAMO
The map area
KALEDONIDER
SVEKOFENNIDER
Granulittbeltet
Hvitehavet
Ladoga
Proterozoiske grønnst.-belter
Arkeiske grønnstens belter
Basement-gneiser, intrusiver

Fig. 1a)

Fig. 1b) Kautokeino greenstonebelt.

Stuorajavri grønnst. = Younger greenstoneseries

Çarajavri-serien = The sandstone/argillite series

Masi-Kvartsitt = Quartzite/Mica (fuchsite)-shist/gneiss

Övre grønnst.-serie = Metatuffites/micashists/metabasalts.

Nedre —— " —— = Basic/Ultrabasic volcanics / tuffites.

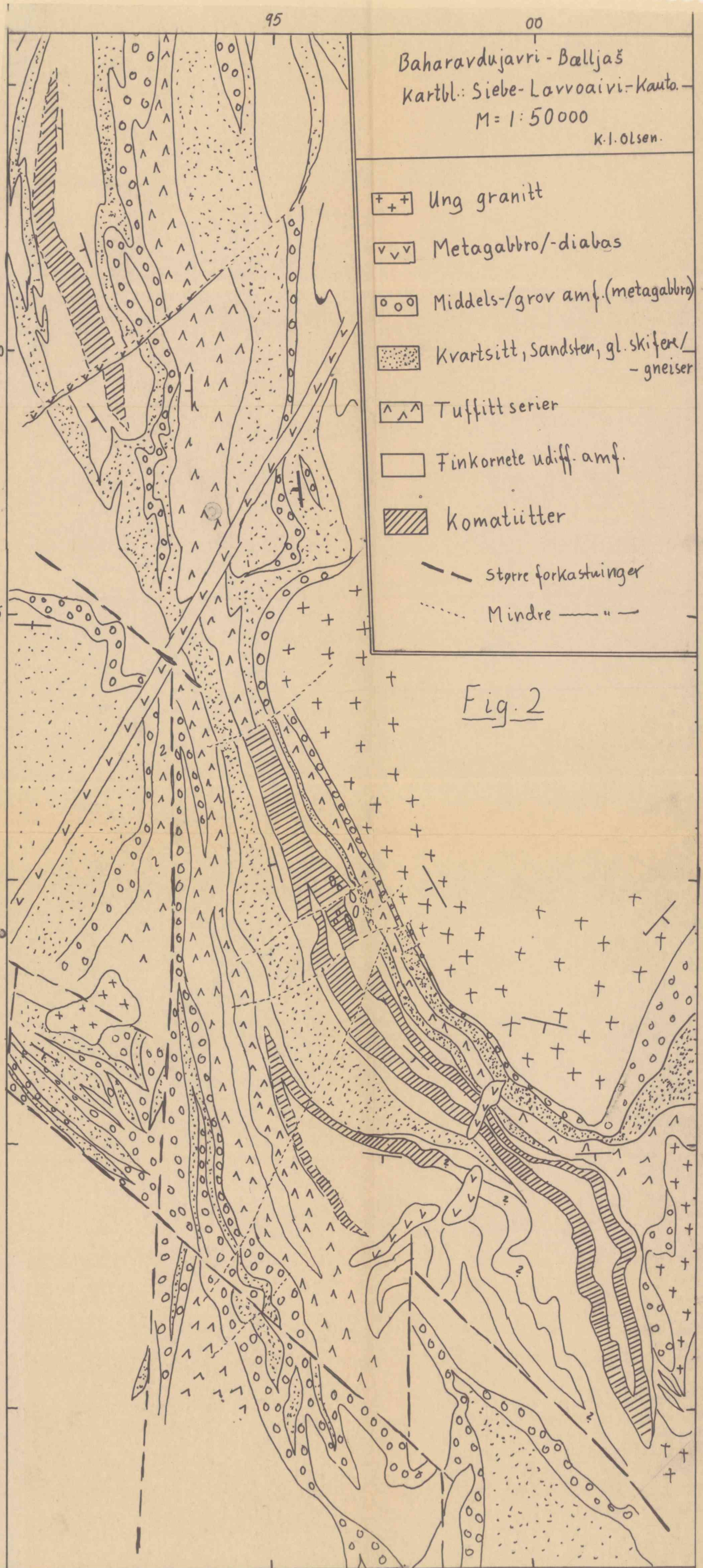

Baharavdujavri - Bæljaš
Kartbl.: Siebe-Lavvoaivi-Kauto.
M = 1:50000
K.I. Olsen.
Ung granitt
Metagabbro/-diabas
Middels-/grov amf. (metagabbro)
Kvartsitt, Sandsten, gl. skifere/-gneiser
Tuffitt serier
Finkornete udiff. amf.
Komatiitter
Større forkastninger
Mindre
95
00
90
95
00
60
55
50
45
40

Fig. 2

VEDLEGG

KIO/bs

THE GEOLOGY AND INTERPRETATION OF THE GEOCHEMISTRY AND Rb-Sr RECONNAISSANCE STUDIES ON GREENSTONES AND ASSOCIATED PLUTONIC ROCKS IN KAUTOKEINO.

Karl Inge Olsen
A/S Sydvaranger Prospektering
Gml. Ringeriksvei 14, 1320 Stabekk.

INTRODUCTION.

In the last 3 years an intense activity have been concentrated on the investigation of Finnmark area and will continue at least another 3 years by NGU. NGU's project is in close cooperation with Finland and Sweden and consists of mapping and ore-prospecting (geochemical, geophysical). Mining companies have shown increased interest in the area, especially in the Karasjok-and Kautokeino greenstonebelts, and A/S Sydvaranger have a large program including regional mapping, which has been performed since the early 70's. The understanding of the geology has increased immensely in spite of the large amount of work left to be done, and the tectonic environment has become quite well established, however, yet there are problems concerning the age of the various units, both the Karasjok and the Kautokeino greenstonebelts and what position the orthogneisses and plutonics in the dome in between and to the west of Kautokeino greenstones shall take.

In this study I will present the geology, the chemistry; major- and trace elements including RE on the greenstones and the associated granitic terrain in Kautokeino. Some conclusions concerning origin of the rock types and the history of the greenstone terrain will be drawn.

Preliminary Rb-Sr isotope studies have been performed and some indications on the age of some of the rock units have been obtained.

GEOLOGICAL SETTING.

Kautokeino greenstonebelt constitutes a part of the northernmost continuation of the karelian-prekarelian Finnish-Sovietic granite-greenstone terrain. The greenstones are bordered by granites - granodiorites and orthogneisses to the west and east. To the east another greenstonebelt is situated in Karasjok between the granite-gneiss dome, which separates it from the Kautokeino greenstones, and the granulite belt, which continues to south into Finland and Soviet. A possible connection exists between the Kautokeino and Karasjok greenstones north and south of the gneissdome. The Karasjok greenstones continue to the Kittilá greenstonebelt in N-Finland, which is dated to archean in age (2700 my).

The Kautokeino greenstones can be devided into two tectonic units differing in the complexity and nature of their tectonic history, the metamorphic grade and composition of volcanics. A probable age difference exists between the two units, the younger marking the onset of proterozoic tectonism, while the older probably is later archean or may represent, together with a granite-dioritic gneiss, a long period of crust formation in the archean.

The older series is composed of a stratigraphy and volcanism, which is similar to archean greenstonebelts, e.g. in Finland, Canada and Australia, although disagreements exist about details on the stratigraphy in Kautokeino. The major units, which I see as the most probable for time being, is from youngest to oldest :

1. Quartzite, quartz-mica (fuchsite)-schists/-gneisses and metasandstones. This sediment series probably change composition laterally towards more pelitic varities from east to west. It starts with a coarser sandstone conglomerate zone at the bottom (greywackes), which is mostly developed in the eastern-most areas close to the granite gneiss terrain.

The sediments possibly lie discordant on the greenstones :

2. Inhomogeneous series of metatuffites immature sandstones and mica schists (biotite + qz + amf. $\pm$ gnt $\pm$ Al - silicate schists) and graphite schists. The lower part of this series may consist of basaltic and possibly ultrabasic extrusives.
3. Quartzites (impure), qz - fsp-biotite schists.
4. Lower volcanic series consisting of basic and ultrabasic volcanic rocks (basaltic and peridotitic komatiites, see later). Primary volcanic structures implicate extrusive origin of the ultrabasic rocks. The upper part develops into more tuffitic varieties.

Any basement has not yet been shown to be present for the greenstones. Field relations seem to indicate at present that the granite-diotite gneisses to the east are intrusive in the greenstone series.

The volcanic series may represent a large time-span, e.g. from series 4 to 2 above, and not only a single small episode of greenstone belt formation. In that case a basement for at least series 2 above could be found. More detailed mapping and geochemical studies has to be done to elucidate this problem.

Metamorphism.

The greenstones and sediments have been metamorphosed in the range from low-amphibolite facies to high amphibolite facies. The grade increases towards the east and south. Hornblende breaks down to clinopyroxene in the basic volcanics and metamorphic olivine grows in the ultrabasic komatiites, probably on to earlier ol-phenocrysts, so that the ol-component of the *matrix* is concentrated in the phenocrysts.

In the metasediments bio-gnt-sill (ky ?) and bio-cord-sill assemblages are observed . The highest grade assemblages may be associated with migmatitization of qz-mica schists.

Common for all the basic rocks is the presence of metamorphic hornblende and plag. and total destruction of primary textures.

Deformation occured in 3 episodes associated with the metamorphism. 2 later deformation events have caused retrogressions (chloritization, serpentinization and serisitization) in connection with the rifting and deformation of the younger greenstones.

THE YOUNGER GREENSTONES.

These greenstones lie in a basin type belt bounded by faults. The rifting crossed right through the older volcanics and sediments. A horst of the old rocks devides the rift into 2 in the north (north of Kautokeino), but the horst thins out near Kautokeino and the rift becomes one unit south of the village (see fig. 1). The rift can be looked at as a continuation of the basin formation taking place in the early proterozoic causing deposition of the Karelian formations (Jatulian greenstones and sediments) SE-wards through Finland and Soviet to the lake Ladoga. The zone parallels a similar belt on Kola (Petsamo foundation) and the mobile belt of the svecofennides in Norway - Sweden - S. Finland. Similar basins adjacent to mobile belts (geosynclines) are found, e.g. Canada (Lake Superior basin, Keweenowan, Sudbury basin) and Australia (Hamersley ?). The stratigraphy is from (youngest to oldest) :

1. Sandstone/argillite series, starting with predominantly argillites and graphite schists at the bottom with an increasing amount of detritical material upwards and a 1 to 2 km thick sandstone/quartzite series lies on the top.

   The series lie discordantly on top of the younger greenstone series and partially on the older greenstone/quartzite series (primary sedimentary contact on the horst N of Kautokeino).

2. A series of laminated tuffites and argillites/graphite schists.

3. Marbles/argillites.

4. The basaltic series, containing variable amounts of basaltic extrusives (lavas).

Intrusions of diabas dikes/sills and metagabbros are numerous, both in the older series adjacent to the rift, along the boarder of the rift and within the younger volcanics. These probably have intruded at various stages of the rift-development; during the initiation of rifting and later during the piling up of volcanics in the basin.

The metamorphism of the series. (as the nomenclature above suggest) is low to middle greenschist facies, and primary textures as ophitic textures in the diabas-sills and lava textures (plag-lists together with magmatic hbl) are preserved.

Biotite and actinolite porphyroblasts are developed in the highest grade of metamorphism. Tectonism is demonstrated by tight upright folds with a N-S fold axis,and by shear zones,both developed adjacent to the rift and within the younger volcanics, the former causing retrogressions (chloritization) brecciation and mylonitization. The shearing probably have been caused by horizontal strike slip movements. Combined with these movements strike-slip/ dip-slip faulting in a NNW-SSE direction occured,and I have suggested that parts of the area can be explained by blockfaulting tectonism, where older and younger greenstoneseries lie complexily intermingled. The intense carbonatization/albitization of the greenstones probably have occured during these processes, together with the brecciation.

The gneiss dome.

The older granite-diorite gneiss massive earth east of the greenstones are folded together with the latter in tight isoclinal folds, but originally they seem to have been intruding the greenstones, which lie as inclusions, lenses and remnants within the gneisses as one crosses into the gneiss terrain.

Younger granites.

Granites/granodiorites intrude late- to post-tectonic relative to the latest tectonism of the younger greenstone belt, and have intrusive contacts to the older volcanics/sediments. The intrusives are massive to weakly foliated, the latter being folded in large open folds around the younger N-S fold axis. They occur as larger or smaller massives or as thin dikes cutting through the older structures.

CHEMISTRY.

In the next I shall present the results of main- and trace elements including REE on the volcanics, mainly of the older series, and some preliminary Rb-Sr isotope investigations on both the greenstones of the older series and the granites and the gneisses. Some trace element features will also be presented for the latter.

Methods.

The XRF-analyses have been performed mostly by aman. Tysseland at the University of Bergen, and a few at the Geol. Survey, Trondheim. Rb- and Sr analyses have been got by XRF at the Geological Museum, Tøyen. Samples with less than 20 ppm Rb, used for the isotope studies, were analysed by the isotope dilution technique.

The REE analyses I have done by the epithermal neutron activiation method in cooperation with aman. A.O. Brunfelt at the Geological Museum, Tøyen. The precision for Ce and Nd is not very good at the lower concentrations in the komatiitic volcanics (up to 50 % error in the measurements at the 1.67 level), however, La, Sm, Tb and Yb are good (below 10 % error).

Rb-Sr isotopes have been analysed by the mass-spectrometer at Geological Museum, Tøyen. The isotope dilution technique was utilized on most of the basic metavolcanics.

The metavolcanics.

In fig. 2 a & b AFM-and CaO-Al_2O_3-MgO relations of the greenstones are shown. It is seen that chemically, the rocks can be classified as belonging to the tholeiitic-komatiitic series characteristic for so many archean terrains (e.g. Timmins and Abitibi of the Superior province in Canada; Barberton, Zebakwian in South Africa; the belts of Yilgarn and Pilbara blocks in W-Australia).

The komatiitic series range in MgO-content up to 30 w-%. For the greatest part of these rocks they satisfy the definition; low TiO_2-content ($<$ 1.0 w-%) and a $CaO/Al_2O_3 \gtrsim 1$ proposed by Arndt 57

This definition, however, very unsatisfactorily include rocks which should be named komatiites. E.g. the TiO_2-content can be higher than 1 w-% for even ultrabasic high-magnesian extruded liquids. The most important constraint should in either case be that the rocks can be proven to represent true magmatic liquids, which have extruded on the earth's surface (ocean floor ?).

The ultrabasic greenstones in Kautokeino have well preserved pillows and gasblebs, and signs of macro-spinifex textures have been observed though they are uncertain. Individual lava-benches of ½ - 1 m in thickness can be identified. At the bottom of these, accumulation of ol-phenocrysts has occured, which become gradationally less abundant towards the top of a bench where (at the surface) numerous gasblebs can be seen (subarile extrusions).

Apparantly the volcanics consist of a continuous series from the low-Mg tholeiites through the medium MgO (10-17 w-%) basaltic komatiites (BK) and to the ultrabasic high Mg komatiites, peridotitic komatiites (18-30 w-% MgO; PK). However, as seen from the Ca-Al-Mg plot, a series of komatiites also have a very high CaO/Al_2O_3-ratio (~1.5) as opposed to the normal value of about 1.0 for the majority of the komatiites. Only one of these with high CaO/Al_2O_3-ratio is a PK, (F16) the others are BK. This PK may have become affected by secondary alteration phenomena by the addition of carbonate. As will be seen later, the main cause for the high Ca/Al-ratio of BK is Al-depletion by magmatic mechanisms. However, most of the BK have CaO/Al_2O_3-ratios close to 1.0.

Variation diagrams, fig. 3, show the behaviour of some major elements and incompatible and compatible trace elements. The $Zr-TiO_2$ plot shows the incompatible nature of these two elements, although there are some scatter, they plot around the line of chondritic. Ti/Zr (~100-110) and the concentration of these two elements will approximately reflect the degree of partial melting of the source (mantle material) and/or the degree of differentiation of the basaltic magma. The partial melt of a mantle source will be in equilibrium with a specific mineral assemblage (ol + opx ± cpx ± gnt ± spinell ± plag) and the major elements like Mg, Ca, Al and Fe will be controlled by these mineral phases.

The $MgO-TiO_2$, $CaO-TiO_2$ and $Al_2O_3-TiO_2$ plots in fig. 3 show how these elements must be controlled by several phases for the tholeiitic series. Isobaric univariancy must be supposed to get almost constant composition for these oxides ($FeO-MgO-CaO-Al_2O_3$; 4 independent components in the magma). The presence of at least 4 phases, 3 solids + magma must be present to satisfy the observed composition of the tholeiites, and ol + opx + cpx + spinell is the probable composition of the residue. Gnt may be present as is seen from the HREE (see fig. 4) for some of the samples. For most of the samples from komatiitic series it is seen that CaO and Al_2O_3 apparently behave like incompatible elements, although some complexities appear.

An incompatible nature reflects the disappearance of several of the above named mineral phases from the residue; cpx and spinell and possibly opx are exhausted at a specific temperature and degree of melting, and the only major mineral phase left is olivin, which controls the Fe-and Mg contents of the liquid. As further melting occures, the MgO-content of the liquid now will increase rapidly, reflecting the amount of olivin being melted. Ol has a preferrence for Mg over that in the liquid. However, the FeO-content will not significantly be changed.

The MgO-TiO_2 relations for the komatiites show the great range of MgO for these rodes. Most of the komatiites satisfy the definition that they shall contain less than 1.0 w-% TiO_2. However, 3 PK and 4 BK show higher values 1.1, 1.3 and 1.5 for the PK, and from 1.5 to 2.1 for the BK. Two other BK and one PK have 0.8 w-% TiO_2 and can be put in the same group. The Al-and Ca-contents apparently also have been controlled. It seems unreasonable that the observed high Ti-contents could have been derived only by some partial melting process, as the high Mg-contents (up to 22 w-%) demands a high degree of melting in the mantle. Fractionation processes increasing the incompatible element concentrations, controlling Al and Ca, and at the same time maintaining a high Mg-value of the liquid is more probable mechanism. This imply that the main mineral fractionating must be gnt, which has a relatively low K_D^{Mg} (mineral-liq.). The spread in the CaO/Al_2O_3-ratio for the BK reflects the difference to what degree Al and Ca have been controlled, and here probably the amount of fractionating cpx is important.

The HREE-depleted patterns support the conclusion that gnt-fractionation may have caused the described compositional features (see fig. 4). The same is shown by the behaviour of Y, which is partioned into gnt in the same way as HREE:

Model calculations can test these features, but is beyond the scope here. As the rest of komatiites is concerned, with compositions in correspondence with the definition mentioned above, most of these also show deviations from the chondritic ratios (Al_2O_3/TiO_2). However, they are devided into two groups, one close to the chondritic line ($Al_2O_3/TiO_2 \sim 20$) and another depleted in Al ($Al_2O_3/TiO_2 \sim 14$ on the mean). The Al-depleted samples group around the chondritic line for the CaO/TiO_2 ratio, but also some Ca depletion can be seen for the PK. A small amount of gnt in the residue can explain the features. The HREE-patterns for these PK are almost flat; however, a small depletion is observed; the $(Tb/Yb)_N$ is on the mean 1.1. Gnt fractination will cause a greater change of this ratio than the same amount of gnt present in a residue after partial melging.

Higher degrees of partial melting probably caused disappearance of gnt in the residue as is indicated for two of the samples, one of which has 30 w-% MgO (s.no.59). The other of these seems to have been affected by alteration, at least with respect to Ca and Mg ($TiO_2 \sim 0.16$ w-%, s.no. F 16).

S.no. 59 has a flat HREE-pattern or slightly enriched ($(Tb/Yb)_N \sim 0.85$). The same is true for the BK falling on the chondrite line for Al_2O_3/TiO_2. The latter could show that "true BK" is formed at other P-conditions than the PK. The other BK with abnormally high TiO_2-contents may have been developed from PK by differentiation.

The high Cr-contents (fig. 3) are demonstrated for the komatiitic series. A similar trend is obtained for Ni. The highest concentration is for s.no.59 and F 16 A (~3400 ppm Cr). The increase of Cr with increasing MgO-content (partial melting) clearly show the release of Cr as cpx and ol dissolves in the melt. The high Cr-(and Ni)-contents clearly demonstrate the primary na-ture of these melts for most of the komatiites, although some gnt fractiona-tion may have occured as indicated in the discussion above. This is the opposite of what is the case for the tholeiitic series, for which all but three exceptions, have Cr-contents less than 200 ppm, and mostly concentrated around 100 ppm. This reflect that considerable differentiation of these magmas has occured, fractionating cpx and olivin and chromite ± plag. ± gnt. This feature is also characteristic for MORB of which primary magmas are more seldom observed.

The three exceptions above have Cr-contents in the range 400 - 500 ppm and may represent primary magmas.

<u>The younger volcanics</u>.

In fig. 2 these rocks are compared with the older series in the A M-plot and only show the overlap with the tholeiitic series. According to trace element contents (not shown here) they fall into two groups; one with low concentrations especially with respect to LIL-elements and one with relatively high concentrations. No trends can be obtained in variation diagrams, which may be attributed to an origin from different source regions in the mantle.

SUMMARY.

Many different mechanisms seem to have occured as seen from the composition of the komatiites, and a grouping of this series can be obtained as follows :

1. Peridotitic komatiites ($MgO \geqslant 18$ w-%).
   a) High-Ti-type (0.85 - 1.54 w-% TiO_2)
      ⇒ gnt. fractionation
   b) Normal low-Ti type.
      (i) Al-depleted (and Ca)
         ⇒ gnt. in residue
      (ii) Al-undepleted (only the most MgO-rich)

   Primary magmas.

2. Basaltic komatiites ($MgO \leqslant 17$ w-%).
   a) High-Ti-type (0.8 - 2.1 w-% TiO_2)
      ⇒ gnt ± cpx fractination
   b) Normal low-Ti type (chondritic Al/Ti and Ca/Ti)
      primary magmas

The normal type BK and the PK seem to orginate from different source regions. However, for type 2 a) (BK) it is difficult to trace their origin, but as will be seen later, they are probably fractionated from PK-magmas.

The presence of gnt in the source region of PK indicate a relatively great depth of formation, while a possible higher level origin for the normal BK 2 b) is possible.

The Al-depletion of PK and high Ti-contents seen for the komatiites are uncommon for the archean greenstone belts. The finnish and canadian, and most australian belts, show chondritic Al/Ti-ratios and near chondritic Ca/Ti-ratios. In that way the chemistry of the Kautokeino greenstones (similar to the Karasjok greenstones) resembles more that of the 3.8 b.y. old greenstones in Barberton (S-Africa) and Pilbara (Australia)

($Al_2O_3/TiO_2 \sim 11$; Kautokeino :

$Al_2O_3/TiO_2 \sim 13\text{-}14$; chondrite : ~ 20).

It has been suggested by several authors that the presence of gnt in the source region of komatiites could indicate a nature of the mantle early in the archean, which was different from that in the latest archean. Whether this was a chemical difference or it reflects a deeper origin ,by the presence of gnt is not understood.

If the feature reflects a time dependent variation,it would mean that the Kautokeino volcanics originated as far back as middle archean.

The tholeiitic series might represent highly differentiated varities from the komatiitic series. As will be seen from the REE-patterns, this may be true for some of them. However, many of them probably formed in a different source region than the BK and PK (flat LREE-patterns).

REE,older volcanics.

In fig. 4 and 5 the different types of REE-patterns obtained are shown. The komatiitic series (fig. 4) is devided in two main groups : LREE-depleted and LREE-enriched patterns.

These two groups can further be devided into two sub groups : HREE-depleted and flat HREE-patterns. Thus we get 4 groups 1 a & b (PK) and 2 a & b (BK).

The REE-patterns of the tholeiitic series (fig. 5) can be devided in the same way in LREE-depleted and -enriched. In addition the tholeiites contain a group of flat LREE-patterns. All these three groups obtained may have either flat or depleted HREE.

The PK is below 10 x chondrite, except for the gnt fractionated varieties (155 and 3). The least fractionated is s.no. 59, which have 3.5 x chondrite.

The BK-series may be up to 30 x chondrite for La, but the HREE lie at the same niveau as those for most of the PK, or only slightly more enriched. The tholeiitic series lie in the range 10 - 40 x chondrite.

Summary :

1 a) PK : LREE depleted; HREE flat

1 b) PK : LREE depleted or flat; HREE depleted

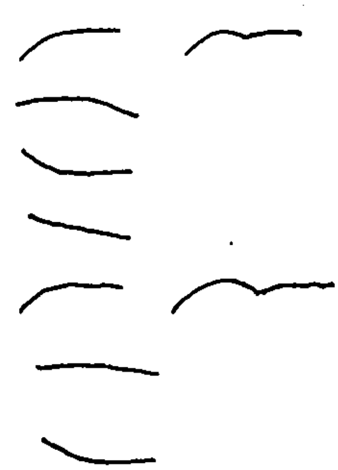
2 a) BK : LREE enriched; HREE flat

2 b) BK : LREE enriched; HREE depleted

3 a) TH : LREE depleted; HREE flat

3 b) TH : LREE flat; HREE flat or depleted

3 c) TH : LREE enriched; HREE flat or depleted



Groups 1 b) and 2 b) correspond to the high-Ti komatiites discussed above, and demonstrate the involvement of gnt in the production of these liquids. The Al-depleted PK is grouped in the flat HREE-group (1 a). Most of these, however, show a slight HREE-depletion. (Mean $(Tb/Yb)_N \sim 1.1$), but have been grouped as flat to differentiate from the real HREE-depleted PK and BK ($(Tb/Yb)_N \sim 1.7$-2.0). At Barberton $(Gd/Yb)_N$ lie at 1.25-1.4 (The $(Tb/Yb)_N$ will become lower), and imply that probably only a smaller amount of garnet has been involved in PK-production in Kautokeino relative to the Barberton greenstones.

S.no. 59 have $(Tb/Yb)_N \sim 0.85$ and probably show that gnt was not present in residue, as also has been concluded earlier.

The variation of the LREE-patterns seen, can be produced by inferring a one stage of small percentage melting of mantle material producing a LREE-depleted residue and LREE-enriched melt. The latter may rise through the mantle and cause metasomatism of the above lying regions, which is the source region for the BK series (LREE-enriched). This is the model which is accepted amoung most authors to explain the nature of the different source regions. It seems as PK is mainly produced in LREE -depleted regions, while the BK is produced in the enriched regions mainly. The tholeiitic series seem to have had their origin in either regions and in addition from a region of undepleted LREE.

The possibility that one type of pattern may be produced from another by fractionation processes can be ruled out.

REE younger volcanics.

In fig. 6 the two types of patterns are shown. One is slightly to strongly LREE-depleted and flat HREE (10-20 x chondrite); the other is LREE-enriched and HREE-depleted (LREE = 65-70 x chondrite and HREE = 10-20 x chondrite).

It may be possible to produce the second pattern from the other by fractionation processes (gnt + cpx). To test this it is necessary to do some model calculations. However, it cannot be ruled out the two types originated from different source regions.

Mantle heterogeneities.

The heterogeneities of the mantle as apparently is implied from the REE-patterns (and also was suggested from other trace elements and from major elements above), may be a feature which is produced simultaneously, i.e.as a part of the same process as the production of PK- and BK-magmas. The other possibility is that the heterogeneities is a characteristic of the mantle produced by some special event and persisted through a shorter or longer period of time. To get information about this, isotope studies must be performed. At present no decisive conclusions has been drawn from Pb, Sr or Nd isotope studies in various greenstone belts.

The initial Sr-isotopes show a wide scatter in various terrains and could indicate isotope heterogeneities in the mantle. However, the cause for this variation can be attributed to contamination processes and secondary alteration processes.

The Pb-isotopes (μ -values) show a narrower range than the Sr-isotopes, but may indicate that the heterogeneities have persisted through time.

The Nd-isotope studies at present indicate only very small deviation from the chondrite evolution curve for the mantle in the archean. However, here awaits more detailed studies and more data to see if this is true.

In the next I shall present some preliminary Rb-Sr-isotope studies on the volcanics from Kautokeino, after first considering the nature of Rb-Sr fractionation processes.

Rb-Sr-K of the older volcanics.

Fig. 7 shows Rb-TiO_2, Rb-Sr and Rb-K_2O variation diagrams. Before, it was shown that the content of TiO_2 is a measure of the degree of partial melting and fractional crystallization; the TiO_2-Zr plot showed the trend from highly developed tholeiitic magmas towards the less developed komatiitic series. The incompatible elements will behave like that. Rb is a LIL-element (large-ion lithophile element) and groups among the "highly incompatible" elements together with e.g. La, and should reflect the depleted or enriched nature of the source regions in the same manner as La.

The Rb-TiO_2 plot shows a very great scatter and no obvious trends can be obtained, as it should if Rb reflected only primary magmatic features. The great scatter must instead show a secondary alteration process mainly causing an increase of Rb for many of the samples. The three lines drawn on the plot represent the trends the volcanics would have taken if their origin were from depleted, undepleted or enriched source regions respectively (Ti/Rb $\sim$ 2700, 1200 or 550-600). Most of the komatiites plot along the depleted trend as is expected from the REE-patterns and many of the tholeiitic series do the same. As seen all the high-Ti basaltic komatiites (BK) also plot along this trend, which supports the suggestion that they may represent gnt-fractionated komatiitic liquids (PK).

Two of the BK (with $TiO_2 \approx 0.85$ w-%) originally were produced from a depleted source (indicated by REE) and it must be concluded that these have got introduction of secondary Rb as seen from the TiO_2-Rb plot.

Some of the samples (BK and TH) with LREE-enriched patterns fall along the enriched line in the Rb-Ti plot (35, F 32 and 22). Other samples (TH) with undepleted patterns lie along the undepleted line in the same figure.

The K-Rb plot very clearly shows the trend for the altered samples and simultaneous secondary introduction of K and Rb with a K/Rb-ratio of around 350.

In this plot one can also pick out the depleted, undepleted and enriched magmatic trends (Rb is more incompatible than K) :

1) K/Rb (depleted) : 1000-3000

2) K/Rb (undepleted) : 750-1100

3) K/Rb (enriched) : 600

In the Rb-Sr plot same three types of patterns may also be drawn.

The plot shows a great scatter, but some system can be got. Some of the samples seem to fall off the trends they showed in the Rb-TiO_2 plot. This may have occured by cpx- and/or plag.-fractionation, following the arrows as indicated in the Rb-Sr plot; e.g. s.no. 3, 15, F 26 and 35. The process produces a range in the Rb/Sr ratios, though not a very large range, for magmas from each of the source regions.

<u>Rb-Sr-isotopes</u>.

I have analyzed the Rb-Sr-isotopes for samples from each of the three types of source regions discussed above. These samples apparently show Rb-Sr relationships of original magmatic nature :

I. Depleted samples ; Rb/Sr (source) : 0.005-0.015
s.no. 164, 119, 15, 3.

II. Undepleted samples ; Rb/Sr (source) : 0.025-0.035
s.no. 95, F 26, 7.

III. Enriched samples ; Rb/Sr (source) : 0.050-0.060
s.no. 35, 22.

Fig. 8 a) shows the Rb(87)/Sr(86) - Sr(87)/Sr(86)-diagram for the above mentioned samples, and a reference isochron of 3000 my. is drawn through each of three groups mentioned above. The isodrons are labelled according to the groups above. The four samples belonging to group I produce an age (errochron) of 3000 $\pm$ 300 my. (2σ), which may indicate the age of the volcanics. The reference isochrons through the two other groups may indicate that isotopic composition originally was different for the three groups of rocks and thus should imply isotopic heterogeneity of the mantle in the archean. However, the few samples analyzed, especially for groups II and III, imply that the features may only be a coincidence. More work has to be done, especially on samples which can be shown to have fractionated Sr to a considerable degree, and belonging to one of the three groups mentioned above.

Some of the samples affected by secondary alteration and Rb-introduction, as seen from the Rb-TiO_2- and Rb-K_2O plots, have also been studied isotopically, and in fig. 8 b) the results are shown in the Rb-Sr isotope evolution diagram. There is some scatter, especially two of the samples fall above the others.

The samples (two of them omitted) produce an age (errodron) of 1900 $\pm$ 200 my. (2σ), which is the time of Rb-introduction. The scatter is probably due to isotopic differences in the rocks at the time of alteration. The I.R. = 0.7025 do not conflict with a 1000 my.-period between the time of rock formation and alteration processes taking places, if an original Sr (87/86)-ratio of 0.7009 is taken for the volcanics.

Conclusions on the Sr-isotopes.

By assuming different source regions for the volcanics according to the REE-patterns and define the type of Rb-evolution for the volcanics characteristic for each of these regions, it has been possible to see which samples are least affected by secondary alteration, thus preserving the original Rb-contents.

A possible age of 3.0 b.y. I.R. = 0.70090 is obtained for the depleted samples. The I.R. falls on the single stage Sr-isotope evolution curve, with a Rb/Sr-ratio of 0.026, by 3.0 b.y. This alone indicates that isotopic heterogeneities did not exist in the mantle in the archean underneath Kautokeino. Thus the indication of groups II and III that heterogeneities existed may not be true. However, the possibility also arise that the undepleted and enriched regions have persisted through time while the depleted nature only is produced simultaneously with the PK-magmas.

THE GRANITE-DIORITE GNEISSES.

The gneisses east of the greenstones range in composition from granodioritic to quartz dioritic. The major elements will not be discussed here. Some trace elements have been used, namely Rb-Sr-Ba-Sc, to try to see if the elements follow some sort of magmatic development among the gneisses. I will assume that Rb behave as an incompatible element during some magmatic process producing the rocks. Rb therefore will be a function of degree of partial melting or (/and) fractional crystallization; i.e. $F = Rb_o/Rb$ where F is the fraction of magma relative to the residual solids or fractional minerals and Rb_o is the original content of Rb in the source material.

By plotting the ratios; Sr/Rb, K/Rb, Ba/Rb and Sc/Rb against F, it is possible to get an idea of what residual minerals are present during melting processes or what minerals fractionate to produce a differentiation series. Rb_0 has to be known and is set to 7 ppm, which is the mean for the unaltered volcanics.

In fig. 9 the resulting plots are shown. A magmatic evolution by different degrees of partial melting of a source seems to be the case. Fractional crystallization processes would lead to quite different trends.

By using appropriate partition coefficients for each element between the different minerals and a granodioritic melt, curves for the different minerals in the diagrams in fig. 9 can be constructed.

K-Rb shows that a mixture of hbl and plag was present in the residue, but do not rule out the presence of gnt and cpx. However, hbl and/or plag must have been present. The Sr-Rb- and Ba-Rb plots show the same.

The Sc-Rb plot imply the presence of ~ 10 % gnt for most of the samples. Two samples show that gnt was the main mineral in the residue for the magmas which they represent.

In fig. 10 REE for some of the gneisses is shown. The HREE-patterns are generally strongly depleted and the LREE is strongly enriched.

The $(La)_N$ concentrations range between 25 and 150 x chondrite. A concentration of 10-15 x chondrite for the source material fits the observed gneiss-values produced by 5-30 % partial melting. This indicates that the archean volcanics may be the source material.

The presence of gnt is well demonstrated by the HREE-patterns. The two samples having the greatest depletion of Sc (in fig. 9) also have the greates depletion of HREE. The positive Eu-anomaly may also have been caused by gnt for s.no. 24 and 92 (small). There are no other chemical indication of plag accumulation. No negative Eu-anomalies are observed, which suggest that plag has not been present during partial melting.

Summary on gneiss-chemistry.

The grano-dioritic gneisses have originated by 5-30 % partial melting of a hbl + gnt $\pm$ cpx-rock (garnet amphibolite). This source probably have been the archean volcanics as described before (PK + BK + TH).

Rb-Sr-isotopes on the gneisses.

All the samples used for the study above have been analyzed for Rb-Sr-isotopes to try to get an age, and see if the isotope geochemistry fit the above conclusions. In fig. 11 the Rb-Sr isotope evolution diagram for the samples is shown. There is a great scatter, but omitting two samples an age of 2400 $\pm$ 300 my (2σ) is obtained, indicating an age of early proterozoic, which could be a minimum age because partial Sr homogenization may have occured during later events. Sr-initial ratio is 0,7034 and do not preclude the greenstones being the source. However, more precise estimates of the mean Rb/Sr of the volcanics must be got. A possibility is that a crustal (i.e. gneissic) residence time of a couple of hundred million years has to be inferred to explain the initial ratio, which also may be true if 2400 my is a minimum age.

Before too far-reaching conclusions are taken, more detailed work has to be done on the gneisses to resolve eventual resetting of Sr-isotopes on local scale, as the sampling was done on a more regional scale, only for reconnaissance studies.

<u>Rb-Sr isotope studies on late to posttectonic granites.</u>

These are granitic to grano-dioritic in composition. Samples mainly from <u>one</u> body have been used (near Baharavdujavri, see fig. 1) with supplement of samples from smaller dikes and other massives further south-east.

The samples define an age of 1715 $\pm$ 32 my, omitting three of the samples, one of which lie above the isochron. This is a narrow dike cutting through a mica schist and may have got radiogenic Sr from that. The two other samples have high Rb/Sr-ratios and are dikes which could be of a younger age than the rest of the granites measured. I.R. = 0,7040, and indicates that the source material for these granites may have been the volcanics as was the case also for the gneisses discussed above.

CONCLUSIONS.

The komatiite-tholeiite series in Kautokeino has probably an archean age. The chemistry of the younger volcanics, which have been produced by later rifting, is tholeiitic and show partially more enriched REE-patterns than the older volcanics. The komatiite-tholeiite series show in general chemical characteristics common with other archean greenstonebelts. Details, however, reveal that the komatiites belong to the Al-depleted groups of komatiites as have only been recognized a few places (Barberton, Pilbara) and in that way are different from e.g. the finnish greenstonebelts. An age difference for the latter may be the case.

Gnt-fractionation of the peridotitic komatiites seem to be a common phenomena in Kautokeino, producing high Ti perioditic- and basaltic komatiites.

Normal basaltic- and peridotitic komatiites have originated from different source regions.

The associated tholeiite series may have been produced by fractional crystallization of either basaltic or peridotitic komatiitic liquids and in addition a third source also seems to be the origin for the tholeiites (flat LREE).

Sr-isotopes on the volcanics could indicate isotope heterogeneities of the archean mantle. In that case the depleted source seems to belong to regions of normal evolution of Rb-Sr-isotopes (Rb/Sr $\sim$ 0.03), while the undepleted and enriched sources may be abnormal.

The granite-diorite gneiss terrain show an origin by different degrees of partial melting of a gnt-amphibolite source, which may represent the greenstone volcanics through which they intruded. The age of 2400 my for the gneisses may be a minimum age, as the great scatter may indicate.

The younger granites (1715 my) may also have been produced by partial melting of basic metavolcanics.

Karl Inge Olsen

Karl Inge Olsen

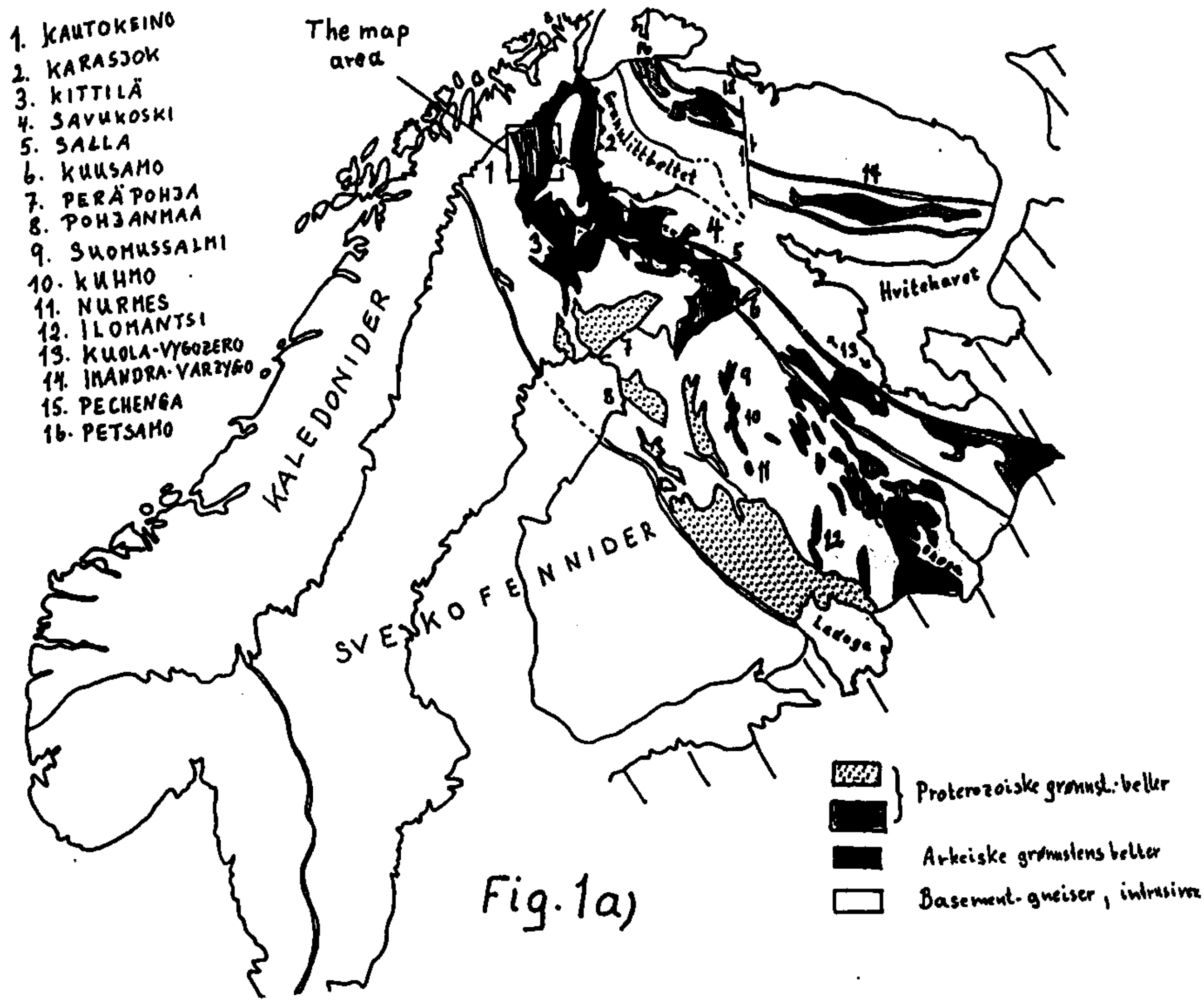

1. KAUTOKEINO
2. KARASJOK
3. KITTILÄ
4. SAVUKOSKI
5. SALLA
6. KUUSAMO
7. PERÄPOHJA
8. POHJANMAA
9. SUOMUSSALMI
10. KUHMO
11. NURMES
12. ILOMANTSI
13. KUOLA-VYGOZERO
14. IMANDRA-VARZYGO
15. PECHENGA
16. PETSAMO
The map area
KALEDONIDER
SVEKOFENNIDER
Hvitehavet
Ladoga
Proterozoiske grønnst.-belter
Arkeiske grønnstens belter
Basement-gneiser, intrusiver

Fig. 1a)

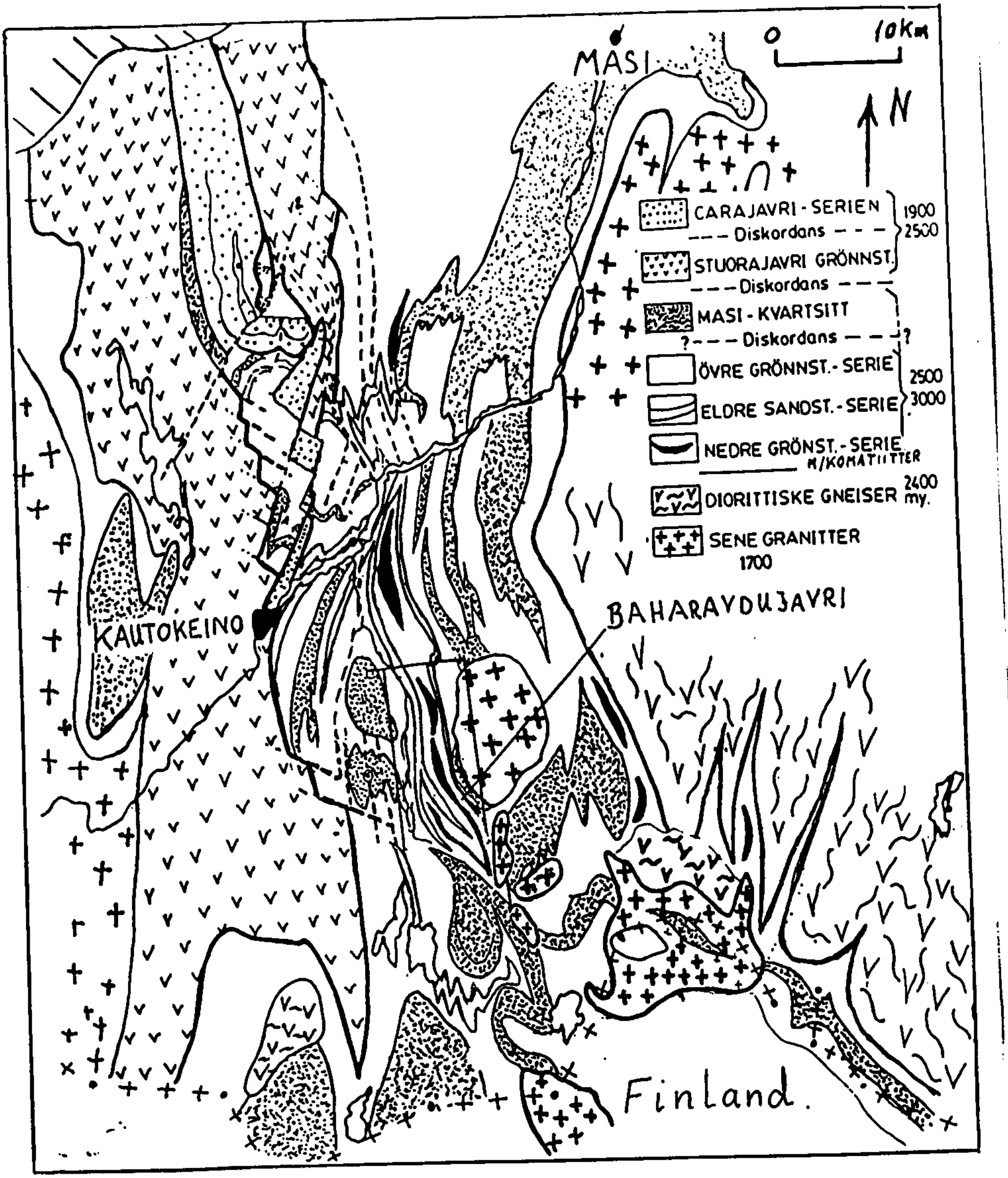
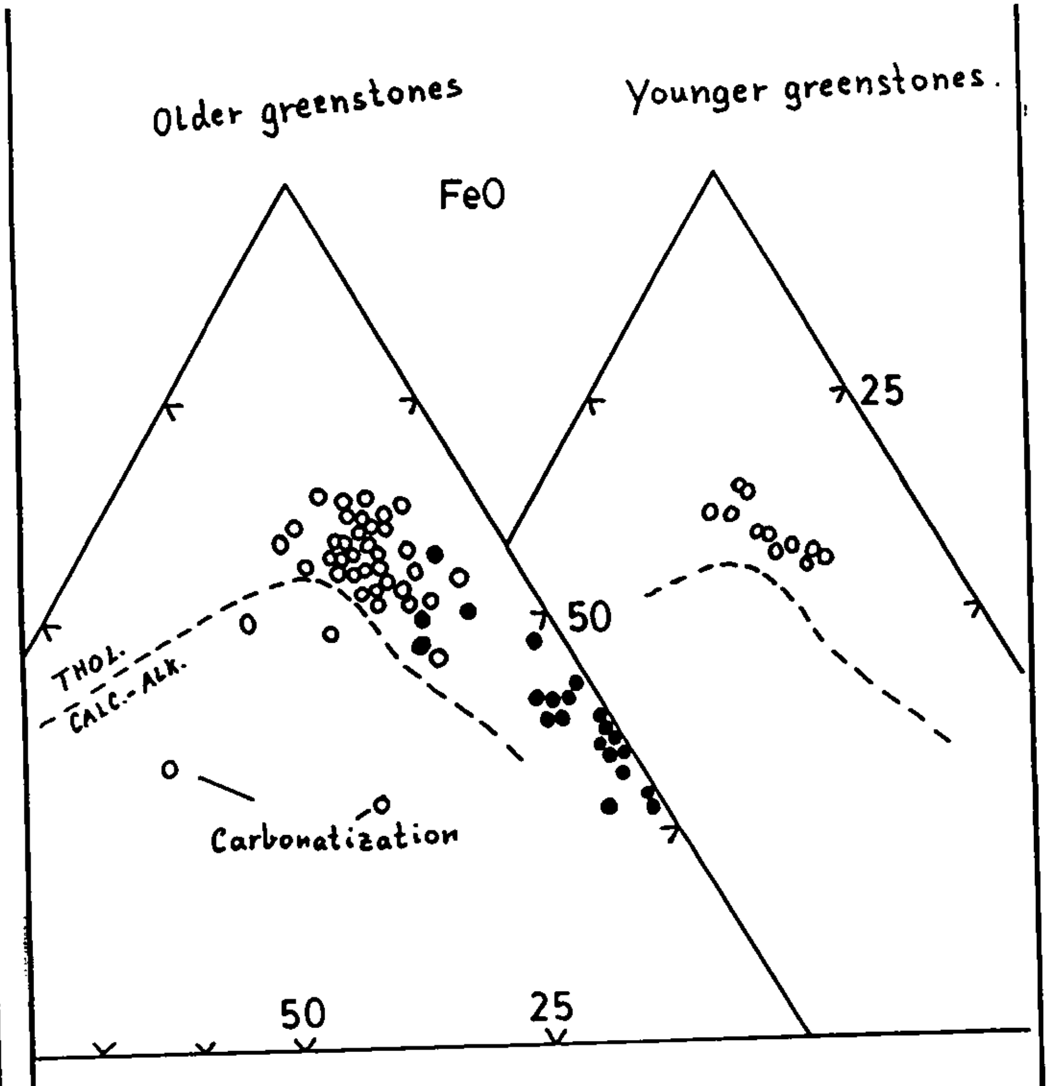


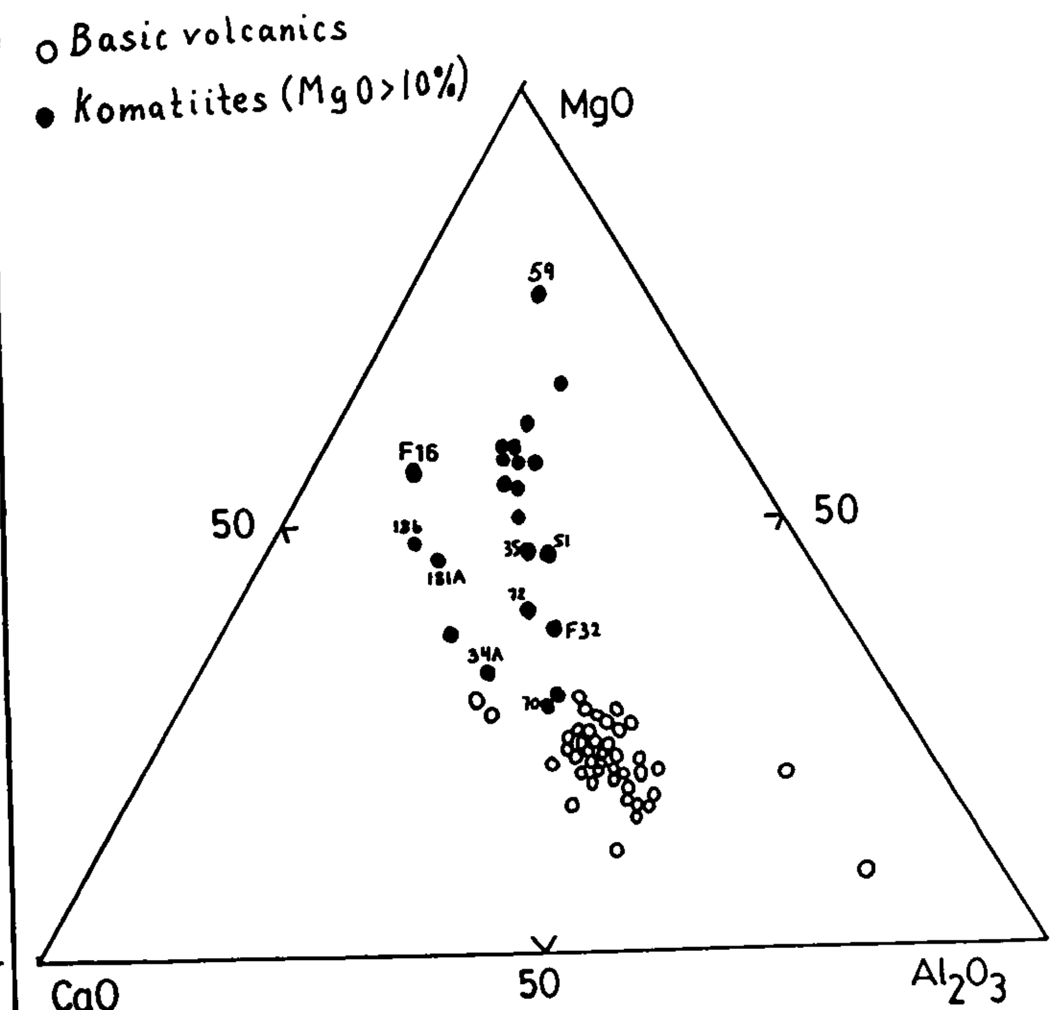
Fig. 1b) Kautokeino greenstonebelt.

Stuorajavri grønnst. = Younger greenstoneseries
Çarajavri-serien = The sandstone / argillite series
Masi-Kvartsitt = Quartzite / Mica (fuchsite)-shist / gneiss
Övre grønnst.-serie = Metatuffites / micashists / metabasalts.
Nedre —— " —— = Basic / Ultrabasic volcanics / tuffites.



Older greenstones
Younger greenstones.
FeO
25
50
THOL.
CALC.-ALK.
Carbonatization
50
25
← A(K_2O + Na_2O)
MgO →

Fig. 2A.



o Basic volcanics
● Komatiites (MgO>10%)
MgO
59
F16
136
131A
35
51
72
F32
34A
70
50
50
CaO
50
Al_2O_3

Fig. 2B.

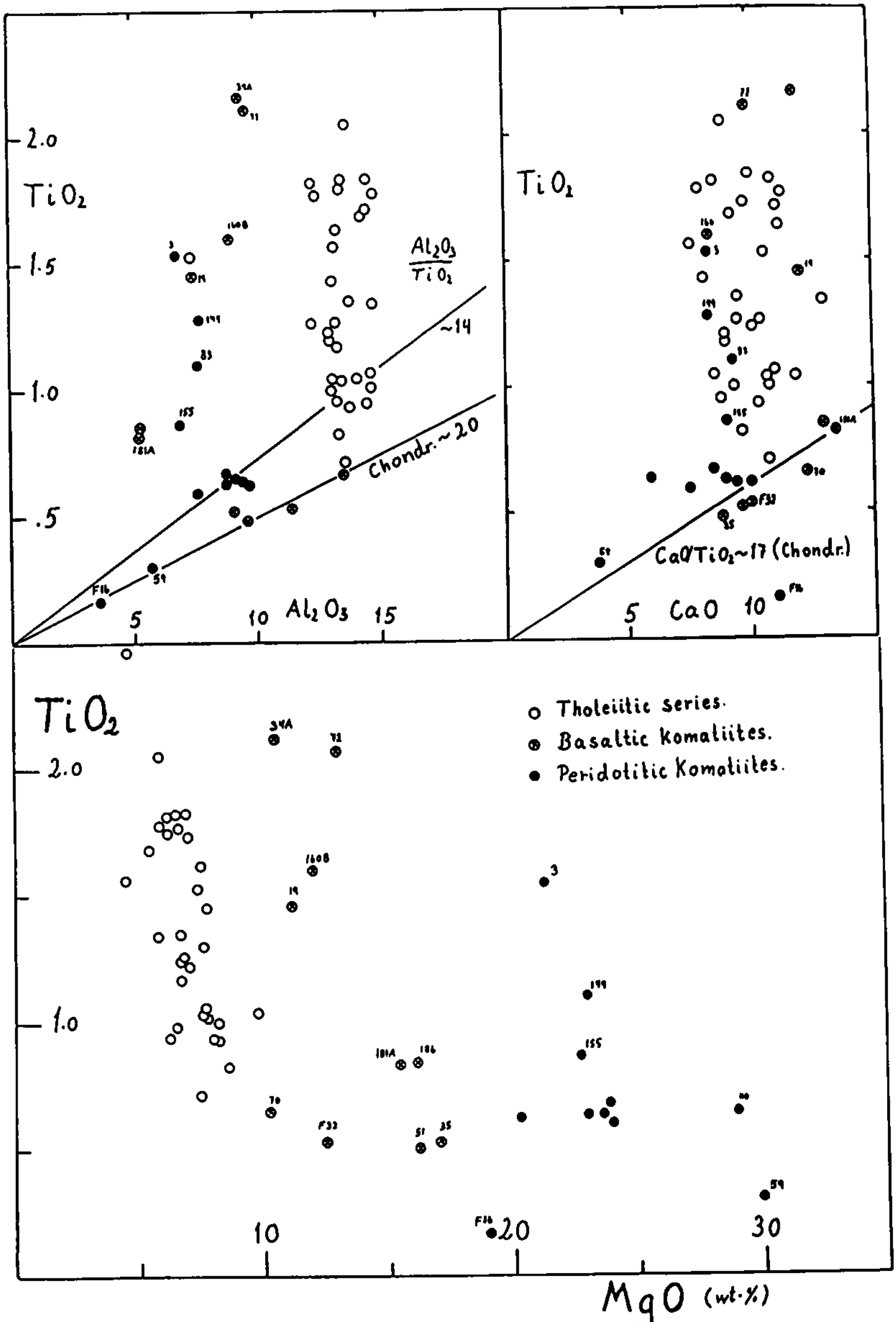

TiO2
2.0
1.5
1.0
.5
Al2O3/TiO2
~14
Chondr. ~20
5
10
Al2O3
15
TiO2
CaO/TiO2 ~17 (Chondr.)
5
CaO
10
TiO2
2.0
1.0
Tholeiitic series.
Basaltic Komatiites.
Peridotitic Komatiites.
10
20
30
MgO (wt.%)

Fig. 3a.

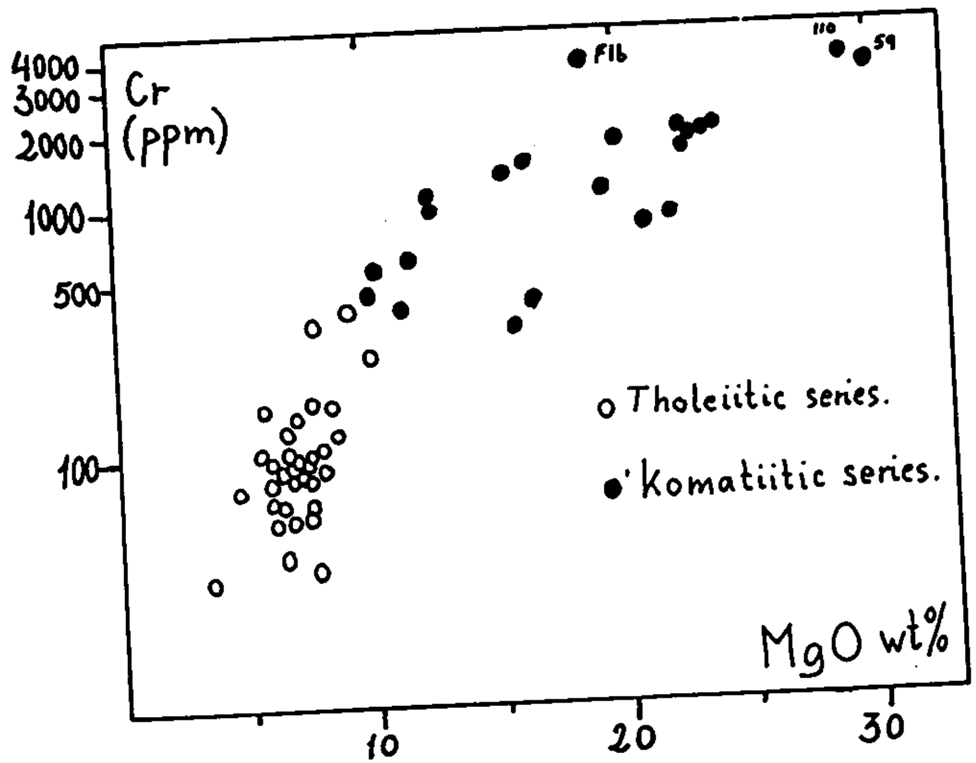
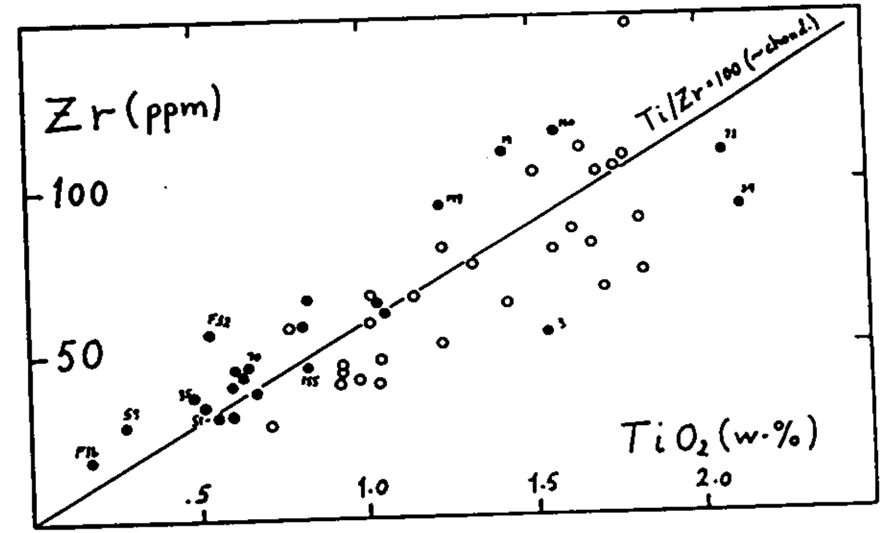
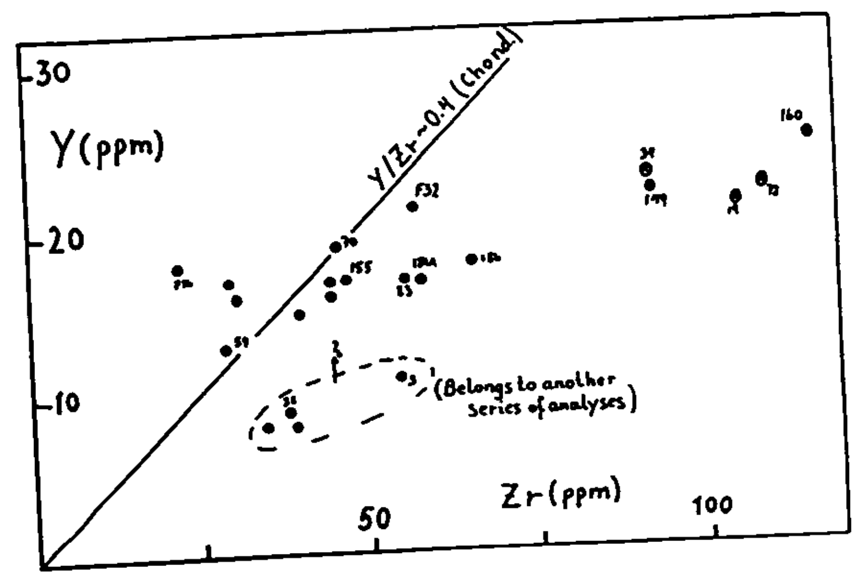

Cr (ppm)
4000
3000
2000
1000
500
100
10
20
30
MgO wt%
Tholeiitic series.
Komatiitic series.
F16
110
59

Fig. 3b.


Zr (ppm)
100
50
Ti/Zr = 100 (~chond.)
TiO2 (w-%)
.5
1.0
1.5
2.0
F32


Y (ppm)
30
20
10
Y/Zr ~ 0.4 (Chond.)
F32
155
(Belongs to another series of analyses)
Zr (ppm)
50
100
160

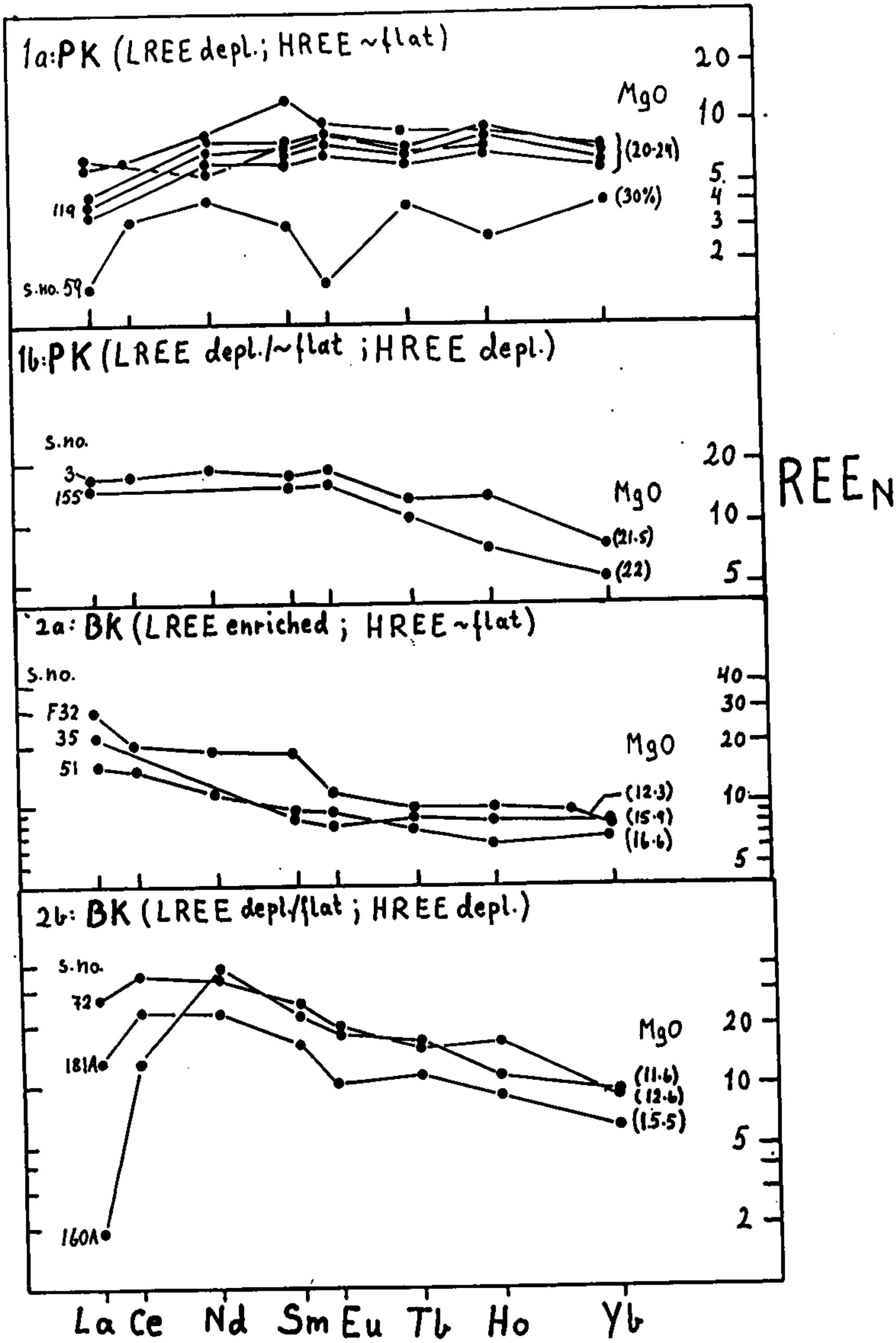

1a: PK (LREE depl.; HREE ~flat)
MgO
(20-24)
(30%)
119
s.no. 59
1b: PK (LREE depl./~flat ; HREE depl.)
s.no.
3
155
MgO
(21.5)
(22)
REE_N
2a: BK (LREE enriched ; HREE ~flat)
s.no.
F32
35
51
MgO
(12.3)
(15.9)
(16.6)
2b: BK (LREE depl/flat ; HREE depl.)
s.no.
72
181A
160A
MgO
(11.6)
(12.6)
(15.5)
La Ce Nd Sm Eu Tb Ho Yb

Fig. 4

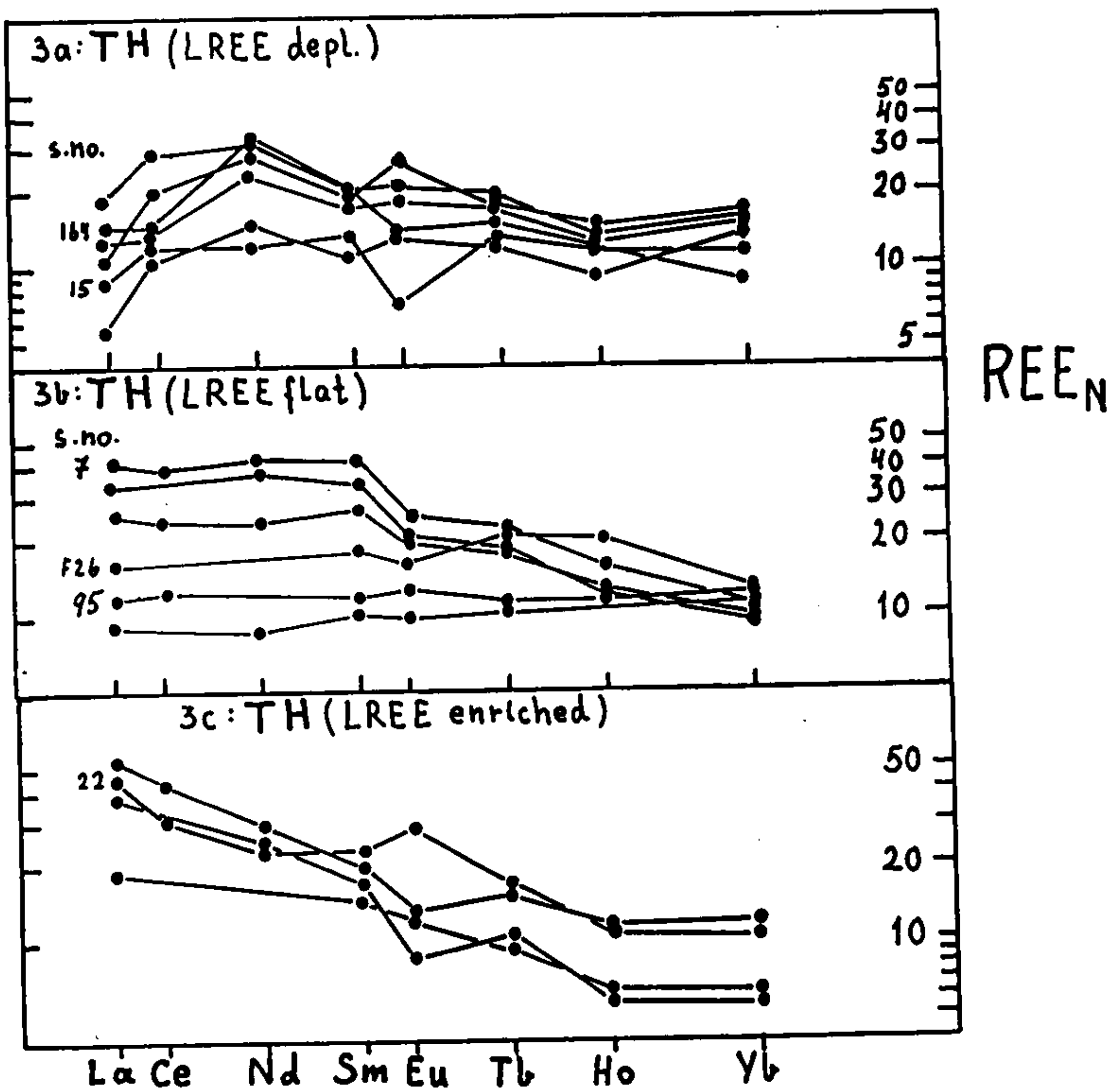

3a: TH (LREE depl.)
s.no.
164
15
50
40
30
20
10
5
REE$_N$
3b: TH (LREE flat)
s.no.
7
F26
95
50
40
30
20
10
3c: TH (LREE enriched)
22
50
20
10
La Ce Nd Sm Eu Tb Ho Yb

Fig. 5.

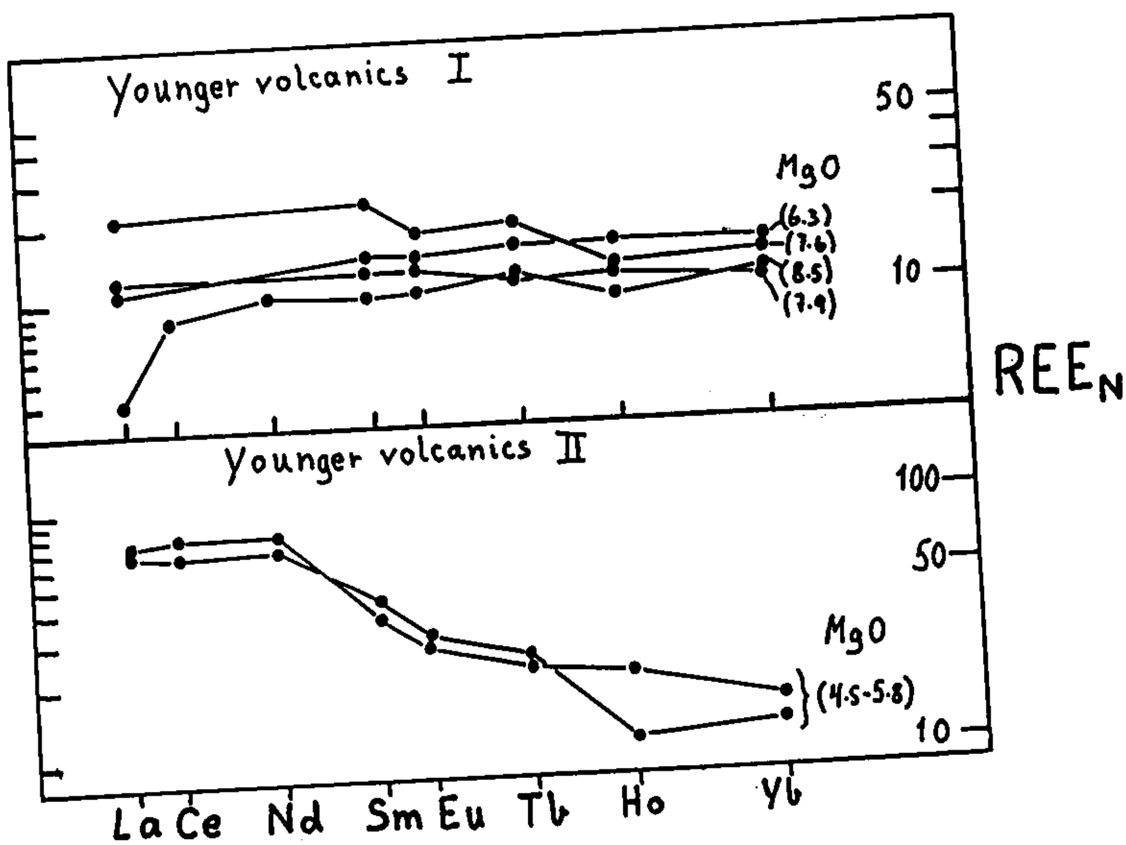
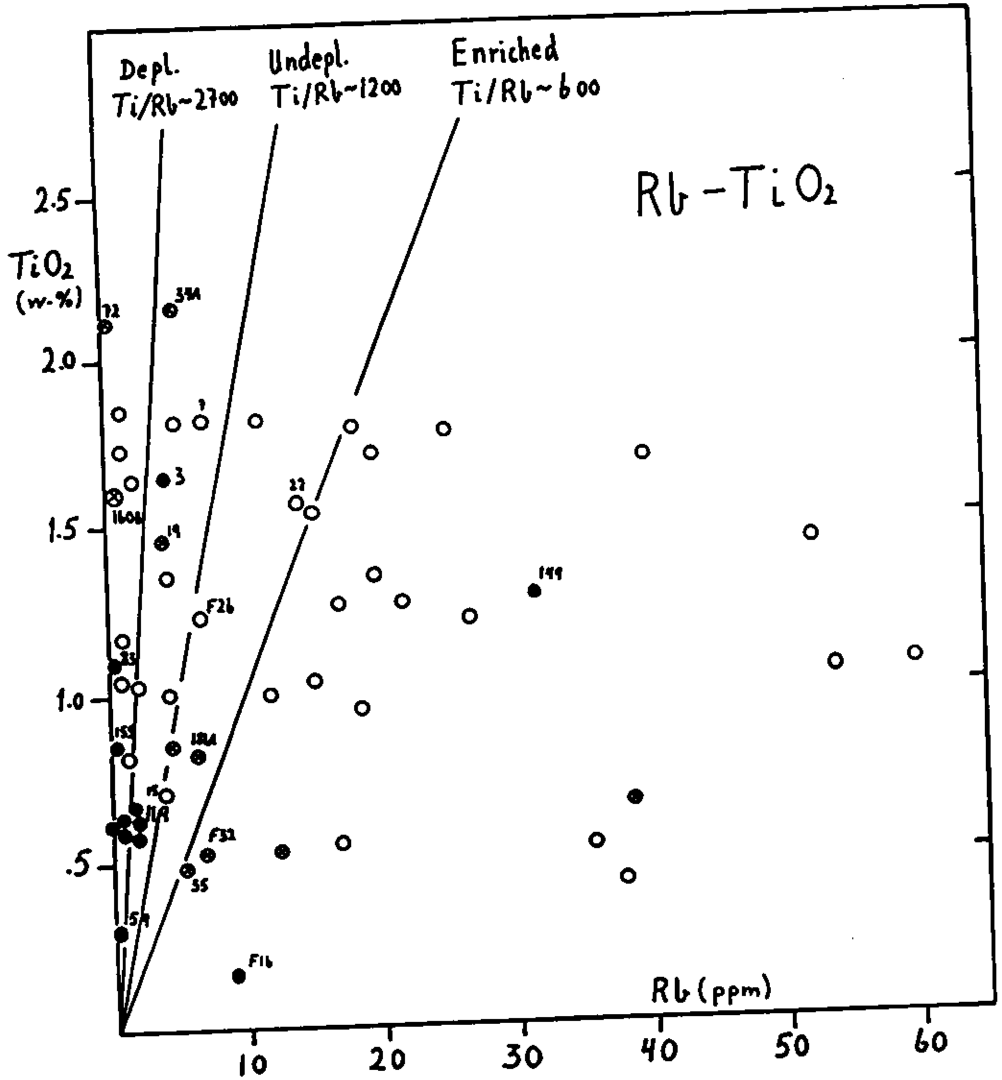

Younger volcanics I
50
10
MgO
(6.3)
(7.6)
(8.5)
(7.9)
REE$_N$
Younger volcanics II
100
50
10
MgO
(4.5-5.8)
La Ce Nd Sm Eu Tb Ho Yb

Fig. 6.



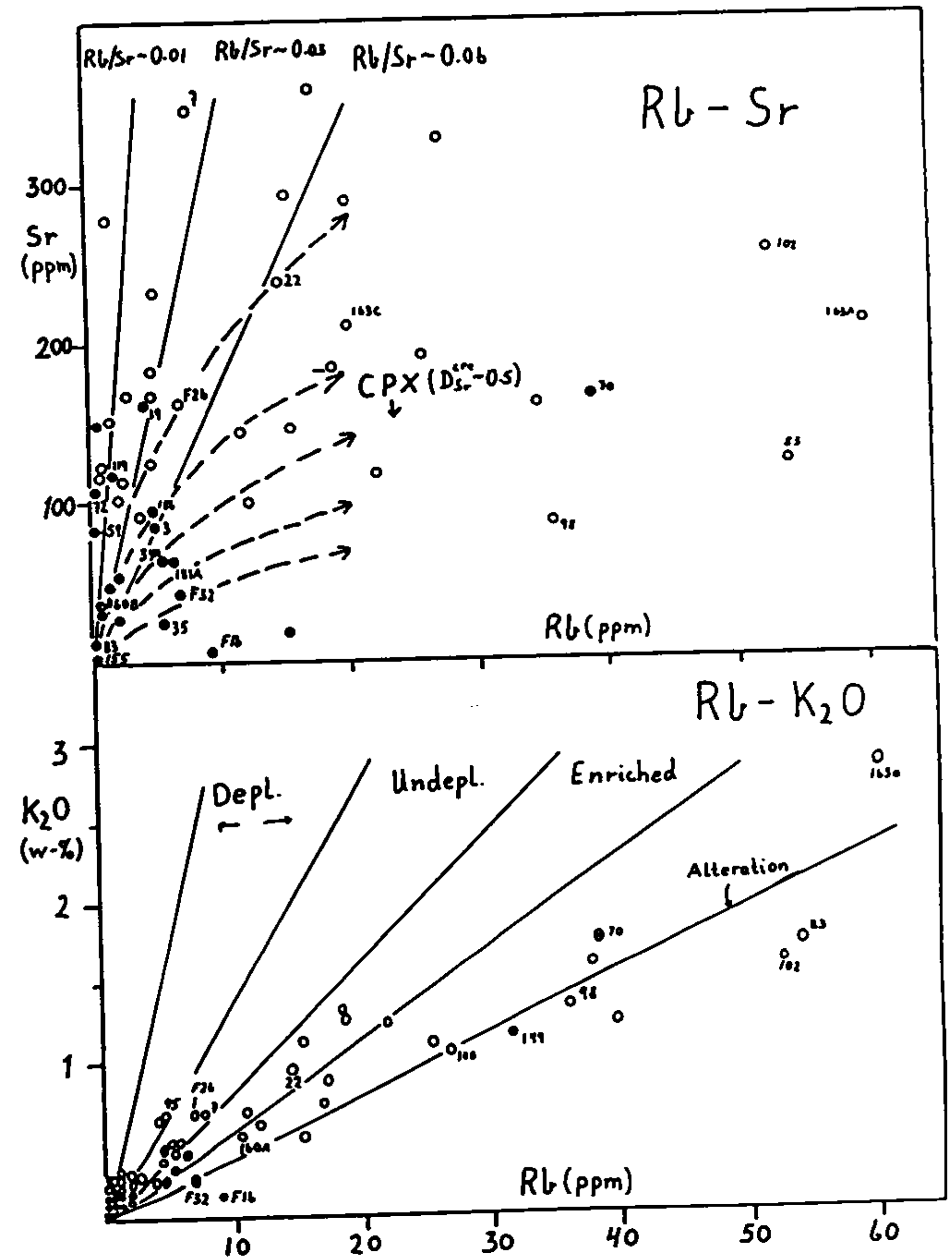


Fig. 7. TiO_2, Sr and K_2O vs. Rb for the older volcanics. In the Rb-Sr plot the liquid paths during evt. CPX-fractionation is shown. Symbols as in fig. 3a.

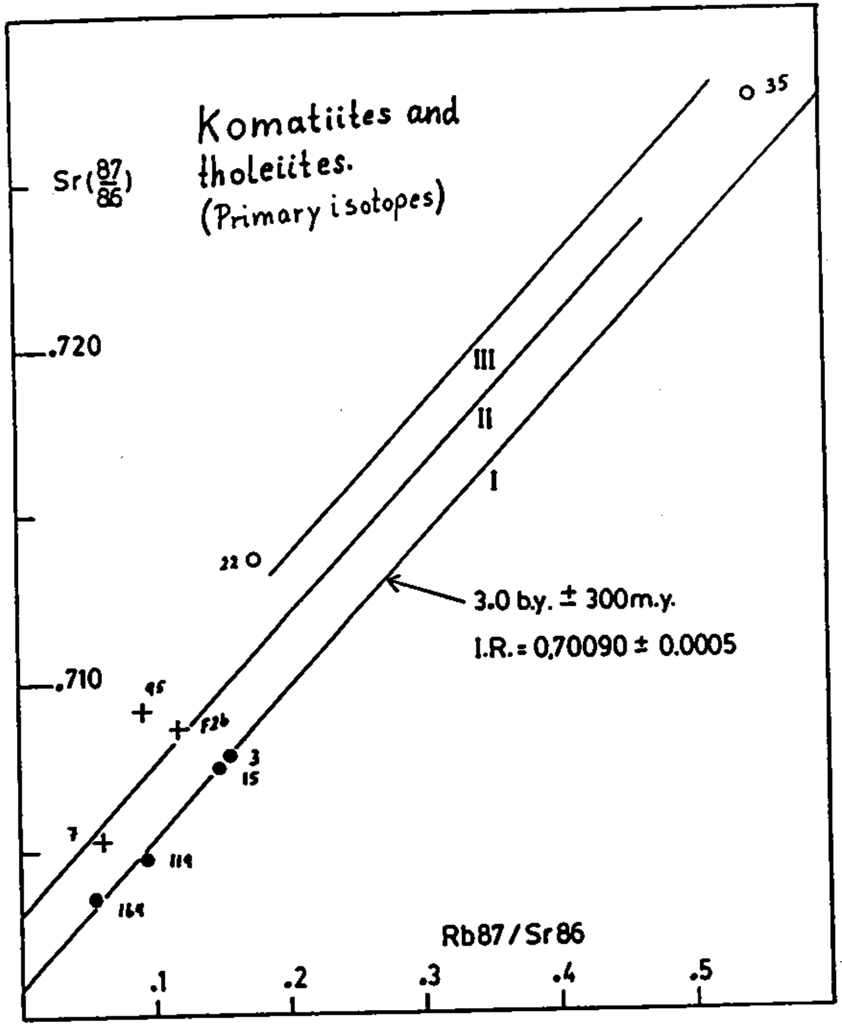
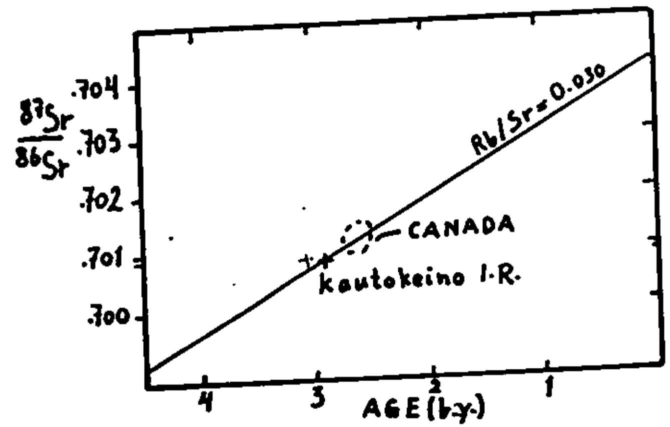
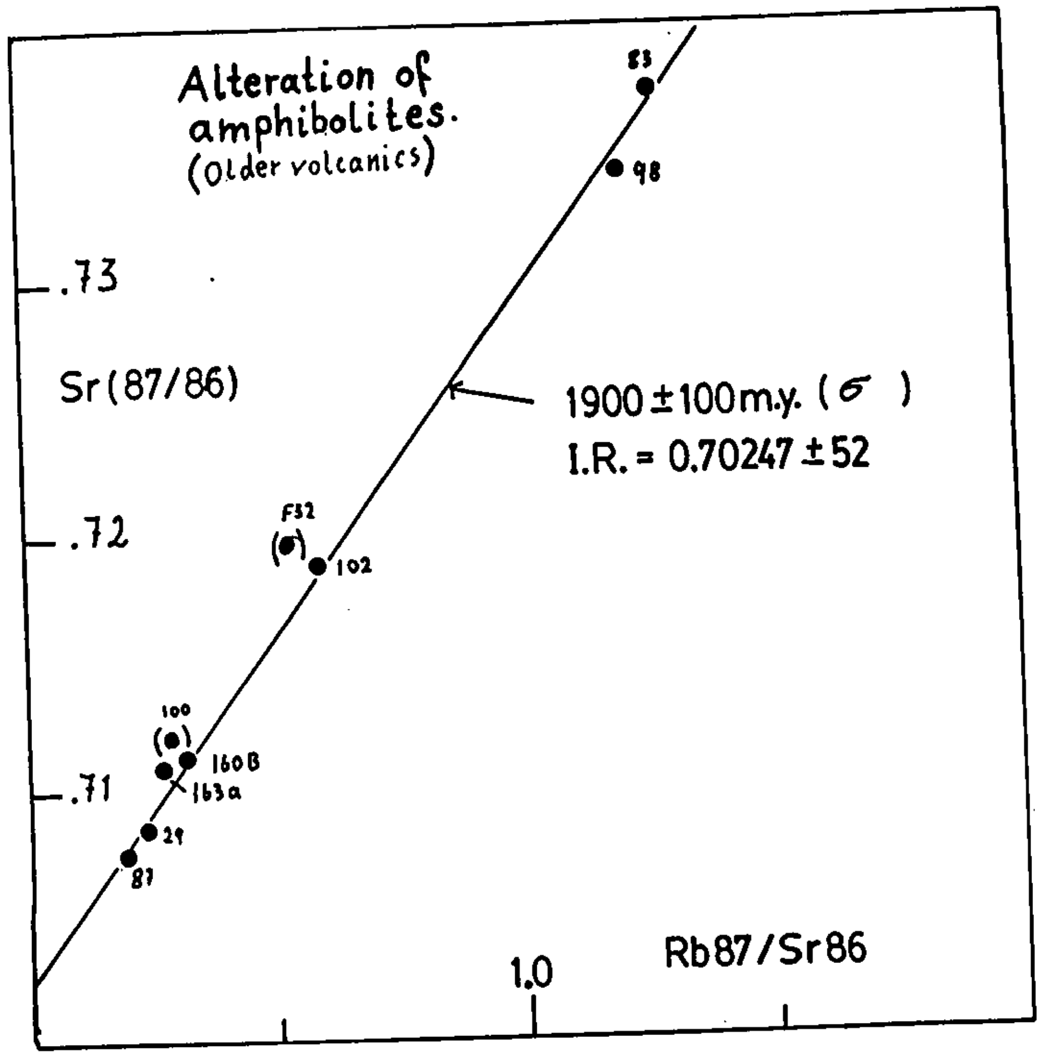


Fig. 8a. "•": Depleted-; "+": undepl.- and "o": enriched in LIL-elements.

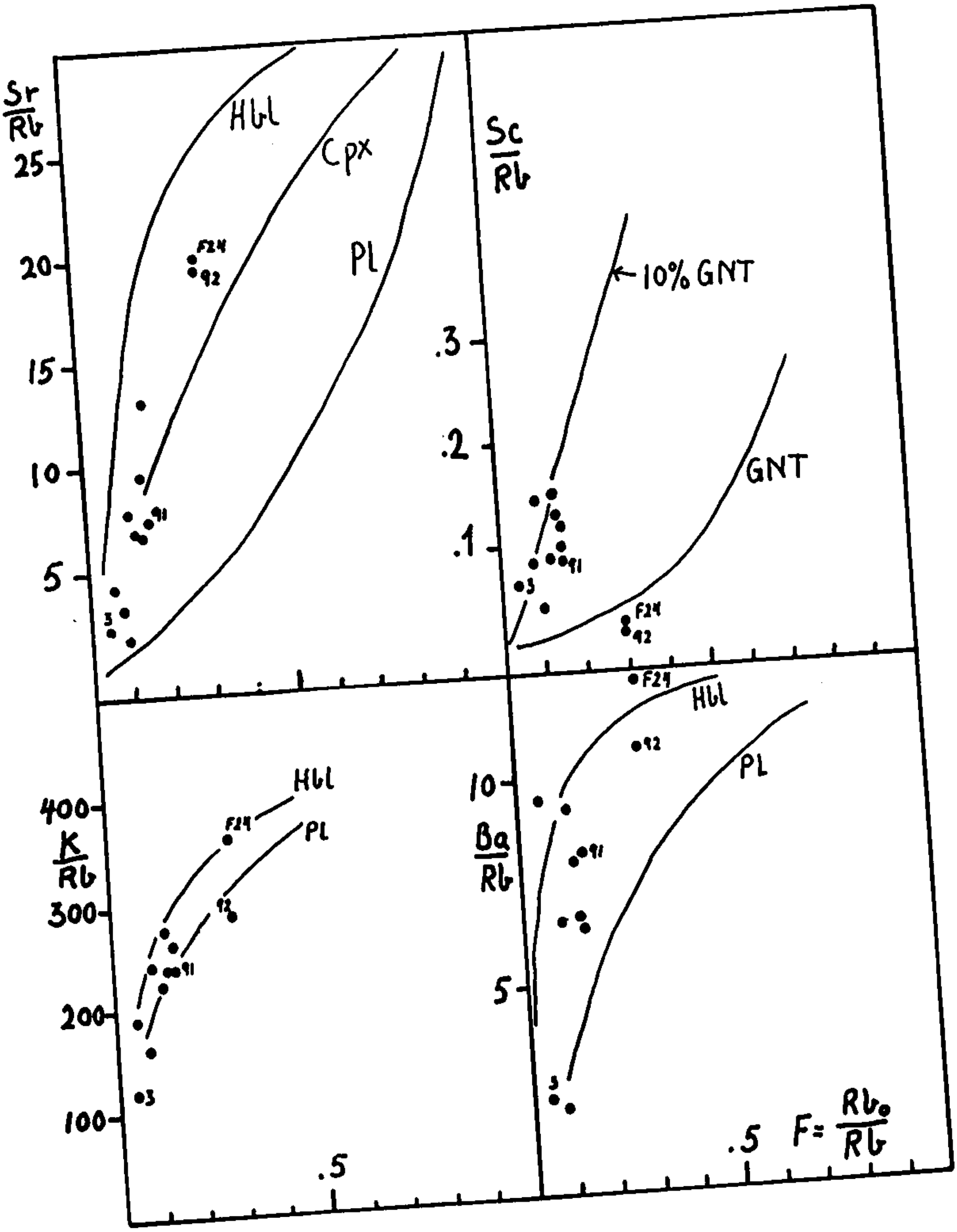




Alteration of amphibolites.
(Older volcanics)
.73
Sr(87/86)
.72
.71
83
98
1900 ± 100 m.y. (σ)
I.R. = 0.70247 ± 52
F32
102
100
160B
163a
29
87
1.0
Rb87/Sr86

Fig. 8b.

Fig. 9. The granodioritic gneisses.
Some trace elements.



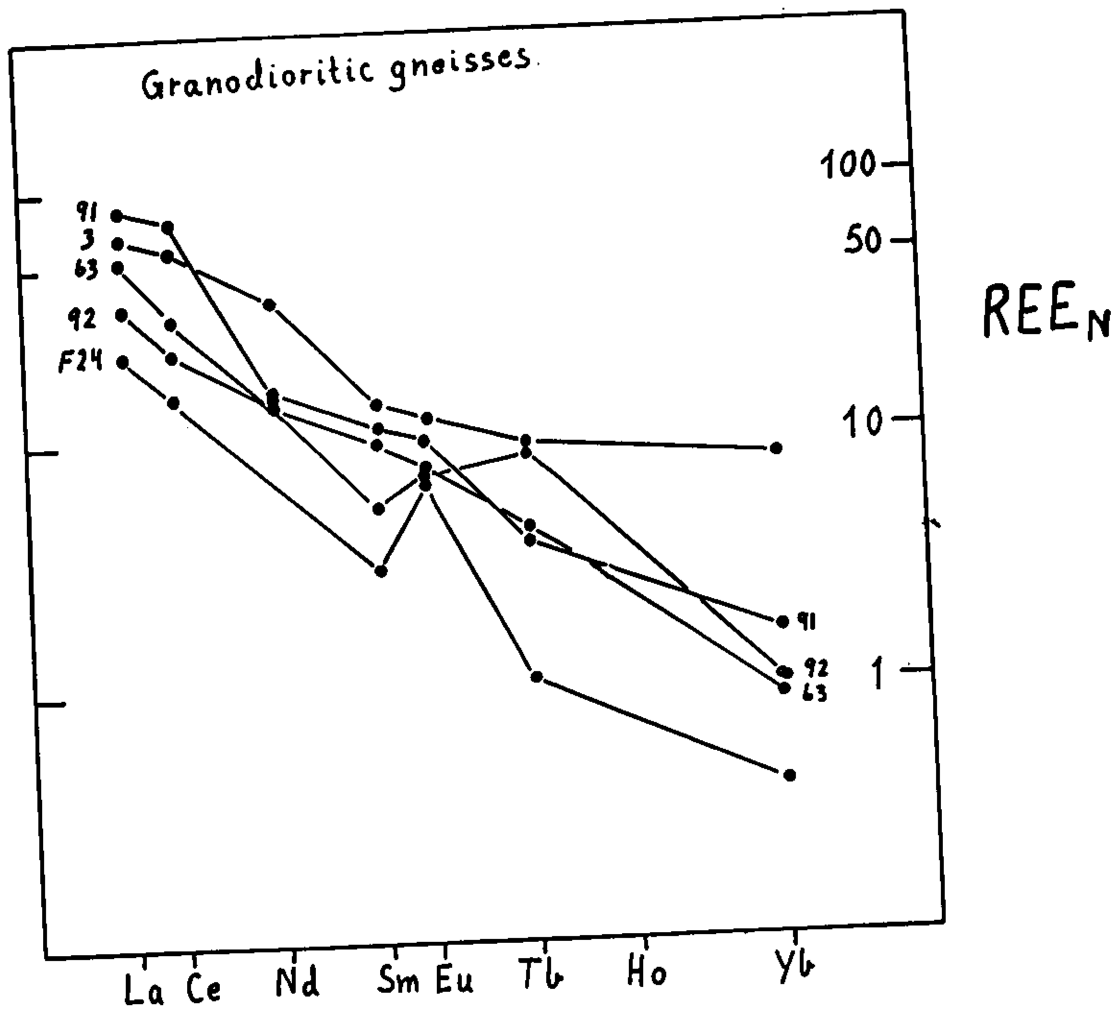

Granodioritic gneisses
100
50
10
1
REE$_N$
91
3
63
92
F24
91
92
63
La
Ce
Nd
Sm
Eu
Tb
Ho
Yb

Fig.10.

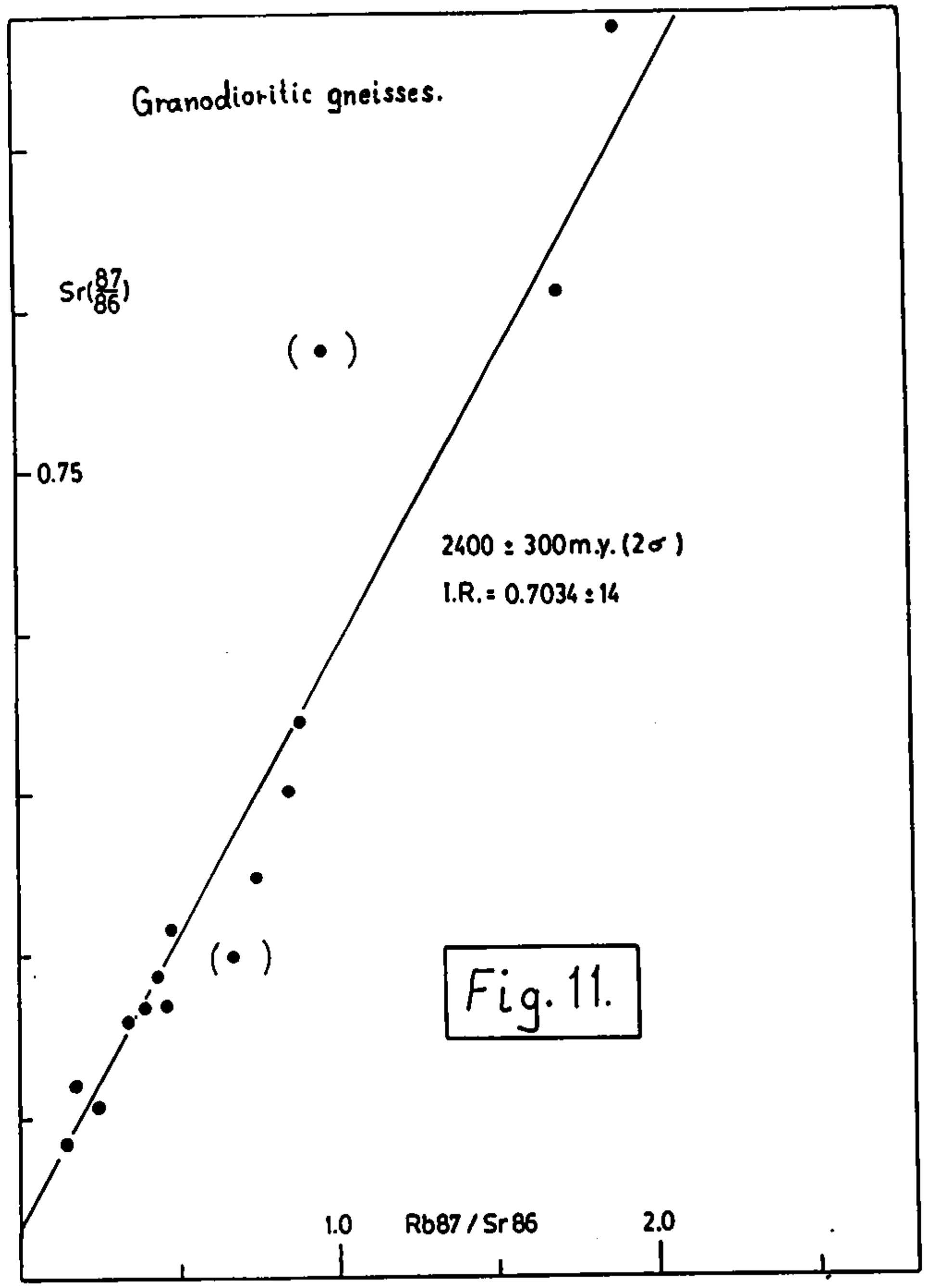

Granodioritic gneisses.
Sr(87/86)
0.75
2400 ± 300 m.y. (2σ)
I.R. = 0.7034 ± 14
1.0
Rb87 / Sr86
2.0

Fig. 11.

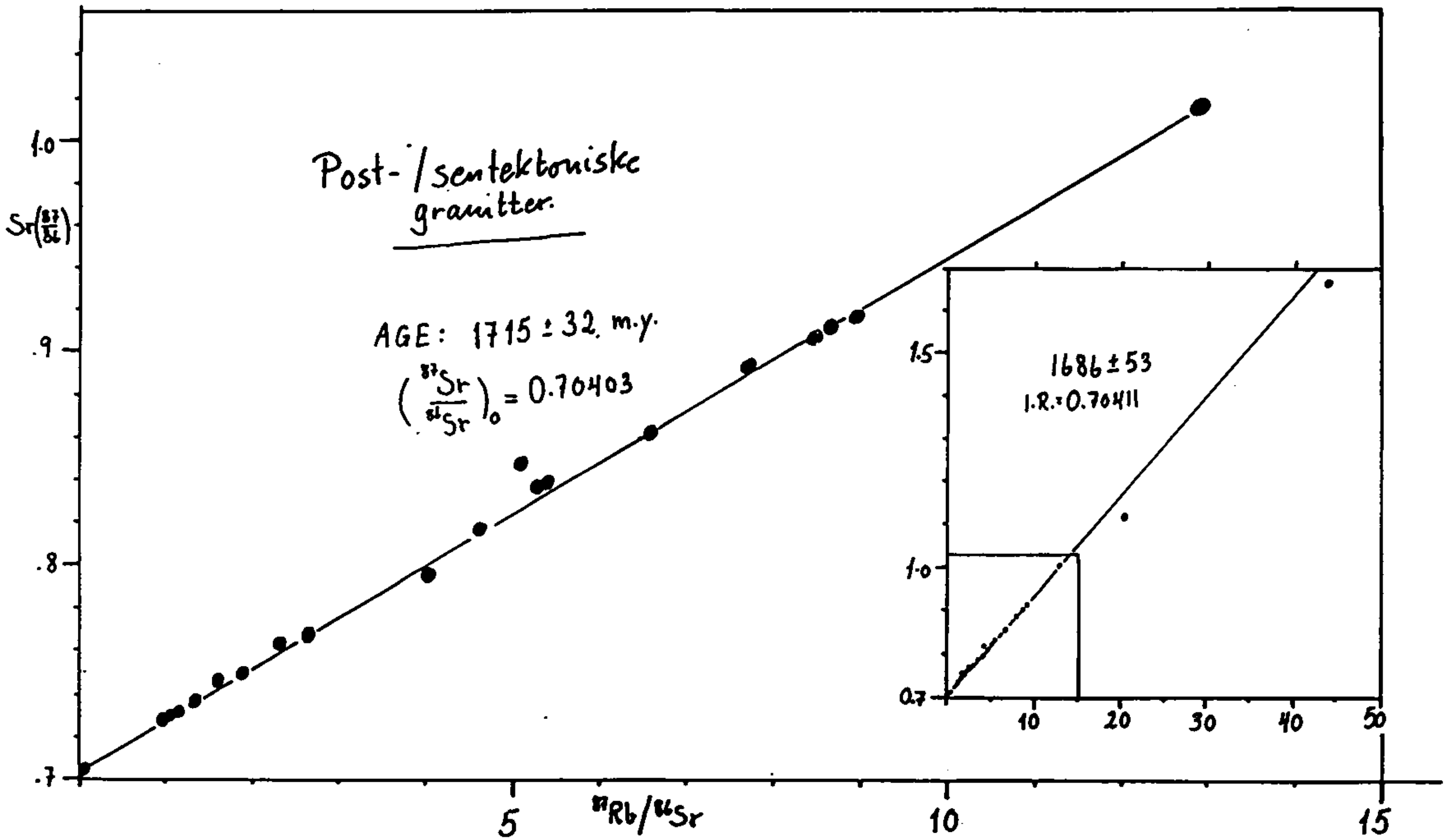

Post- / sentektoniske granitter
AGE: 1715 ± 32 m.y.
$\left(\frac{^{87}Sr}{^{86}Sr}\right)_0 = 0.70403$
1686 ± 53
I.R. = 0.70411
$Sr\left(\frac{87}{86}\right)$
$^{87}Rb/^{86}Sr$
1.0
.9
.8
.7
5
10
15
1.5
0.7
20
30
40
50

Fig. 12.