5/14/91

DEPARTMENT OF THE INTERIOR
U.S. GEOLOGICAL SURVEY

CONSULTANCY SERVICES IN PLATINUM-GROUP MINERAL EXPLORATION FOR THE DIRECTORATE OF MINERAL RESOURCES

Contract No. 569/PIO/ADB/1988

By: Michael L. Zientek[1] and Norman J Page[2]

OPEN-FILE REPORT 90-527

Report prepared by the U.S. Geological Survey in cooperation with the Directorate of Mineral Resources, Ministry of Mines and Energy, Directorate General of Geology and Mineral Resources, Republic of Indonesia under the auspices of the Asian Development Bank

This report is preliminary and has not been reviewed for comformity with U.S. Geological Survey editorial standards and stratigraphic nomenclature.

[1]U.S. Geological Survey, Spokane, WA 99201
[2]U.S. Geological Survey, Tucson, AZ 85705, USA

1990

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EXECUTIVE SUMMARY

The objectives of the U.S. Geological Survey's platinum consultancy were to improve the knowledge of the Directorate of Mineral Resources (DMR) staff about platinum-group elements (PGE), compile information on PGE occurrences in Indonesia, train in analytical techniques for the PGE, advise on establishing analytical capability for PGE, and advise and design methods for PGE exploration in Indonesia. The final report presents the results of these activities.

A two week workshop on *Platinum-Group Element Deposits and Environments* was presented from May 12 to 27, 1989. The course included lectures and practical training with rocks and thin and polished sections. In addition, exercises were used to focus the application of this information on developing a mineral resource assessment.

Robert R. Carlson inspected the laboratories and advised on additional material needed to perform PGE analyses. He also gave instruction in PGE chemistry and analytical techniques and focussed on practical training for the fire assay chemist.

Information (published, unpublished, and new data) gathered by the U.S. Geological Survey and Directorate of Mineral Resources on PGE occurrences in Indonesia are summarized in this report. Most of the investigations have focussed on Kalimantan and include field work, laboratory studies (particularly the identification of platinum-group minerals (PGM) using analytical tools in the United States), as well as compilation and synthesis of data in the office. A mineral resource assessment of southeastern Kalimantan identified 4 permissive areas for the occurrence of primary PGE deposits. Detailed investigations of one of the permissive areas (Riam Pinang) in southeastern Kalimantan were directed at defining sources of PGM known to occur in placer deposit in S. Tambanio. The two most valuable exploration methods for defining prospective areas are recording the PGM seen in pan concentrate samples in the field and Pt, Pd, and Au analyses of pan concentrate samples. Geologic mapping, examination of pan concentrate and stream sediment samples, PGE analyses of rock, pan concentrate, and stream sediment samples, scanning electron microscope and X-ray diffraction studies; and petrographic observations indicate at least two sources for the PGM in the alluvial deposits in this area: (1) alluvial deposits on terraces 20 to 30 meters above the present drainages and (2) intrusive dunitic bodies that are probably parts of Alaskan type ultramafic complexes.

Recommendations for additional exploration in the Riam Pinang area include: (1) identification and evaluation of the elevated alluvial deposits by photogeologic interpretation, field mapping, and geochemical studies and (2) geologic field mapping, geophysical mapping-ground magnetic studies, and geochemical investigations to define the Alaskan type ultramafic complexes that probably are the source of the PGM. The area of the Riam Pinang needs to be completely studied and understood before selecting another area in Kalimantan for study because insights gained from the Riam Pinang can be applied to evaluations of new areas. Besides continuing a search for lode sources of PGM in Kalimantan, the other known occurrences of PGE on other islands in Indonesia should be systematically evaluated.

STATEMENT OF CONTRACT OBJECTIVES

The objectives of the contract include: (1) improving the knowledge of the Directorate of Mineral Resources (DMR) staff on geology, geochemistry, geophysics, and exploration techniques for platinum-group elements; (2) advising on compilation methods for existing platinum-group element (PGE) information including geology and occurrence data; (3) advising on the evaluation and exploration of prospective PGE areas; (4) helping design methods and phases for exploration after preliminary examination of sites; (5) giving practical training in analytical techniques for PGE and associated pathfinder elements, and (6) giving assistance and advice in the establishment of the necessary analytical capability for PGE.

ACTIVITIES

The major activities of the U.S. Geological Survey (USGS) in coordination with the Platinum-Metals Team in DMR consisted of: (1) preparation and presentation of a workshop entitled *Platinum-Group Deposits and Environments*; (2) evaluation of laboratory equipment and supplies for doing fire assay PGE analyses and instructional training and advice in techniques and methods for PGE analysis; (3) compilation of information on PGE occurrences in Indonesia; (4) assessment of the PGE potential of southeastern Kalimantan via field and laboratory studies; and (5) development of recommendations related to PGE exploration and evaluation in Indonesia.

Preparation for the workshop given in Bandung began August, 1988 in the United States. It involved extensive efforts by M.L. Zientek, N.J Page, J.A. Peterson, and D.L. Mosier to put together over 1200 pages of information to be used as course notes and to gather and prepare polished slabs, thin sections and polished sections from diverse PGE localities world-wide. Organization and preparation continued after arriving in Bandung, April 26, 1989 until, Page and Zientek presented the workshop between May 12 and 27, 1989.

R.R. Carlson spent part of May 16-27, 1989 inspecting old and new laboratories in the company of Andi Djunudin and Soeharto Oemar and noted the operating condition and state of repair of the analytical instruments, availability of necessary materials, and the capacity of the sample preparation area. After the inspection, he compiled a list of additional necessary materials and instruments for practical training in PGE analysis by fire-assay techniques. Some time was spent in explaining observations and recommendations concerning the state of the equipment and techniques.

Carlson compiled a list of available chemists and their current specialities before giving preliminary instruction in platinum-group element chemistry and analytical techniques. A shortened and simplified version of this material was presented to the members of the PGE course. Several days were spent in instructional training of a fire-assayer, wet chemist, and atomic absorption spectrographer in the details of how to perform fire-assay-emission spectrography and atomic absorption for PGE and on site instruction of the fire-assayer in use and repair of the fire-assay equipment.

Before arriving in Indonesia and during the time in Indonesia, Zientek and Page compiled and checked information on occurrences of PGE. This information is summarized in this report and forms the basis for preparing a mineral resource data base.

Our principal counterpart in DMR was Bambang Pardiarto. Bambang directed the efforts of the DMR Platinum Exploration Team in the office and in two field surveys in the Riam Pinang area supported by P.T. Aneka Tambang. The first survey was conducted in August and September, 1989 by Bambang Pardiarto, Pudjosudjarwo, Bambang Nugroho Widi, Tata Henda, and A. Muchsin (surveyor). The second survey was conducted in February, 1990 by Bambang Pardiarto, Bambang Tjahjono S, Bambang Nugroho Widi, and Semi (surveyor). Zientek helped plan and guide the field and laboratory investigations done by the Platinum Exploration Team and assisted in interpretation of the results of the surveys.

Because of budgetary limitations, field activities of the USGS investigators were limited to short trips to visit active prospect areas. As part of the assessment of the PGE potential of southeastern Kalimantan, Zientek visited Kalimantan between June 1 - 5, 1989 with geologists from DMR and P.T. Aneka Tambang. Participants in the field excursion included 12 geologists from DMR, Bandung (Yaya Sunarya, Deddy T. Sutisna, Pudjosudjarwo, Hendro Wahjono, Wahyu Widodo, Simpwee Soeharto, Iwa Gartiwa, Umi Kuntjara, Ronald P. Sibarani, and Zulkifli Oesman) and two geologists from Aneka Tambang (Alwi Wikrama and Marolop Simanjuntak). In addition, Samsi Djamiun, chief of the branch office for Aneka Tambang in Pleihari, joined the group for parts of two days. The itinerary for this trip is outlined below:

June 1	Bandung - Banjarmasin - Banjarbaru
June 2	Tanah Ambungan (magnetite - spinel ore in clinopyroxenite); Batakan (podiform chromite in tectonized harzburgite)
June 3	Au - PGM placers on S. Tambanio near Riam Pinang; diamond -Au - PGM placers at Cempaka

June 4 Pigat (Au in sheared serpentinite); Pamali area, Sungai Ahim (Pamali breccia and podiform chromite)
June 5 Banjarbaru - Banjarmasin - Bandung

Zientek and Page returned to Kalimantan December 1 and 4, 1989 to field check some of the information gathered by the Platinum Metals Team in the Riam Pinang area. Participants were Yaya Sunarya, Bambang Pardiarto, Pudjosudjarwo, Gusti Hidayat, and Suparmo (from DMR) and Eddy Sutrismo, Alwi Wikama, Aries Widjaja, H. Kardiansjah, and Suhaili Saudani of P.T. Aneka Tambang. The itinerary for this trip follows:

December 1 Bandung - Banjarmasin - Banjarbaru. Short trip to illustrate geographic setting of the diamond-Au-PGM placer deposits near Cempaka
December 2 Geologic and geophysical investigations, Riam Pinang area
December 3 Au-PGM placer at S. Pirik; stratabound sulfide deposits and placer deposits near G. Damargusang.
December 4 Banjarbaru - Banjarmasin - Bandung

Zientek traveled to the Celatuh area in West Java to look at exposures of ultramafic rock on March 25 and 26, 1990.

Laboratory investigations by the USGS included several weeks of scanning electron microscope investigations of platinum-group mineral (PGM) concentrates from various localities by Robert Oscarson in Menlo Park, California, X-ray diffraction analyses of mineral grains by Richard C. Erd in Menlo Park, and PGE analyses of rocks by Robert Carlson and other chemists in Denver, Colorado. Laboratory investigations by DMR included mineralogical studies of heavy mineral concentrates, and selection and preparation of samples for PGE analysis by P.T. Geoservices (Ltd.) via P.T. Aneka Tambang. Joint, cooperative office investigations by DMR and the USGS included examination of rocks, compilation and revision of geologic, stream sediment, heavy mineral concentrate, PGE analytical data, and mineral occurrence maps for southeastern Kalimantan and for the prospect area selected for more detailed study. Other compilation efforts included the description and cataloging of all known PGE occurrences in Indonesia.

WORKSHOP ON PLATINUM-GROUP ELEMENT DEPOSITS AND ENVIRONMENTS

The workshop was presented as lectures and laboratory exercises by Zientek and Page as well as practical exercises of mineral exploration and assessment for PGE in Indonesia. The workshop generated the necessary background knowledge and enthusiasm to design a PGE exploration program for part of Kalimantan by the Platinum Exploration Team with advice and recommendations of the USGS. It also provided a framework to consider other mineral deposit types and the modern techniques for mineral resource assessment and exploration. The outline of the lecture notes for the course is included in appendix A.

The topics covered in the course were:

(1) Supply, demand, prices, commodity, chemical, physical properties, and mineralogy of the PGE,
(2) Mineral deposit models and their uses,
(3) Mineral Resource assessment techniques,
(4) Overview and introduction to platinum group mineral deposits covered in the course,
(5) PGE associated with large layered stratiform intrusions,
(6) PGE deposits associated with ophiolite assemblages,
(7) PGE deposits associated with mafic and ultramafic rocks in greenstone belts and rift zone environments,
(8) PGE deposits associated with "zoned Alaskan" and synorogenic mafic and ultramafic intrusions,
(9) Outline of analytical methods for PGE,
(10) PGE deposits associated with alkaline intrusions in mafic and ultramafic rocks,

(11) Case studies of stream sediment and soil geochemistry in the exploration for PGE,
(12) PGE deposits associated with hydrothermal systems,
(13) PGE deposits associated with sedimentary rocks,
(14) Overview of geophysical techniques applied to mafic and ultramafic rocks and associated mineral deposits,
(15) Mineral resource assessment techniques applied to placer deposits in Kalimantan,
(16) Review of PGE deposits and environments discussed in the course.

The course participants were:

NAME	AFFILIATION
Yaya Sunarya, Ir.	DMR/Metallic Min. Exploration
R. Simpwee Soeharto, M.Sc.	"
Pudjosudjarwo, B.Sc.	"
S. Widasaputra, Ir.	"
Hendro Wahjono, B.Sc.	"
Bambang Pardiarto, Ir.	"
Deddy T. Sutisna, M.Sc.	"
Wahyu Eidodo, Ir.	"
Danny Z. Herman, Ir.	"
Atok S. Prapto, BE	"
Iwa Gartiwa GS., BE	"
Syahya Sudarya	"
Dodo Djuanda, BE	"
Rudy Gunradi, Ir.	"
Djoko Santoso, Ir.	"
Bambang Nugroho Widi, Ir.	"
Tata Henda, Ir.	"
Yusuf Laleno, Ir.	"
Deddi Sugandi, Ir.	"
Sumadi, B.Sc.	"
Akih Sumpena, BE	"
Umi Kuntjara, Ir.	"
Zamri Ta in, Ir.	"
Ronald Sibarani, Ir.	"
Achmad Tholib, Ir.	"
Maman Sumantri, Ir.	DMR/Geophysics
Edi Sumardi	DMR/Geophysics
Zuldifli Oesman, Ir.	DMR/Peat and Coal
Edi Suhaedi, Ir.	DMR/Peat and Coal
Susi Ernawati, Ir.	DMR/Geochemistry
Nuryasin	DMR/Geochemistry
Bagdja P.	DMR/Geochemistry
Wiwien E.T.	DMR/Geochemistry
Rosmimik	DMR/Geochemistry
Oman	DMR/Geochemistry
Sudradjat	DMR/Geochemistry
Alwi	P.T. Aneka Tambang
Marolop Simanjuntak, B.Sc.	P.T. Aneka Tambang

PLATINUM-GROUP ELEMENT ANALYTICAL PROCEDURES: REVIEW OF METHODS, STATUS OF LABORATORY FACILITIES, AND RECOMMENDATIONS

Review of methods

The instruction provided R.R. Carlson covered the following topics related to analytical techniques for the PGE; a method of analysis of dore´ beads is presented in appendix B.

I. The platinum-group metals-a brief history of their discovery and early chemistry
II. General obstacles to successful platinum group analysis
III. An overview of analysis for PGE (platinum-group elements)
    A. Extraction of PGE
        1. In organic leach
        2. Organic leach
        3. Volatization
        4. Fusion
    B. Detection Systems
        1. Gravimetric
        2. Colorimetric
        3. Atomic absorption
            a. Flame
            b. Flameless
        4. Emission spectrographic
        5. Neutron activation
        6. X -ray
        7. Ion chromatographic
        8. Inductively coupled plasma
            a. Emission spectrography
            b. Mass spectroscopy
IV. Analytical techniques
    A. Inorganic leach methods for:
        1. Colorimetric determination
        2. Atomic absorption determination
        3. Neutron activation
    B. Organic leach method
    C. Ion chromatography techniques
    D. Emission spectrography
    E. Fire-assay preconcentration methods
        1. Classical Pb assay
            a. Gravimetric determination by acid parting
            b. Acid digestion to:
                i. Flame atomic absorption determination
                ii. Graphite furnace (flameless atomic absorption determination)
                iii. ICP-mass spectroscopy determination
            c. Emission spectroscopy determination
        2. NiS assay, acid digestion to:
            a. Atomic absorption determination
            b. Neutron activation determination
            c. ICP-mass spectroscopy determination.

The instructional notes for this outline are included as appendix C.

Status of laboratory facilities and recommendations

Based on a review of the laboratories and equipment Carlson recommended the following actions to develop a PGE analytical capability in DMR utilizing a fire-assay/emission spectrographic method:

(1) The existing 10 year old emission spectrograph must be repaired. It is in relatively good condition, but is currently inoperable due to some unknown electrical problem (could be extremely simple or moderately difficult to repair). One of the two spectrographic film readers is reportedly operational if supplied with proper voltage. The emission spectrograph is not in demand for analytical work, and it could therefore be dedicated to PGE analysis. It would also allow for the determination of all six PGE whereas fire-assay/graphite furnace atomic absorption analysis would only give results for Pt, Pd, and Rh. Use of the emission spectrograph would also eliminate contamination problems for the graphite-furnace atomic absorption unit that could result from running the silver or gold bead used to collect the PGE. A dark-room would be required in the new lab.

(2) The fire-assay furnaces are new and operable, but the room needs to be completed with the addition of a flux/sample mixing laboratory bench and dust hood (preferable a bench-level laminar flow hood). An acid digestion hood is also planned for the room, but is not currently present.

(3) Two balances are needed: a top - loading 120 g flux/sample balance graduated to 1/100 g (Mettler PIZO) and a 9 -10 mg balance for lighter weighing of silver or gold inquarts.

(4) Other hardware that are needed include:
   a. 4-6 polyethylene canisters (3 to 4 liter size) with tight fitting lids for flux reagents
   b. an assortment of 0.1 liter to 0.25 liter scoops for transferring flux reagents
   c. medium and small nickel spatulas
   d. cupel tongs
   e. a hearth rake for bone ash
   f. 20 - 40 ml water dipper on a furnace length handle
   g. stainless steel mixing forks for flux mixing
   h. a supply of 30 g (mostly) and 40 g (20 percent of total) crucibles
   i. 20 - 45 kg of bone-ash

(5) Reagents (the Australian premixed flux is probably not suitable for the variety of sample types that would be submitted):
   a. Litlarge (such as c.p. Pueblo brand - ASARCO)
   b. Silica, 140 mesh (Fisher Scientific)
   c. Sodium carbonate, calcined, purified (Fisher Scientific, Baker)
   d. Sodium tetraborate, fused-ground (Fisher Scientific, Baker)
   e. Graphite, grade No. 38 (Fisher Scientific)
   f. Silver oxide, Ag_2O powder - Specpure, Johnson Matthey Chemicals
   g. Electrodes: Ultra Carbon anodes-No. C001489-00 U-Z grade, Ultra Carbon cathodes No. 001686-00 U-Z grade
   h. Film: 35 mm Kodak spectrum analysis No. 1
   i. Developer - D - 19
   j. Gas: 70 percent argon / 30 percent oxygen mixture
   k. PGE compounds: Specpure, Johnson Matthey Chemicals, Ltd:
      1. $(NH_4)_2 Os Cl_6$
      2. $(NH_4)_2 Ru (H_2O) Cl_5$
      3. $(NH_4)_2 Ir Cl_6$
      4. $(NH_4)_2 Pt Cl_5$
      5. $(NH_4)_2 Pd Cl_4$
      6. $(NH_4)_3 Rh Cl_6 H_2O$
      7. $(NH_4) Au Cl_4$

OVERVIEW OF PLATINUM-GROUP ELEMENT OCCURRENCES IN INDONESIA

The presence of PGE in Indonesia has been known since 1831 when it was discovered in Kalimantan. Later (1904), PGE were reported from Sumatra. Between 1831 and 1922, about 53,700 troy ounces are estimated to have been produced (Quiring, 1962). Laurite (RuS_2) was first identified in materials from Kalimantan by Wohler (1866) and since that time various investigations on PGE in Indonesia have been published.

During the course of the consultancy, information was collected on known PGE occurrences in Indonesia and forms the background for the focussed investigations in southeastern Kalimantan. The information is organized by island and represents a summary of old, new, published and unpublished data (Figure 1).

Java

Platinum group element minerals are reported to occur near Cilacap and in the Jampang Kulon area.

CILACAP, CENTRAL JAVA

Minute quantities of platinum-group minerals were reported to occur in black sands along the seashore near Cilacap (Banyumas). Anonymous (1918) cites Maier (in Natuurk. Tijdschrift voor Ned. Indie, XVII, p. 395) who described metal with bluish silvery luster together with gold in sands of Cilacap. Currently, P.T. Aneka Tambang is mining 300,000 tons/year of iron-rich black sand from the Cilacap area. No PGM have been reported from this production.

JAMPANG KULON, WEST JAVA

In 1985, a DMR team found 2 grains of PGM in pan concentrate samples from alluvial gold deposits in the Jampang Kulon area (Figure 2). The sample location is on the tributary of the Cikaso River. The drainage basin in which this sample occurs is underlain by the Lower Miocene Jampang Formation which consists largley of andesitic breccia, lava, and tuffs. The only exposure of ultramafic rock in the region is the Ciletuh ultramafic rock complex that crops out approximately 20 km to the west (Sukamto, 1975).

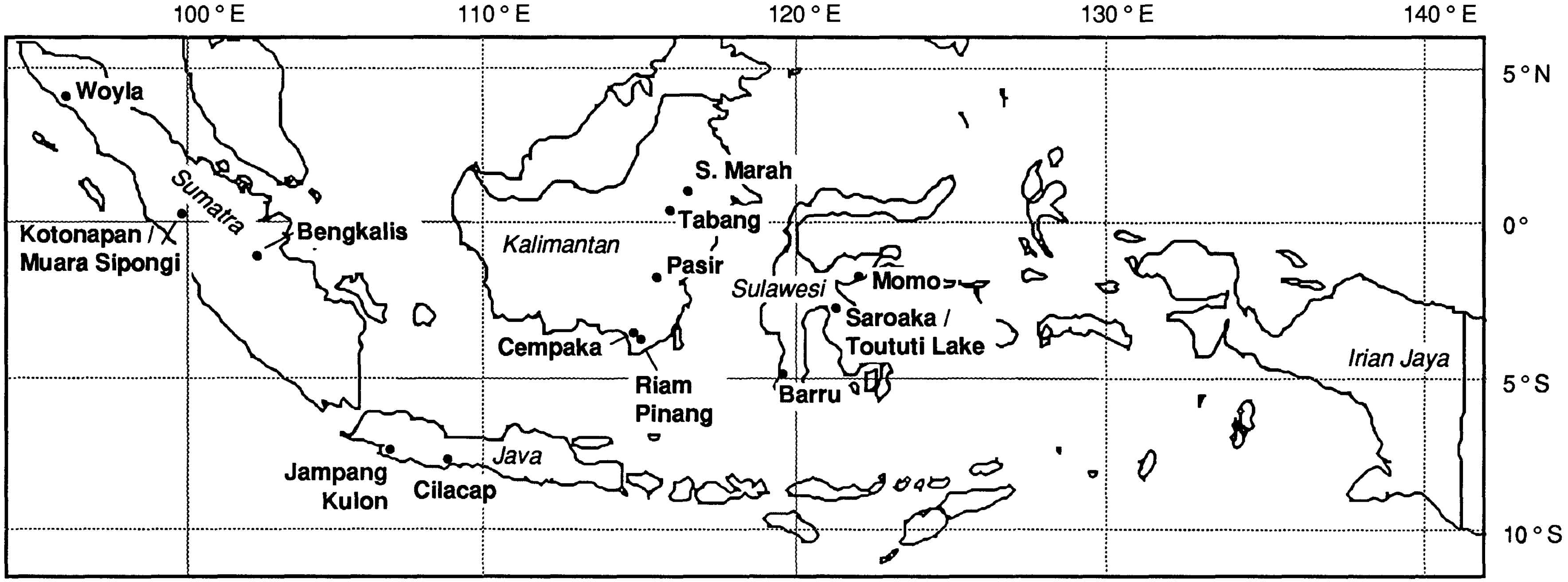
Sumatra

Alluvial deposits containing PGM have been described from the River Woyla near Tutup in northern Sumatra and from Bengkalis, Riau in central Sumatra. Platinum-group elements are reported to occur in skarn deposits near Muara Sipongi. Platinum and palladium analyses have been done on Pasaman ultramafic rock samples.

GENDONG CONCESSION, RIVER WOYLA, TUTUP, ACEH

Alluvial gold, platinum - iron alloy, osmium - iridium alloy, cinnabar, copper - zinc alloy, and copper - tin alloys are found in the rivers which drain the Meulaboh - Tutup area (Bowles and others, 1984). Dredging of modern alluvium on either side of a bend in the Woyla river 2 km west of Tutup was conducted from 1940 to 1942 (Figure 3). The source of most of the Au and PGM in the modern alluvial are two to three terraces of sands, clays, and conglomerates (Tutup Formation); these gold bearing deposits cover an area of 416 km^2 with a thickness of about 10 m

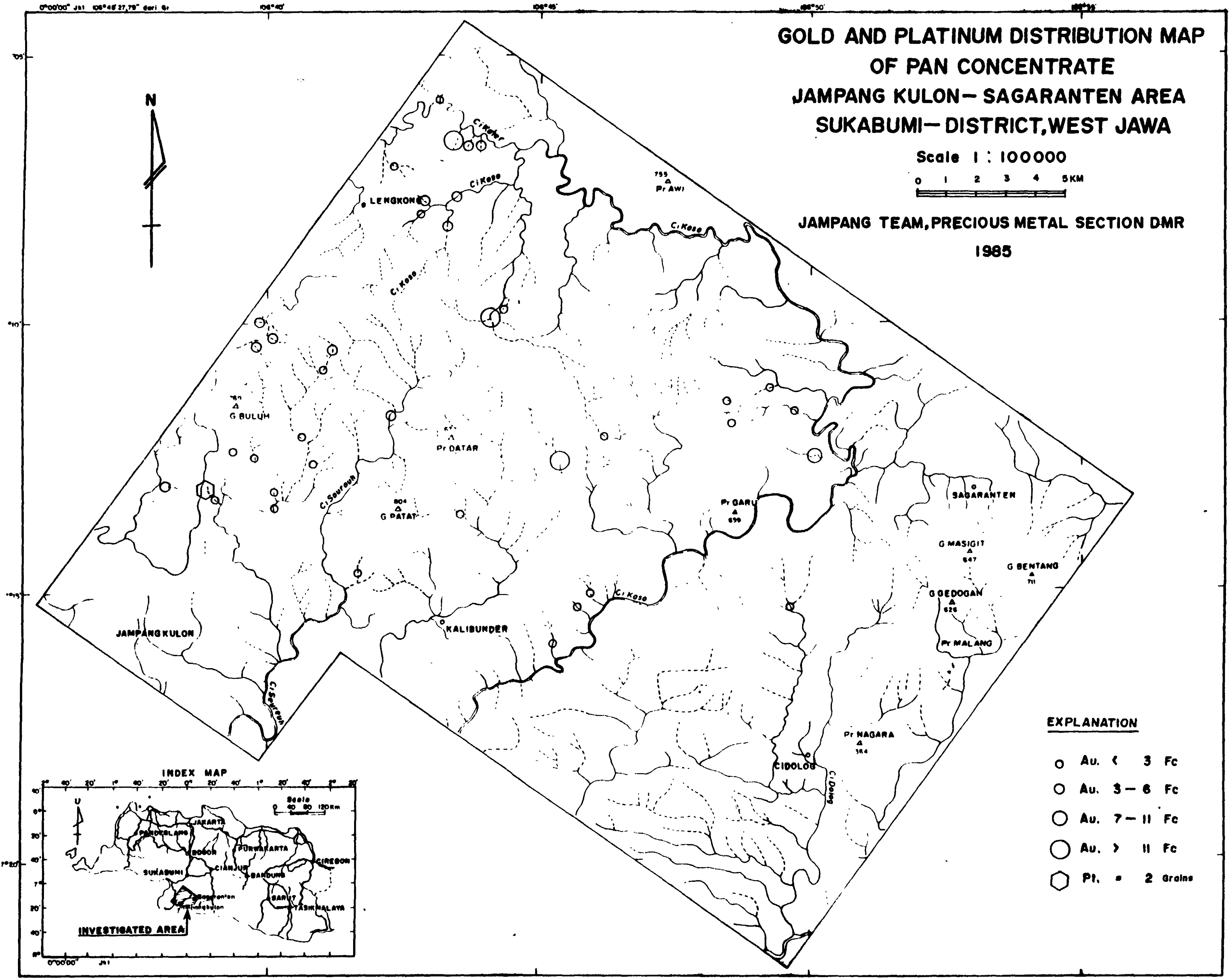
Figure 1. Location of PGE occurrences in Indonesia.


100 ° E
110 ° E
120 ° E
130 ° E
140 ° E
5 ° N
0 °
5 ° S
10 ° S
Woyla
Sumatra
Kotonapan /
Muara Sipongi
Bengkalis
Kalimantan
S. Marah
Tabang
Pasir
Cempaka
Riam
Pinang
Sulawesi
Momo
Saroaka /
Towuti Lake
Barru
Java
Jampang
Kulon
Cilacap
Irian Jaya

……

Figure 2. Distribution of Au and PGM in pan concentrate samples from the Jampang Kulon - Sagararten area, west Java. Fc is size-weighted estimate of the volume of Au in a pan concentrate sample.

……

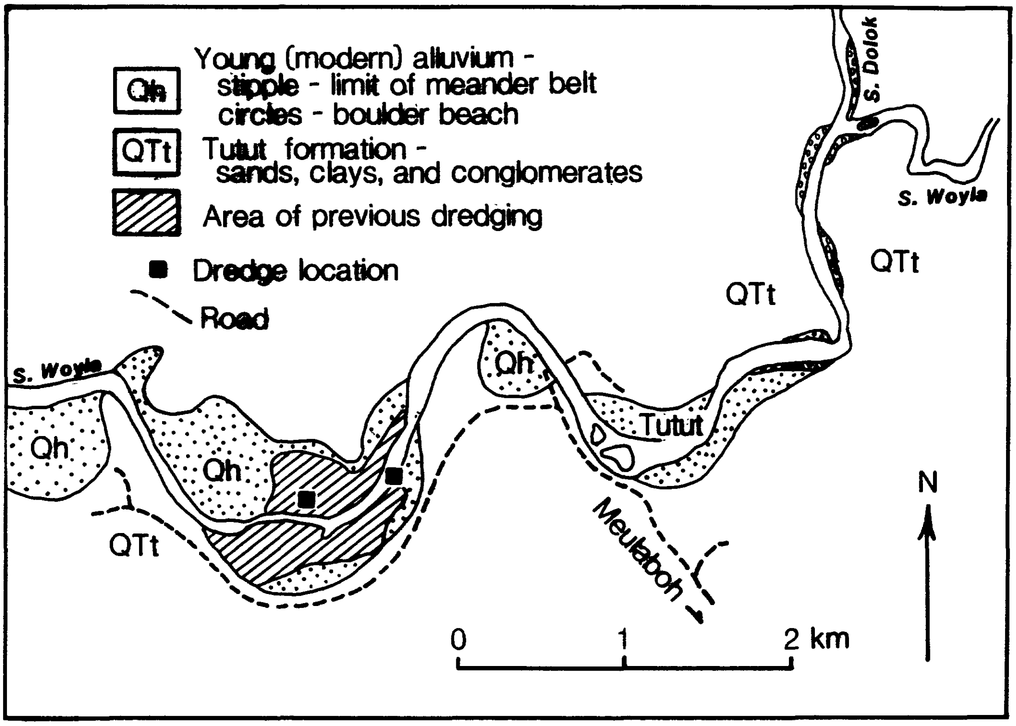


GOLD AND PLATINUM DISTRIBUTION MAP
OF PAN CONCENTRATE
JAMPANG KULON – SAGARANTEN AREA
SUKABUMI – DISTRICT, WEST JAWA

Scale 1 : 100000

JAMPANG TEAM, PRECIOUS METAL SECTION DMR
1985

Figure 3. The remains of dredging operations in the River Woyla near Tutup, north Sumatra modified from Bowles and other (1984).


Qh
Young (modern) alluvium -
stipple - limit of meander belt
circles - boulder beach
QTt
Tutut formation -
sands, clays, and conglomerates
Area of previous dredging
Dredge location
Road
S. Woyla
S. Dolok
S. Woyla
QTt
QTt
Qh
Qh
Qh
Tutut
QTt
Meulaboh
N
0
1
2 km

on the Woyla and its tributaries (Cameron and others, 1982; Bowles and others, 1985). Production figures and ore grade for the dredging operation are unknown except for general statement that platinum production was on the order of kilograms per month.

Samples of precious metal concentrate produced today contain 93 percent Au, 5 percent Ag, 1.5 percent PGM, and 0.5 percent Hg (Bowles and others, 1984). Bowles and others (1984) use these figures and the reported dredge capacity to estimate recoverable ore grades of 0.15 ppm Au; 0.0008 ppm Ag; 0.002 ppm PGE, and 0.0007 ppm Hg. Au: PGE, therefore is about 60: 1 . Dredging operations were resumed in this area in 1987 by MMC. Additional references: Young and Johari (1980).

SINGENGGOE SKARN DEPOSIT, KOTANOPAN, NORTH SUMATRA

Hundeshagen (1903 - 1904) described a skarn that contains up to 8 ppm Pt, 4 ppm Au, and 2 ppm Ag. The skarn mineralogy was 80 percent wollastonite, 12 percent grossular garnet, and 5 percent bornite. Cu-rich ores from the same locality (2 to 10 percent bornite and malachite) contained only trace quantities of Pt. PGM were not observed in thin section or finely powdered concentrates but were found in nearby river sands as rounded grains 0.1 to 0.3 mm in diameter. The locality was originally described as situated near the main road (Sumatra highway) at the Singenggoe river near Kotanopan. Bowles and others (1984) note that confusion has since arisen over the position of this skarn occurrence. In later summaries and on the 1: 250.000 geologic map of the area (Rock and others, 1983), the Pt - bearing skarn is noted as occurring 12 km to the southeast, at the Pagaran Si Ajoe mine. Despite regional and detailed mapping and sampling programs in the Muara Sipongi area (Rock and others, 1983; JICA and MMAJ, 1983, 1985), Pt contents of skarn deposits were not investigated. Bowles (1984) presented analyses of 2 flakes of high - Ag alluvial gold from the River Gadis, which drains the Muara Sipongi area, that had 0.01 to 0.02 percent Pd and suggested these grains may had been derived from gold - silver veins in Tertiary volcanic rocks.

BENGKALIS AU-PGM PLACER DEPOSITS, RIAU

PGE was produced as a by product of alluvial gold deposits in central Sumatra (Bengkalis, Riau). The alluvial deposits occur on S. Singingi, a tributary of the S. Indragiri, southwest of Rengat, in the Logas area. Production by means of a bucket dredge during the period 1937 to 1940 was 1060 kg gold and 2.564 kg platinum (van Bemmelen, 1949). Au/Pt is therefore about 400/1.

P.T. Aneka Tambang continued dredging operations in the area formerly mined by the Dutch in 1966; work continued until 1971. P.T. Aneka Tambang has defined approximately 30 million m^3 of gravel with 180 mg/m^3 Au by Bangka drilling approximately 10 km downstream from the old dredge field. Trace amounts of PGM also occur there.

PGE ANALYSES OF PASAMAN ULTRAMAFIC ROCK, NORTHERN SUMATRA

Table V - 1 in JICA and MMAJ (1985) presents chemical analyses of Pasaman ultramafic rocks. Thirteen samples are harzburgite and there is one sample each of dunite and dolerite. The rocks were analyzed for major elements as well as Cr, Ni, V, Co, Pt, Pd, and Au. The highest Cr content is 3400 ppm. For all 15 samples, Pt is less than 50 ppb; 11 samples have Pd below 10 ppb; 4 samples have 10 ppb Pd. Au ranges from 5 to 1050 ppb; 5 samples have Au greater than 200 ppb.

Sulawesi

Samples of placer and lateritic chromitite, laterite, and dunite from South Sulawesi have been analyzed for Pt, Pd, and Rh (Group Ophiolite, 1988; Table 1). The samples are from three areas: Soroako, Towuti Lake, and Barru. Results for various rock types are summarized below:

Table 1. Summary of Pt, Pd, and Rh analyses of samples from the Soroako, Rowuti Lake, and Barru areas, South Sumatra.

Rock type (Number of samples)	Pd(ppb) Min/Max/Mean	Pt(ppb) Min/Max/Mean	Rh(ppb) Min/Max/Mean
Chromite-rich beach-sand (11)	0.7 / 11 / 4.4	< 1 / 30 / 9.7	< 0.5 / 4.3 / 1.1
Laterite (21)	1.6 / 33 / 12.2	< 1 / 42 / 15.8	< 0.5 / 4.8 / 1.7
Chromitite (15)	< 0.5 / 22 / 6.2	0.5 / 29 / 3.4	< 0.5 / 19 / 3.8
Dunite (3)	2.1 / 5.2 / 4.0	1.8 / 5.2 / 4.0	< 0.5 / 0.7 / 0.6
Sand (1)	2	6.2	< 0.5

PGM are also reported from heavy minerals concentrates from beach gravels near Momo and Baubuang in Central Sulawesi (approximately 138 km southwest of Luwuk. The concentrates were made from gravels collected at shallow depths (few meters) in holes drilled for gas exploration by Total Oil Co. (France) in 1988.

Kalimantan

Platinum was discovered in Borneo (Kalimantan) in 1831. From that date to 1922, Quiring (1962) estimates the total production of platinum metals has been about 53,700 troy ounces. The mineral laurite, was first identified in Kalimantan (Wohler, 1866). Placer PGM are known from 3 localities in East Kalimantan and numerous localities in South Kalimantan (Plate 1). Mertie (1969) also indicates platinum and osmiridium were found in placer deposits in west Borneo (between south Borneo and Serawak); however, we have not been able to locate any information about these occurrences.

MARAH AREA, EAST KALIMANTAN

Alluvial PGM have were discovered during the course of placer exploration on the S. Marah and the S. Telan in East Kalimantan. Approximately 90 test pits have been put into terrace gravels on the S. Marah, S. Wahau, and S. Telan, north and northwest of Muarawahau by P.T. Aneka Tambang (Figure 4). These rivers ultimately drain into the S. Mahakam.

Six test pits were put into gravels on S. Wahau; 46 on S. Telan, and 38 on S. Marah. Noteable concentrations of PGM were found only in the pits on the S. Telan and S. Marah. The terrace deposits are 2.5 to 7 m thick; the productive gravels near bedrock are 0.5 to 3 m thick. Widths of the terraces ranges from 200 to 1000 m. Grades of the gravels are low, approximately 50 mg/m^3 Au and 10 mg/m^3 PGM. Au/PGM (grains) in these test pits is 20/1. Preliminary investigations of the mineralogy of the PGM from a bulk sample collected from a test pit on S. Marah (SM 20) is summarized in Table 2. The bulk sample from this location contained 120 mg/m^3 Au; 14.002 mg/m^3 Ag; and 6.620 mg/m^3 Pt. Platinum minerals dominate; the studied particles are subangular to subrounded, generally about 0.8 mm in diameter.

A belt of ultramafic rocks approximately 500 m to 1 km wide occurs upstream from the platinum-occurrences on S. Telan and S. Marah. There are no 1: 250.000 scale geologic maps for this area.

Figure 4. Map showing the occurrence of PGM, S. Marah area, East Kalimantan.

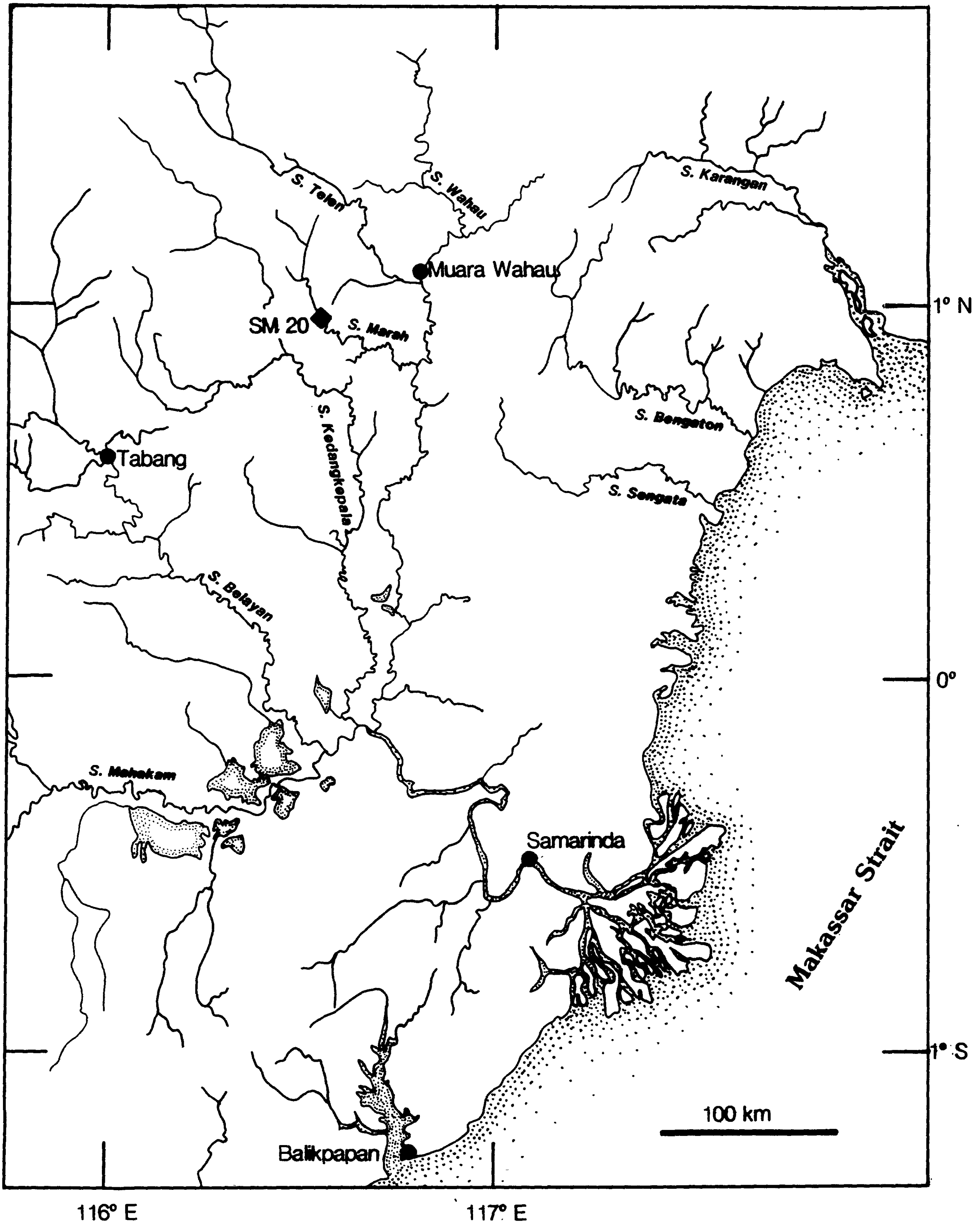

S. Telen
S. Wahau
S. Karangan
Muara Wahau
SM 20
S. Marah
1° N
S. Bengalon
Tabang
S. Kedangkepala
S. Sengata
S. Belayan
0°
S. Mahakam
Samarinda
Makassar Strait
1° S
100 km
Balikpapan
116° E
117° E

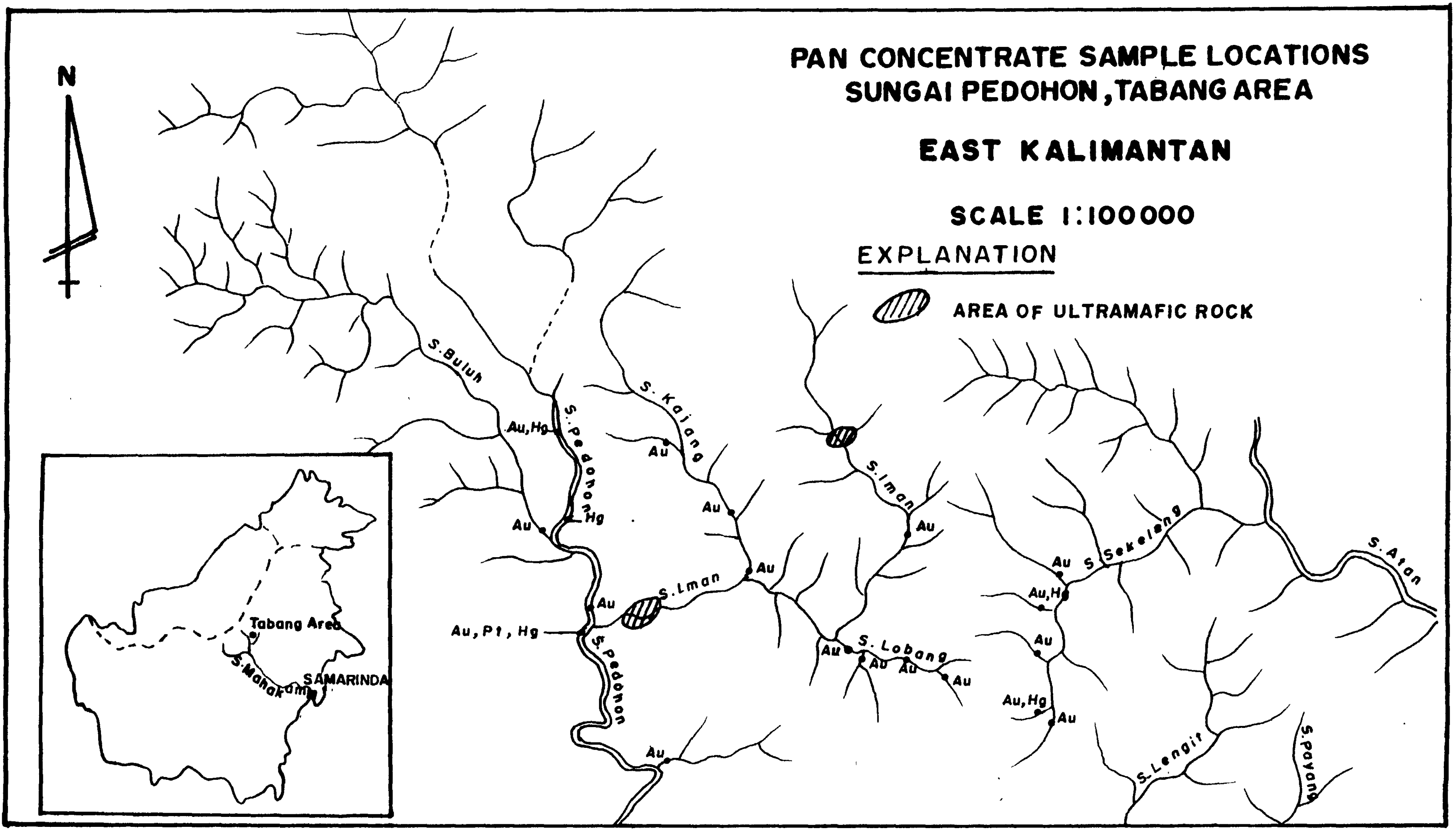
Table 2. Summary of SEM investigations on PGM from S. Pedohon and S. Marah, East Kalimantan and Cempaka, South Kalimantan

Phase	**Number of grains** **S. Pedohon**	 **S. Marah**	 **Cempaka**
Pt-Fe alloy dominant			
no inclusions	13	6	15
chromite inclusions	1		1
intergrown with tulamenite			1
laurite inclusions	1		
Os-Ir alloy inclusions	10	1	
Cooperite		2	
Intergrowth of Os-Ir alloy with minor Pt-Fe alloy; chromite inclusions	1		
Os-Ir alloy dominant			
no intergrowths		1	1
intergrowth with Pt-Fe alloy		1	
intergrowth with Pt-Fe alloy and laurite	1		
intergrowth with laurite	1		
intergrowth with Ir-Fe-Rh and Ir-Rh-Sb phases	1		
Amalgam			2
Size range of investigated particles (mm)	0.6 to 1.5	0.3 to 1.4	0.2 to 1.7
Mean size of investigated particles (mm)	1.1	0.8	0.9

TABANG AREA, EAST KALIMANTAN

PGM were discovered during the course of reconnaissance geologic investigations in this area (DMR under contract to P.T. Ingold). PGM were found at one location on the S. Pedohon, immediately downstream from the confluence of the S. Pedohon and S. Imau near the village of Tabang (Figure 5). S. Pedohon is a tributary of the S. Belayan. The sample was taken from modern alluvial deposits in the stream channel. Au/PGM is about 5/1. Cinnabar was also found in the pan concentrate sample.

Figure 5. Map showing the occurrences of Au, PGM, and cinnabar (Hg) in pan concentrate samples, Tabang area, East Kalimantan. Location of ultramafic rock exposures shown by cross-hatchuring.



PAN CONCENTRATE SAMPLE LOCATIONS
SUNGAI PEDOHON, TABANG AREA

EAST KALIMANTAN

SCALE 1:100000

EXPLANATION

▨ AREA OF ULTRAMAFIC ROCK

Detailed investigations of the mineralogy and morphology of the particles are summarized in Table 2 and Figures 6 - 9. The principal mineral is Pt - Fe alloy. Os - Ir alloys are common, both as plate like-inclusions and intergrowths with Pt - Fe alloy (Figure 6) and as isolated grains. Laurite occurs as inclusions in Pt-Fe alloy (Figure 7) and intergrown with Os - Ir alloy and Pt-Fe alloy (Figure 6D). An unusual particle, illustrated in Figure 8, consists of an intergrowth of Os - Ir alloy (bent, sheet-like grains), and two unidentified phases. One phase contains Ir - Rh - Fe - Sb - S (Figure 9) and typically shows distinct cleavage or parting (Figure 8B). The second phase consists of Ir - Fe - Rh (Figure 10) and typically forms mottled or smooth surfaces on the particle (Figure 8B). Inclusions of chromite were found in two particles (Figure 11).

The morphology of the individual particles is quite varied. Some grains are very angular or preserve delicate intergrowths of phases; others are subrounded. This variation in the degree of rounding is illustrated for equant particles of Pt - Fe alloy in Figure 12. The size of the particles studied averaged 1.1 mm.

Rocks in the vicinity of this area are dominantly andesitic and basaltic rocks with some beds of sandstone and limestone. Small dioritic intrusions are also present. A very small exposure of ultramafic rock occurs upstream on S. Imau. It is the only ultramafic rock exposure mapped in the survey area.

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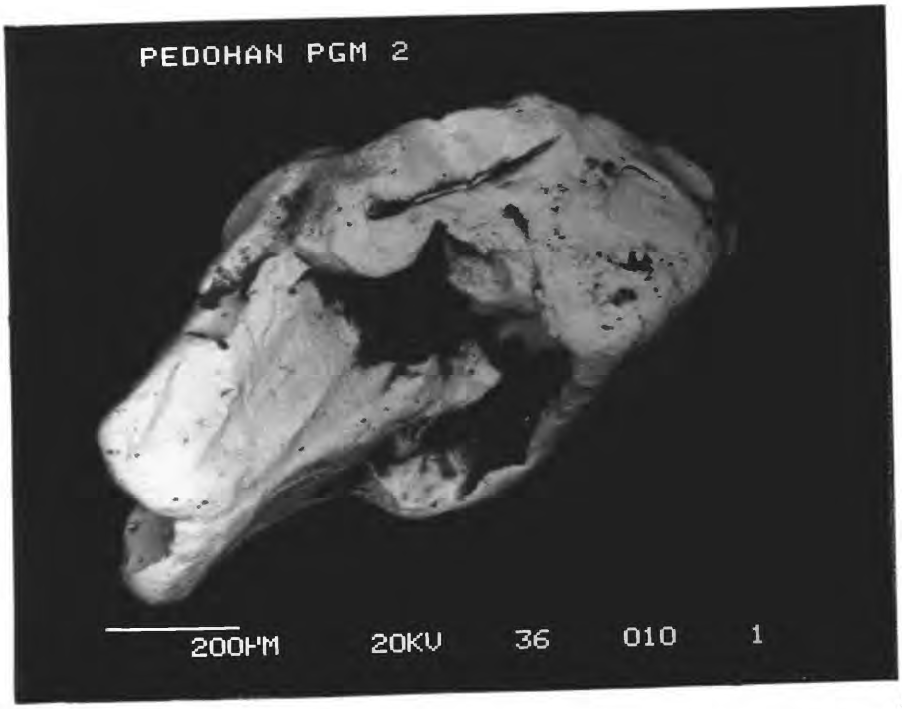
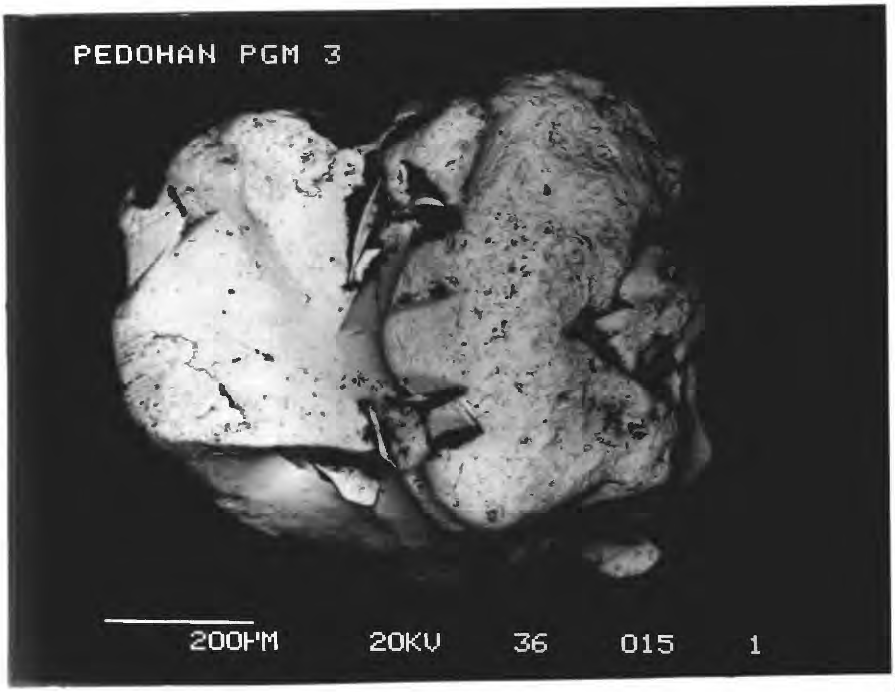
Figure 6. Back scattered electron images showing variation in the proportion of Pt-Fe alloy and Os-Ir alloy in PGM particles from S. Pedohon, Tabang area, East Kalimantan. Grains in A and B have few isolated blades of Os-Ir alloy in Pt-Fe alloy. Grain in C has about 30 percent Os-Ir alloy (blades) in Pt-Fe alloy. Grain in D is dominantly Os-Ir alloy (blades or plates); space between Os-Ir alloy is filled with Pt-Fe alloy and laurite (medium gray phase). E is detail of lower left corner of grain in D, showing laurite (medium gray) surrounded Os-Ir alloy plates surrounded by Pt-Fe alloy (smooth). Dark areas in all images are mixtures of clay minerals and iron-manganese oxides on the surfaces of particles.

……

Fig. 6A, B

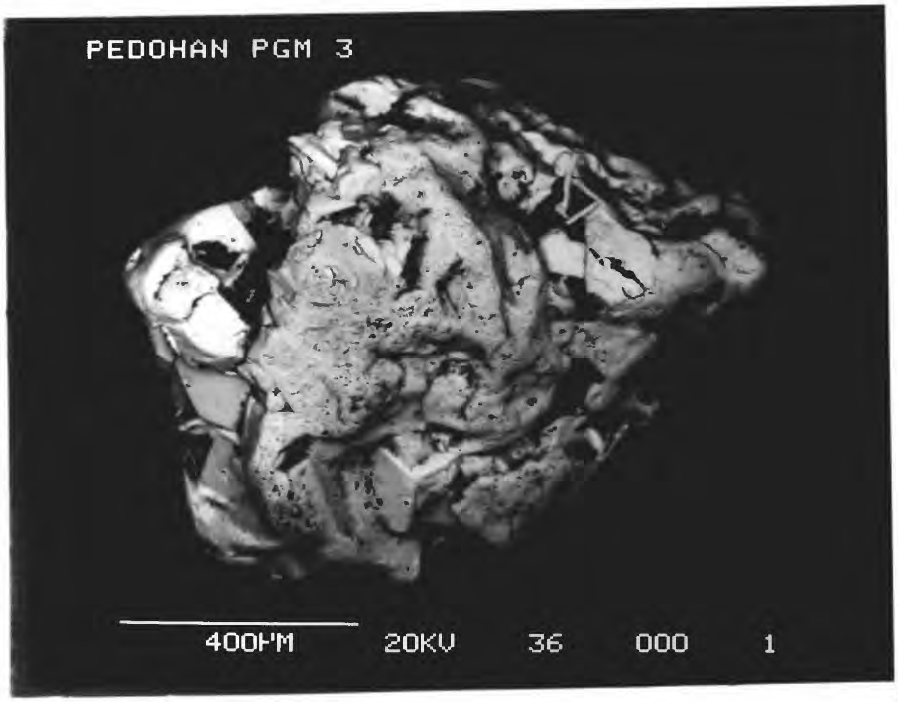

PEDOHAN PGM 2
200µM 20KV 36 010 1

A

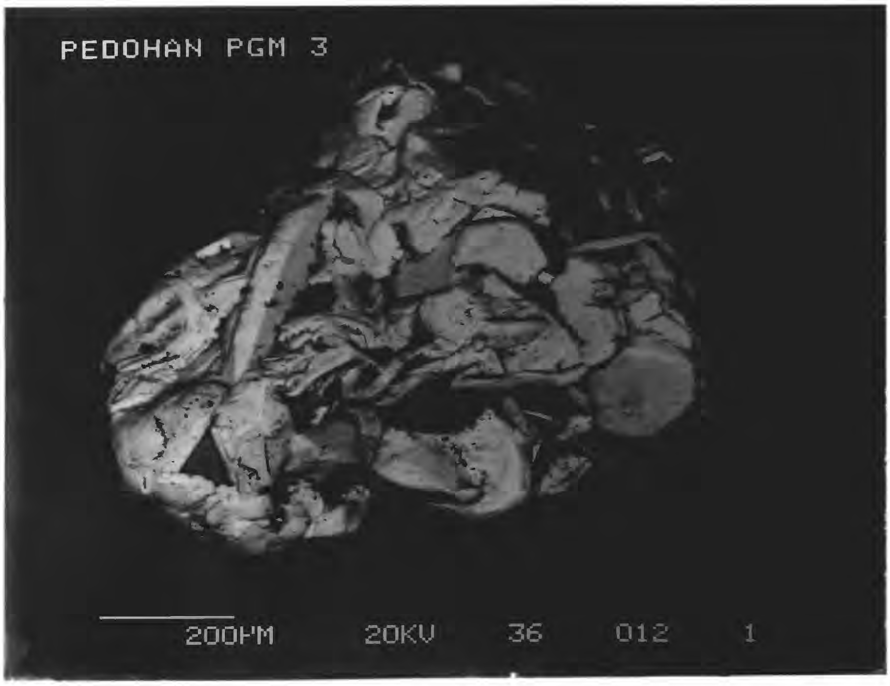

PEDOHAN PGM 3
200µM 20KV 36 015 1

B

Fig. 6C, D

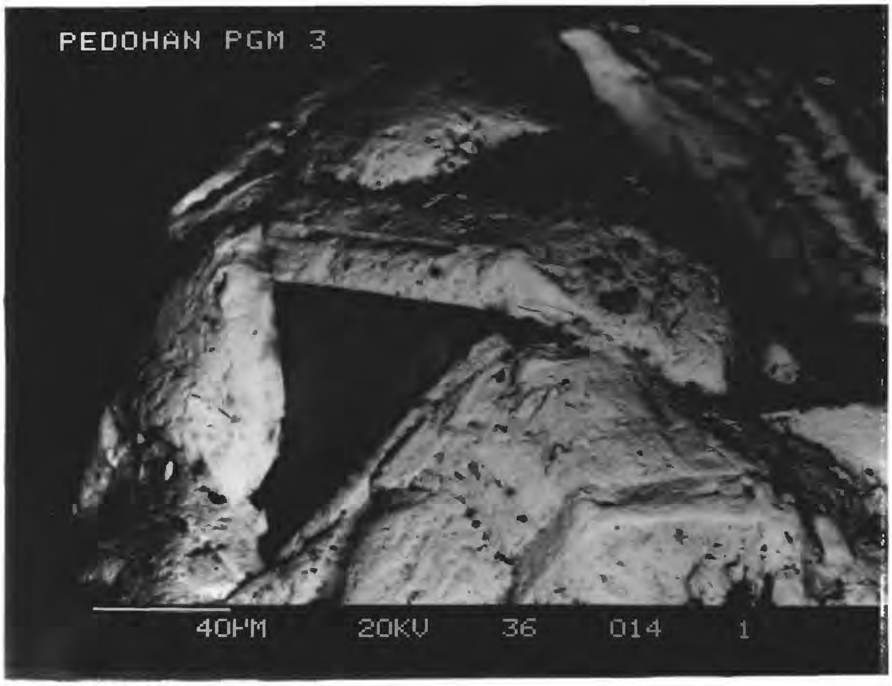

PEDOHAN PGM 3
400µM 20KV 36 000 1

C


PEDOHAN PGM 3
200µM 20KV 36 012 1

D

Fig. 6E



E

……

Figure 7. Back scattered electron image of Pt-Fe alloy (bright) with inclusions of laurite (medium gray-top center) and Os-Ir alloy (blades-bottom) in PGM particle from S. Pedohan, Tabang area, East Kalimantan. Dark areas are mixtures of clay and iron-manganese oxides on the surface of particle.

……

Fig. 7

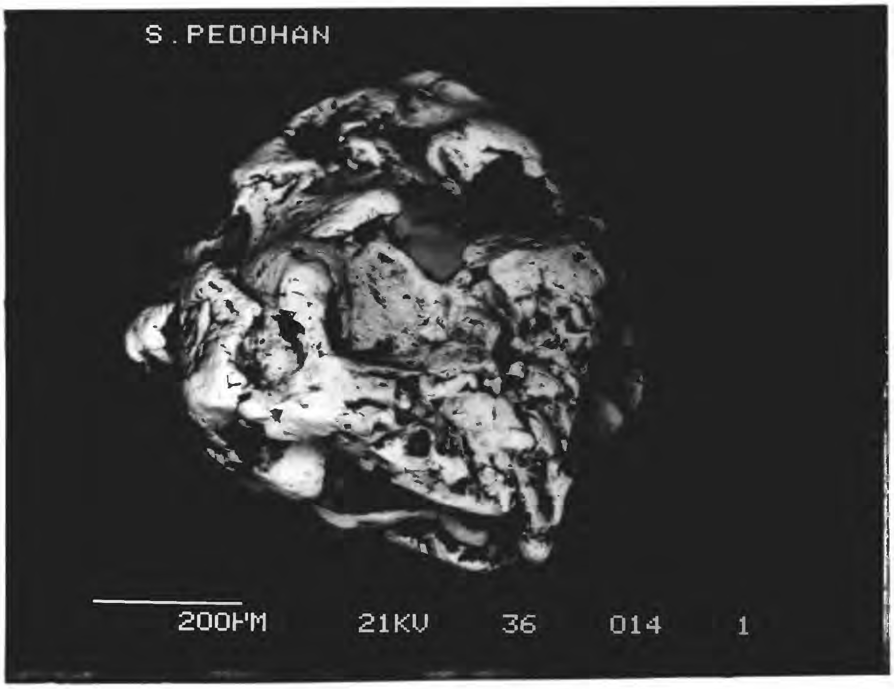
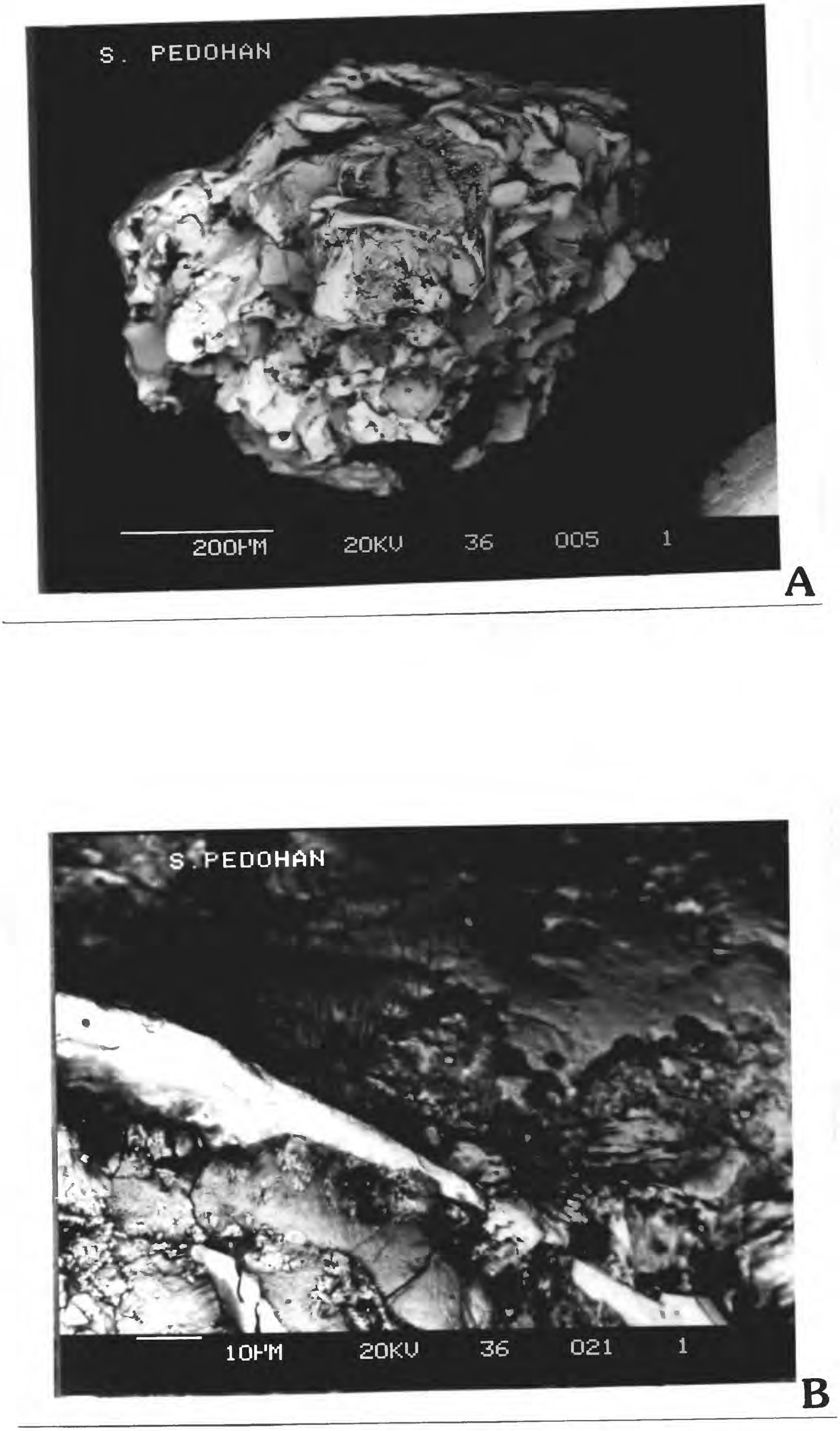


Figure 8. Back scattered electron image of PGM grain from S. Pedohon, Tabang area, East Kalimantan that consists of intergrowths of Os-Ir alloy, an Ir-Rh-Fe-Sb-S phase, and an Ir-Fe-Rh phase (A). Detail (B) shows Os-Ir alloy (bright, bladed), Ir-Fe-Rh phase (smooth, medium gray, bottom center), and Ir-Rh-Fe-Sb-S phase (strong parting or cleavage, top left).

Fig. 8A, B

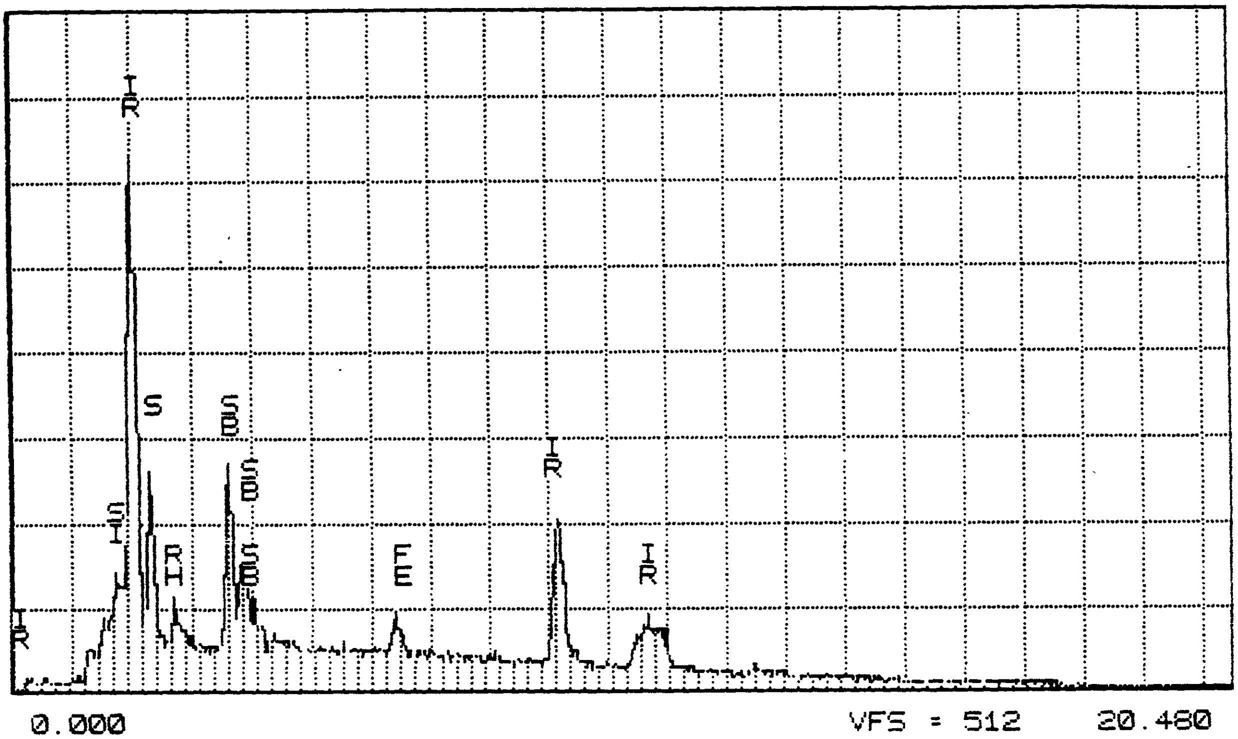


....

Figure 9. X - ray energy spectrum for Ir-Rh-Fe-Sb-S phase, S. Pedohon, Tabang area, East Kalimantan.

....

U. S. GEOLOGICAL SURVEY, MENLO PARK MON 10-JUL-89 13:32
Cursor: 0.000KeV = 0

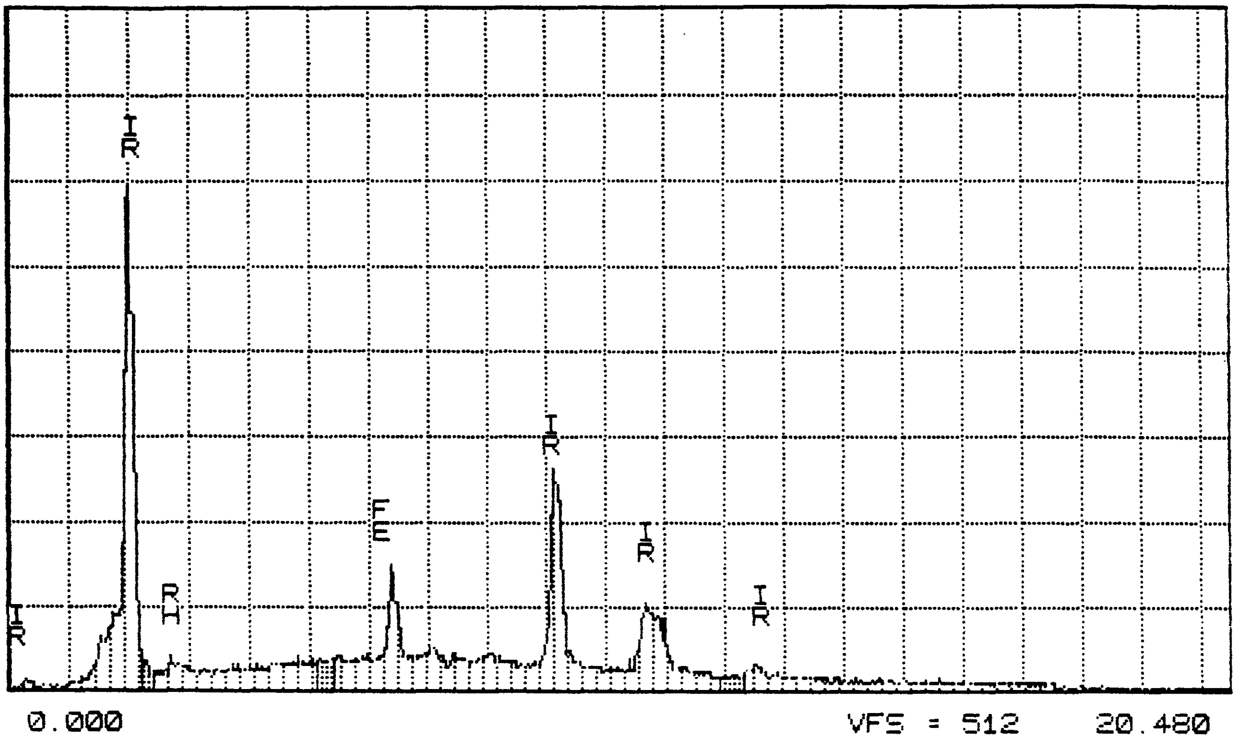


30 S. Pedohan H Ir-Fe-Rh-Sb-S

Figure 10. X-ray energy spectrum for Ir-Fe-Rh phase, S. Pedohon, Tabang area, East Kalimantan.

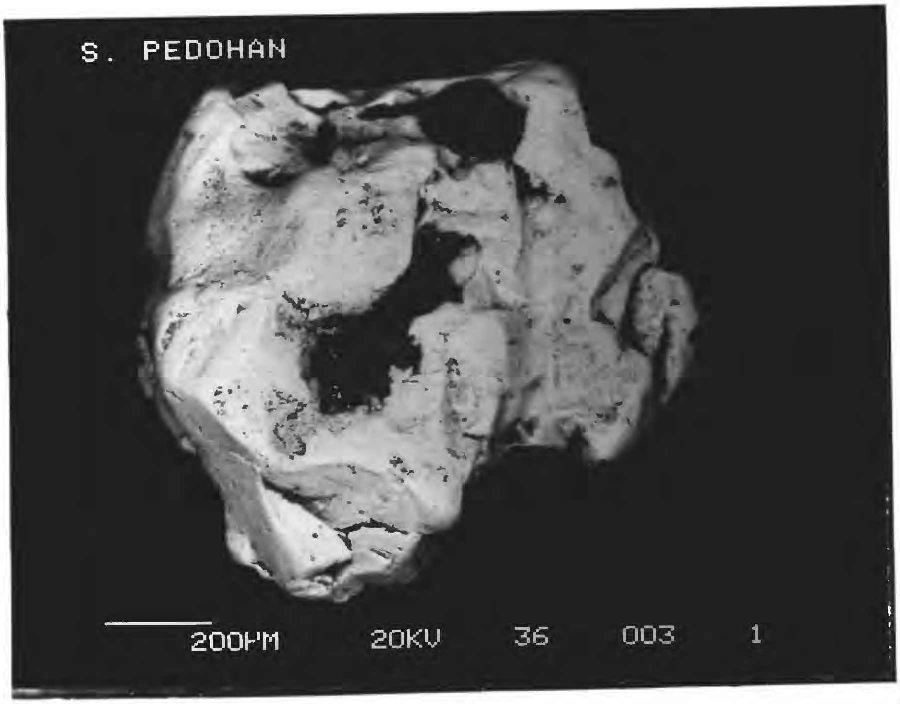
U. S. GEOLOGICAL SURVEY, MENLO PARK MON 10-JUL-89 13:51

Cursor: 0.000keV = 0 ROI (1)11.950:12.290



30 S. Pedohan H Ir-Fe-Rh

Figure 11. Back-scattered electron images of Pt-Fe alloy with inclusions of chromite, S. Pedohon, East Kalimantan.


S. PEDOHAN
200μM 20KV 36 003 1
A

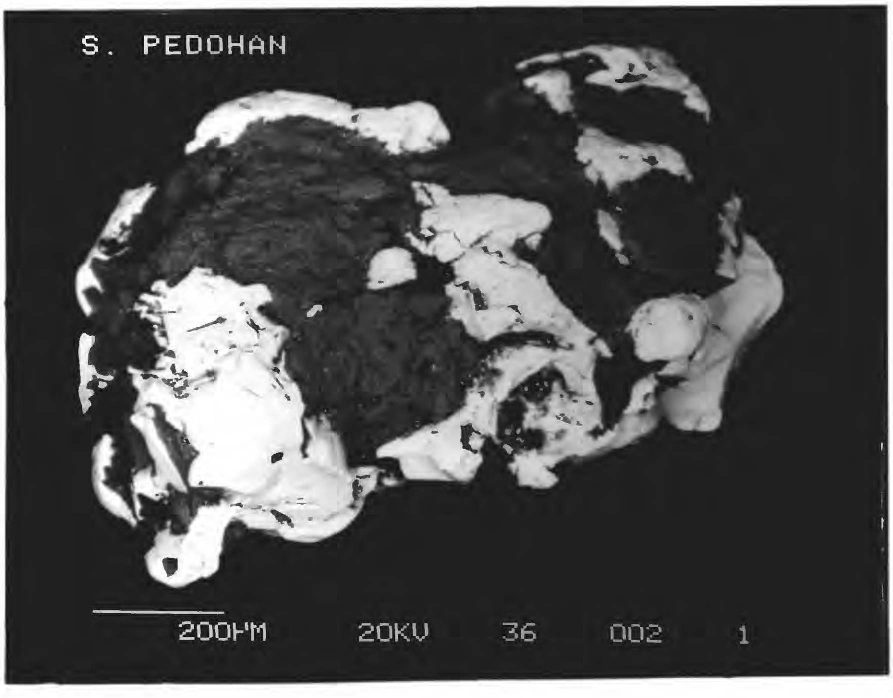
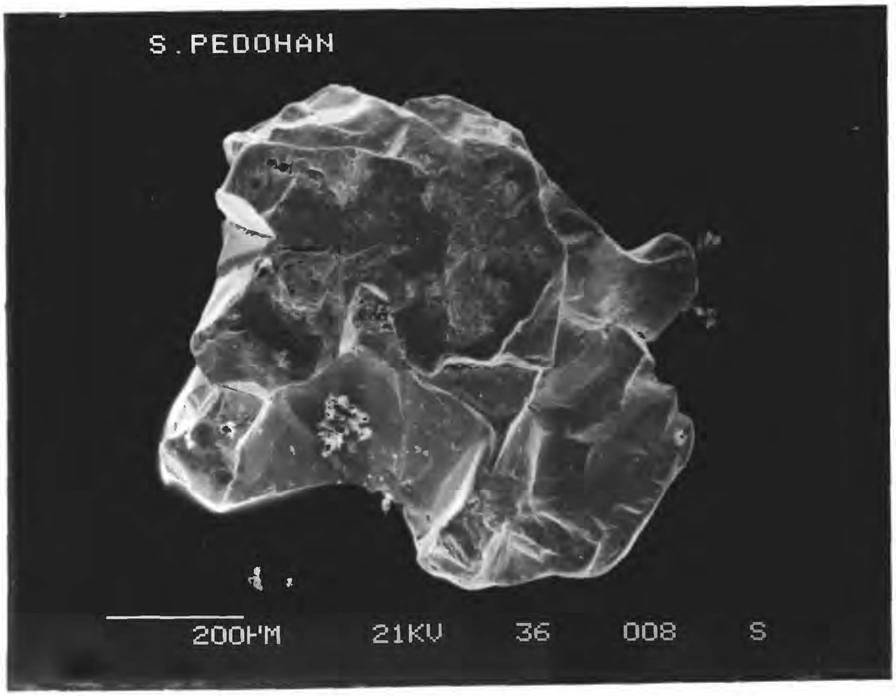
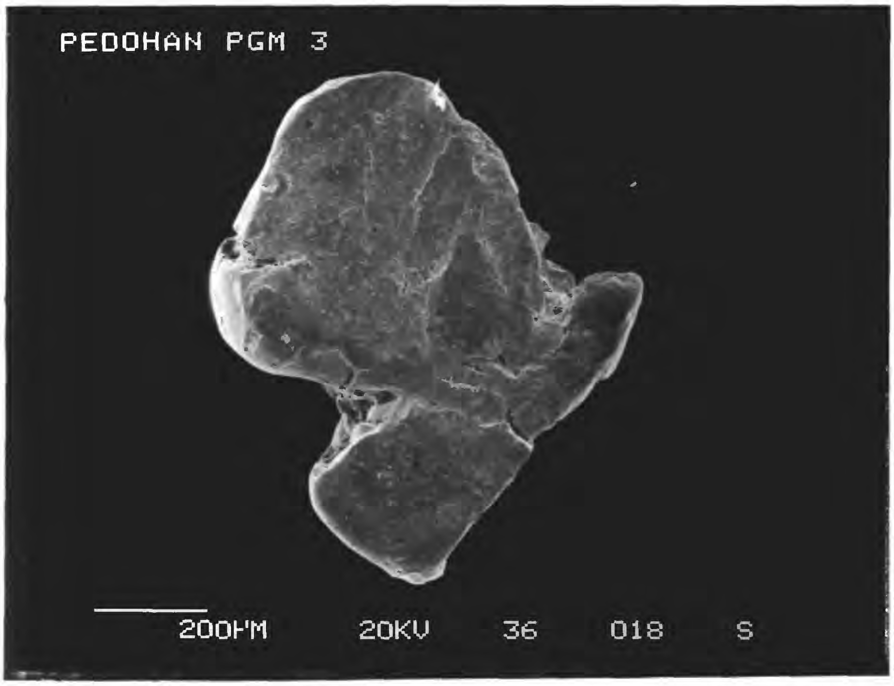

S. PEDOHAN
200μM 20KV 36 002 1
B

Figure 12. Secondary electron image of grains of Pt-Fe alloy from S. Pedohon, Tabang area, East Kalimantan, showing increasing degree of rounding from A (very angular) to D (subrounded).

Fig. 12A, B

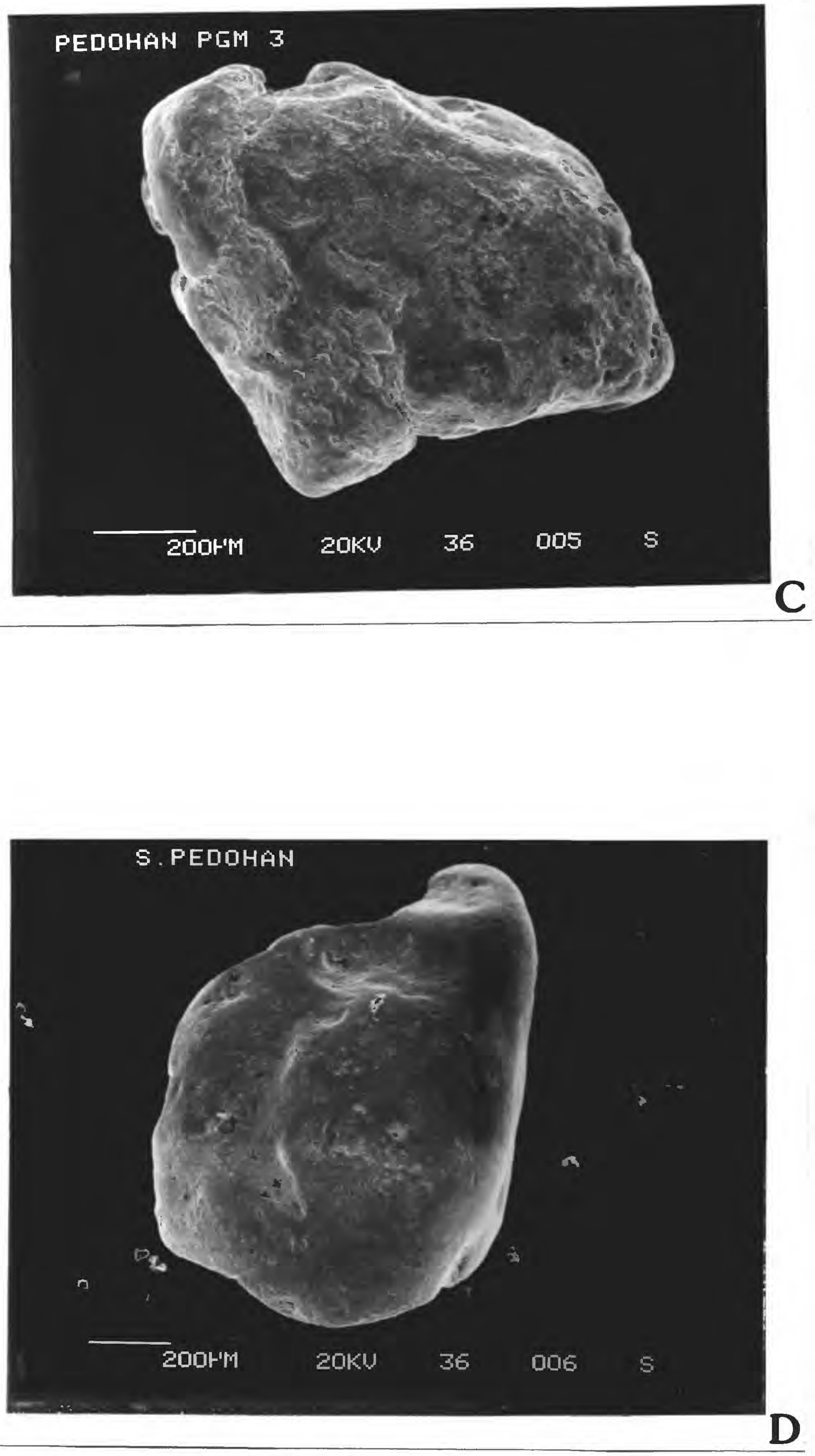


A



B

Fig. 12C, D


PEDOHAN PGM 3
200µM 20KV 36 005 S
C
S.PEDOHAN
200µM 20KV 36 006 S
D

PASIR AREA, EAST KALIMANTAN

Pt was detected in pan concentrate and stream sediment samples collected during regional exploration of the Pasir area by P.T. Ingold Pasir Mineral - DMR. Available information about these samples is summarized below:

- a pan concentrate sample with 12 ppm Pt - located on S. Kesunga (Longitude: 115° 59' 1" E, Latitude: 1° 40' 23" S) near village of Rantaubuta. Appoximately 15 km west-south-west of Samuntai.
- a pan concentrate sample with 8 ppm Pt - located on S. Kesunga (Longitude: 115° 57' 24" E; Latitude: 1° 42' 48" S) near village of Rantaubuta. Approximately 20 km west-south-west of Samuntai.
- a stream sediment sample with detectable Pt (0.x or higher ?) - located on S. Sekum (Longitude: 116° 10' 16" E; Latitude: 1° 33' 22" S), a tributary of S. Adang. Near village of Lonikis. Approximately 12 km north-north-east of Samuntai.
- 3 stream sediment samples with detectable Pt (0.x or higher ?) - located on S. Pait and tributaries (approx. Longitude: 116° 7' 19" E; Latitude: 1° 33' 9" S). S. Pait is a tributary of S. Adang. Near village of Lonikis. Approximately 11 km north of Samuntai.

The bedrock underlying the area of the pan concentrate samples has been mapped as Pitap Formation, which consists of Cretaceous sandstones interbedded with graywacke, claystone, and conglomerates (Umar and others, 1982). The bedrock underlying the area of the stream sediment samples is the Tertiary Pamaluan Formation which consists of shale and claystone with interbeds of marl, sandstone, and limestone. An ultramafic complex, approximately 58 km long and 6 km wide, crops out in a northerly trend between the sample locations. The pan concentrate samples lie immediately west of the complex; the stream sediment samples lie immediately to the east.

SOUTH KALIMANTAN

The association of Au and PGM with the diamond placers in this area is well known (van Bemmelen, 1949; Mertie, 1969). Maps showing the distribution of diamonds in placers have been published (noteably Krol, 1920). The richest diamond grounds were described as occuring near Tjempaka (Cempaka) or Goenoeng Lawak (old name for Cempaka area) (Anonymous, 1918; van Bemmelen, 1949; Mertie, 1969). Au: Pt was said to range from 9/1 to 10/1. Diamonds (and platinum and gold) were described in the alluvial deposits and many tributaries of the Riam Kiwa, the Riam Kanan, and the Kusan. Diamonds, gold and platinum were also noted to occur in the basal conglomerates of the Manunggal Formation. Published investigations of the PGE/PGM in these diamond-bearing placers are limited. Mertie (1969) republished 4 analyses of nuggets and 4 analyses of osmiridium from the Goenoeng-Lawak region (Table 3; nugget analyses plotted in Figure 13). Stumpfl and Clarke (1966) and Stumpfl and Tarkian (1973a,b) described a placer concentrate identified only as being from the Riam Kanan. Their concentrate contains 40 percent Pt - Fe alloy, 35 percent Os - Ir alloy (iridosmine, osmiridium, rutheniridosmine), 20 percent gold-silver-copper alloys, and 5 percent oxides (martitized titanomagnetite, psuedobrookite-hematite intergrowths, chromite). Sn-Cu alloys were also described. The PGM were noted to be coarser than the Au particles. Burgath (1988) described alluvial PGM from two diamond-bearing placers, S. Besar and Jambunau. Summaries of his findings are presented in Tables 4 and 5.

Table 3. Analyses, in percent, of platinum metals, Goenoeng Lawack region, Borneo (from Mertie, 1969). (Analyses recomputed to 100 percent. N.D., no data)

	A	B	C	D
Platinum	73.98	74.64	84.15	74.89
Iridium	6.46	8.22	.67	3.18
Osmium	1.21	.50	.31	N.D
Osmium + iridium	9.30	8.75	3.87	9.23
Osmium + ruthenium				1.30
Rhodium	.53	N.D	N.D	.64
Rhodium + palladium		1.34		
Palladium	1.52			.24
Iron	6.11	6.10	10.87	10.68
Copper	.89	.45	.13	.44
Total	100.00	100.00	100.00	100.00

A and B. Nuggets (Bleckrode, 1858), C. Nugget (Bocking, 1855), D. Quiring (1962).

Table 4. Characteristics of the PGM - bearing placer at Jambunau, South Kalimantan (Burgath, 1988; Burgath and Simandjuntak, 1983).

Location	near Bunglai on the western shore of Riam Kanan Lake
Geology	Sketch of "shaft" given in Figure 2, p. 18 of Burgath and Simandjuntak (1983). No vertical scale. Diamond–, gold-, and platinum-bearing layer noted as pebbles in brown earthy matrix. Pebbles are as noted at Awangbangkal. No ultramafic rock was recognized in gravel
Mineralogy	8 grains of Pt-Fe alloy; one with inclusions (see below); 1 grain of Pt-Osmiridium. Microprobe analyses given in Burgath (1988)
Size of particles	Not available.
Morphology of particles	Pt-Fe alloy forms subrounded to angular grains and splinters. Projections and deep embayments. Spongy grain with pores filled with silicate (Fe-Al silicate with Ca, Ti, and V). Pt-osmiridium grains are subrounded with embayments
Associated minerals in concentrate	Au, diamond, silicates
Comments	Analyses of Pt-Fe alloy from Jambunau cluster and are distinct from those at Sungai Besar

Table 5. Characteristics of the PGM - bearing placer at Sungai Besar, South Kalimantan (Burgath, 1988)

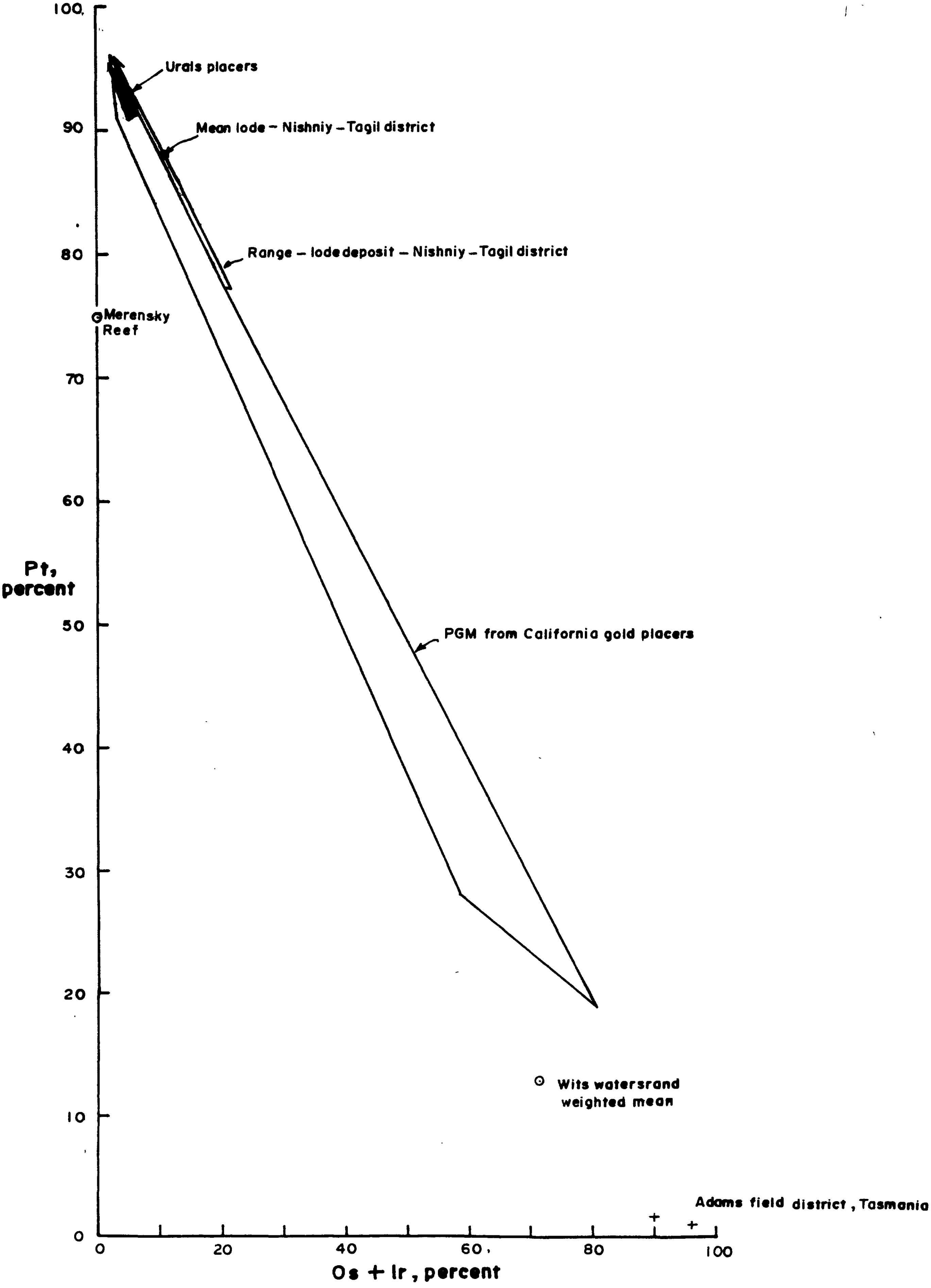
Location	Very general location shown in Figure 1 of Burgath (1988)
Geologic information	None
Mineralogy	Pt - Fe alloy - 2 grains; rutheniridosmine 1 grain; Pt-osmiriduim - 1 grain; Osmiridium - 1 grain, Microprobe analyses given in Burgath (1988)
Size of particles	No information
Morphology of particles	Large rounded grains, with partially lobate marginal zone and few, indistinct pores. Os-Ir-Ru alloys are small, subangular to part rounded, compact
Associated minerals in concentrate	Au, diamond, pink garnet, zircon
Comments	Analyses of Pt-Fe alloy cluster and are distinct from Jambuneau

Descriptions of PGM and Au placers without diamonds are rare. Anonymous (1918) described the placer Rinaat in the Pleihari district as a gold-PGM placer with no diamonds. The particles were described as small nuggets instead of the scales and minute grains seen elsewhere. Burgath (1988) described PGM from a Au-PGM placer at S. Banyumin (Table 6).

Table 6. Characterisitics of PGM - bearing placers at Sungai Banyumin, South Kalimantan (Burgath, 1988).

Location	Drainage system north of Gunung Damargusang southeast of Banjarbaru. See Figure 1 in Burgath (1988)
Geologic information	None
Mineralogy	Pt-Fe alloy (3 grains)
Size of particles	< 200 µm to 1750 µm
Morphology of particles	Grains with cubic (octahedral) outlines; others with irregular projections. Angular to subrounded with signs of mechanical wear
Associated minerals in concentrate	Au, magnetite, ilmenite, rounded pink garnet euhedral whitish brown cloudy garnet, bluish green amphibole

Figure 13. Variation in the proportion of Pt to Os + Ir for PGE-placer and lode deposits related to Alaskan-type ultramafic intrusions. PGE analyses were recomputed to 100 percent, free of Au and impurities. Data for Bol'shoi Gusevki river from Smirnov (1977); all other information from Mertie (1969).


Urals placers
Mean lode – Nishniy – Tagil district
Range – lode deposit – Nishniy – Tagil district
Merensky Reef
PGM from California gold placers
Wits watersrand weighted mean
Adams field district, Tasmania
Pt, percent
Os + Ir, percent
100
90
80
70
60
50
40
30
20
10
0
0
20
40
60
80
100

Because of the potential for finding a lode deposit in this area, a detailed summary of the occurrence of platinum-group elements was prepared for this report. Information used to produce the maps shown in plates 1 and 2 includes published reports by Krol (1920), unpublished DMR reports, work in progress by the DMR Platinum Exploration Team in the Riam Pinang area, and discussions with Alwi Wikrama, P.T. Aneka Tambang. Consideration of the geologic map and the mineral occurrence map allow us to propose several different categories of PGE occurrence for the purpose of discussion:

(1) Au - PGM placers and areas favorable for the occurrence of primary platinum-deposits.
(2) Diamond - Au - platinum occurrences in the Cretaceous Manunggul Formation, that serve as a secondary source for these minerals in modern placers.
(3) Diamond - Au - PGM placers in large paleochannels on the alluvial plains west of the Bobaris - Meratus Mountains.
(4) Diamond - Au - PGM placers in alluvial terrace and modern channel deposits of rivers and streams on pre-Tertiary basement draining areas with exposures of Manunggul Formation.
(5) PGE contents of podiform chromitites, largely from the Bobaris Range.
(6) PGE contents of other potential pre-Tertiary PGE source rocks.
    a) Tanah Ambungan Cr - Fe
    b) Pigat Au
    c) Riam Pinang Fe - skarn

Au - PGM placers

Au - PGM placers were identified south of the Riam Kanan. To the north, the occurrence of diamond-, gold-, and PGM-bearing Manunggul Formation in the upper reaches of the principal stream and tributaries obscures the occurrence of any primary PGM source. Eight PGE - Au placers have been identified:

(1) S. Kalaan. Au and PGM subequal. The placer deposits are terraces that extend for approximately 15 km from the headwater tributaries S. Kahung Kanan and S. Kahung Kiwa downstream to the confluence of S. Kalaan with S. Tuyup. Diamonds are present in the placers downstream from the S. Tuyup. Placer workings are old. DMR panning survey in this drainage found no PGM.
(2) S. Tuyup. Au dominate; PGM rare. Placer deposits in terraces extending for 8 - 10 km from headwaters downstream to S. Haparoy. Workings are old. SEM investigations of alleged PGM particles collected at two stations along the S. Tuyup or its tributaries by a DMR panning survey showed they were lead (Pb).
(3) S. Batulaki. Au and PGM subequal. Placer deposits extend from near headwaters at least 20 km downstream.
(4) S. Jernih. Au and PGM subequal. Placer deposits occur in terrace gravels for approximately 3.5 km in the upper course of the drainage. Downstream the river has a steep gradient and no gravel deposits are present.
(5) Betaga area. Au and PGM subequal. Placer deposits in terrace gravels near the confluence of S. Ketel and S. Kiram. Placer workings occur 1.5 km upstream from the confluence on both drainages and approximately 1 km downstream. Workings don't extend further downstream because productive gravels become too deep. Deposits are currently being worked.
(6) S. Banyumin. Au and PGM subequal. Placer workings in terrace gravels extend for 1.2 km in the headwaters of S. Banyumin. Most workings are old. Downstream the productive gravels become too deep to work. Burgath (1988) described PGM from a concentrate from this placer; a summary is presented in Table 3.
(7) S. Tabanio. Au and PGM subequal. A 14 km paystreak extends from the area near Riam Pinang downstream to S. Danau Djingah. Placers are being actively worked. Au placer upstream from Riam Pinang area. Downstream from S. Danau Djingah, the gravels are too deep to work by the local miners. Results of detailed investigations of the Riam Pinang area and placers at S. Pirik and S. Danau Djingah are presented in another section.

(8) S. Sebuhur. PGM dominant placer. Workings extend for approximately 3 km above the confluence with S. Panggung. Worked by the Japanese during WW II. Shafts were sunk approximately 15 m to exploit productive gravels.

These Au - PGE placers define 4 areas prospective for the occurrence of lode PGE deposits: (1) an area in the Pematang Kuliling Range and near the headwaters of the S. Kalaan and S. Tuyup; (2) the area near the headwaters of the S. Batulaki, S. Pihik, and S. Jernih; (3) the area near G. Damargusang in the Betaga area and in the headwaters of S. Banyumin; and (4) the area upstream from deposits on S. Sebuhur.

Diamond - Au - PGM in the Manunggul Formation

Van Bemmelen (1949), citing the work of earlier investigations, describes the occurrence of diamonds (with Au and PGM) in the Upper Cretaceous conglomerates of the Manunggul Formation. Diamonds have been found in basal conglomerates of this formation at S. Pinang (tributary of the Riam Kiwa), S. Artain, and the rivers rising on the Bukit Besar. In the Meratus Mountains, the diamonds have not been found in the basal conglomerates but occur in conglomerates found stratigraphically higher in the formation. Examples include the S. Artain (tributary of S. Tebatan) and S. Hadjawa. Basal conglomerates northwest and southeast of the Bobaris peridotite have also produced diamonds.

The content of diamonds, gold, and PGM in the Manunggul Formation is very low. Sampling (10 test pits, 20 m^3 each) showed values of 0.005 ct/m^3 diamond and < 20 mg/m^3 Au + PGM (Alwi Wikrama, personal comm.). Precise locations of test pits are not known.

Pleistocene paleochannels in the vicinity of Martapura

There are several large paleochannels in what has been mapped as the Martapura Formation near Martapura that contain diamonds, Au, and PGM. These are the deposits referred to in earlier summaries that described the richest diamonds grounds as being near Tjempaka (Cempaka; Anonymous, 1918) or Goenoeng Lawak (Anonymous, 1918; Mertie, 1969; van Bemmelen, 1949). The Martapura Formation is reported to be Pleistocene in age and consists of unconsolidated deposits of gravels, sand, and clay. The Pliocene Dahor Formation is somewhat more indurated and does not appear to contain concentrations of diamonds, Au, or PGM.

The general position and trends of these paleochannels can be determined simply by mapping were local miners have been digging for diamonds (see, for example, Krol, 1920). Van Bemmelen notes that there were 200 mines with 3000 - 4000 miners in this general area in 1836. The local miners are limited by the depth of the gravels but principally by swampy ground (which marks post- Pleistocene marine transgression of these deposits). The paleochannels extend beneath the swamps and are currently being explored by mining companies.

The description of these deposits will focus principally on the Cempaka - Danau Seran paleochannels which have been extensively explored, followed by brief summaries of what is known of the other channels.

Cempaka - Danau Seran paleochannels

The Cempaka - Danau Seran paleochannels occur west of Cempaka in the drainage system of the modern S. Apukan (Figure 14). The exploration project on the paleochannels was started in 1968 by P.T. Aneka Tambang. The project was joint ventured with Acorn Resources, Australia (40 percent) and British Petroleum Minerals (40 percent) in 1986. Exploration was finished in 1988 and construction of dredge facilities may begin in May, 1990.

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Figure 14. Map showing the outline of the Cempaka and Danau Seran paleochannels near Cempaka, South Kalimantan.

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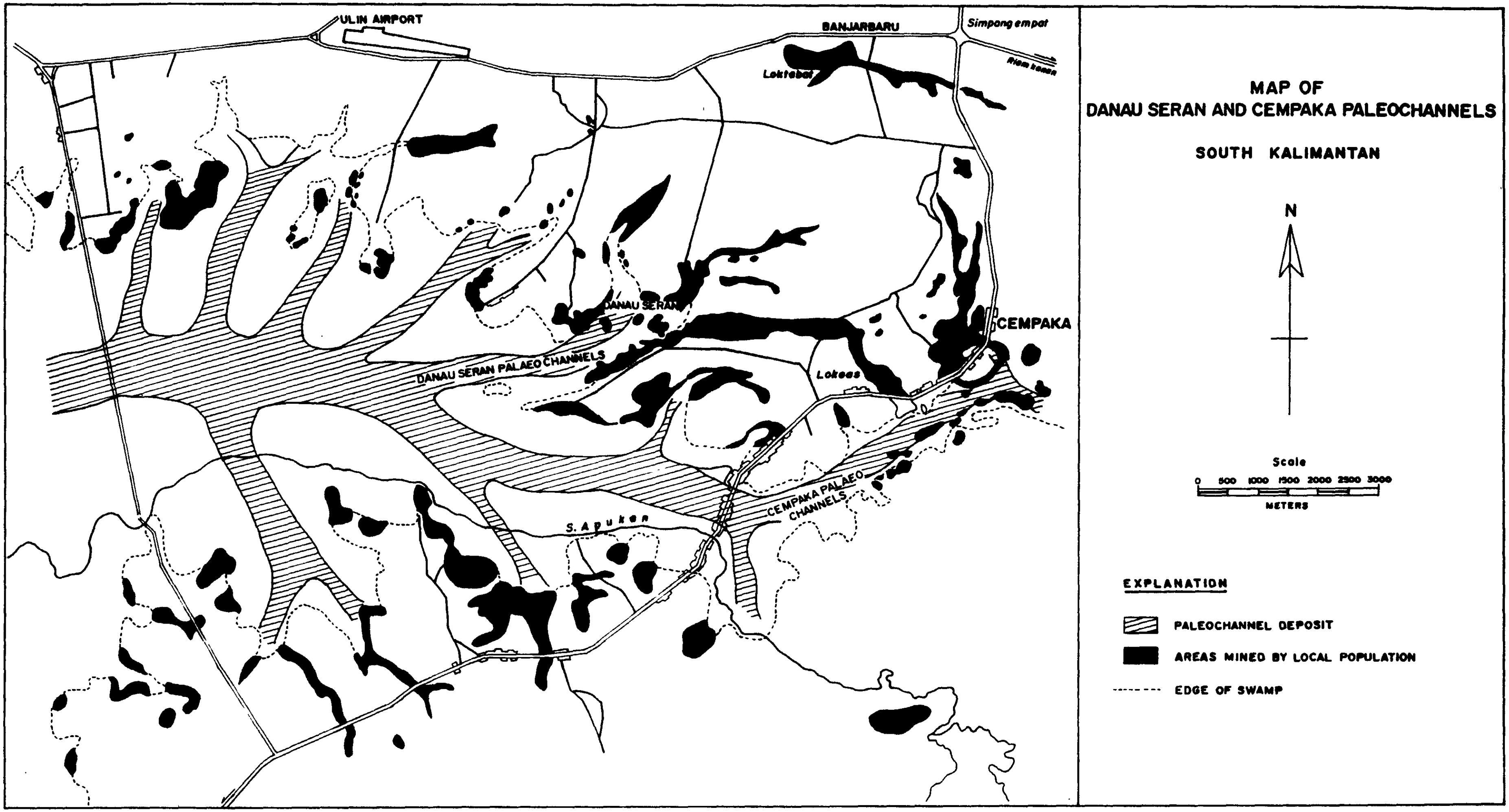


MAP OF
DANAU SERAN AND CEMPAKA PALEOCHANNELS

SOUTH KALIMANTAN

The paleochannel is approximately 15 km long and the gravel beds are 7 to 23 m deep. The gravel beds occur in channel deposits, up to 3 m thick, and terrace deposits, up to 0.5 m thick. The gravels in these channels are 200 to 800 m wide. Drilling and mapping has outlined 20 million m^3 of diamond, gold, and PGM gravels in the deposit. The cobbles in the diamond-bearing gravels consist largely of quartz (80 percent) but schist (5 percent), volcanic rocks (10 percent) and jaspar (5 percent) are also found. The diamond-bearing gravels may overlie an older grey gravel in the same channels. These gravels have abundant volcanic rocks clasts and coal fragments but contain no diamonds and little Au or PGM. Generally, the footwall to the diamond-bearing gravels beds is clay. Indurated lenses of conglomerate have been found in the footwall deposits.

Bulk sampling (6000 m^3 from six localities in the deposits) indicates a grade of 0.1 to 0.3 ct/m^3 diamond, 80 mg/m^3 Au, and 40 mg/m^3 PGM. Eighty percent of diamonds are gem quality and range in color from clear to pink to blue to yellow (Figure 15). Forty percent of the diamonds were under 1 carat; 20 percent were over 5 carats. The largest recorded diamond found in these gravels weighted 167 carats. Particles of gold are much coarser than the PGM; the ratio of Au grains to PGM grains is 5 - 10 to 1. The weight ratio of Au/Pt is 2/1. The PGM and most of the Au occurs as flattened flakes (Figure 16). The PGM are dominated by Pt-Fe alloy, usually in flattened grains < 2 mm in maximum diameter. Tulameenite intergrown with Pt-Fe alloy, Os-Ir alloy, and amalgam also occur (Table 2). Analyses done by P.T. Aneka Tambang on PGM concentrates show 67 percent Pt; analyses republished by Mertie (1969) from the Goenoeng Lawak region (Table 4) show Pt values ranging from 74 to 84 percent. Minerals found in concentrates include rutile, corundum, topaz, cinnabar, cassiterite, and chromite. Gravels that were cut down through by the Cempaka - Danau Seran paleochannel yield only 0.003 ct/m^3 diamond.

Other paleochannels

Paleochannels are known to exist under or near S. Alalak/ Cinta Puri, S. Bogor/Gadung, S. Putjungputjung, Riam Kanan, and Riam Kiwa. Preliminary exploration work (Bangka drilling) has been done on S. Alalak/Cinta Puri and S. Bogor/Gadung paleochannels; work is planned on S. Putjungputjung. The areas near the Riam Kanan and Riam Kiwa have been exploited by local miners but are now too heavily urbanized to allow commercial exploration or development.

Where explored in one section, the S. Alalak/Cinta Puri channel gravels are 500 m wide, 19 m deep, and approximately 2.5 m thick. Those at S. Bogor/Gadung are 200 m wide, 15 m deep, but < 0.5 m thick. Clay forms the substrate on both channels. The ratio of Au to PGM grains is approximately 5 to 1 for S. Alalak; Au is finer grained than at Cempaka. The PGM in both of these channels differs in physical appearance from the Cempaka-Danau Seran paleochannel. The particles are dark gray, dull, and sub-rounded to sub-angular.

Paleochannels are also being explored in the drainage basin south of the Cempaka/Danau Seran paleochannel (S.Maloka/ Teratat). The tributaries from the south and east contain only Au. Those draining from the north carry diamonds and PGM in addition, apparently eroded from the Cempaka/Danau Seran deposits.

Diamond-Au-PGM placer deposits along Riam Kanan, Kiwa, Kusan and their tributaries

Van Bemmelen (1949) states that almost the entire production of diamonds in southeastern Borneo came from river terraces and alluvial river gravels. Diamond, Au, and PGM placer deposits occur on Pleistocene terraces and in modern alluvial deposits on the Riam Kanan, Riam Kiwa, and S. Kusan and their tributaries that drain areas underlain by part of the Manunggul Formation (Plate 1 and 2).

Figure 15. Photograph of diamonds from the paleochannels near Cempaka, South Kalimantan. Dots on grid have 1 mm spacing.

Fig. 15

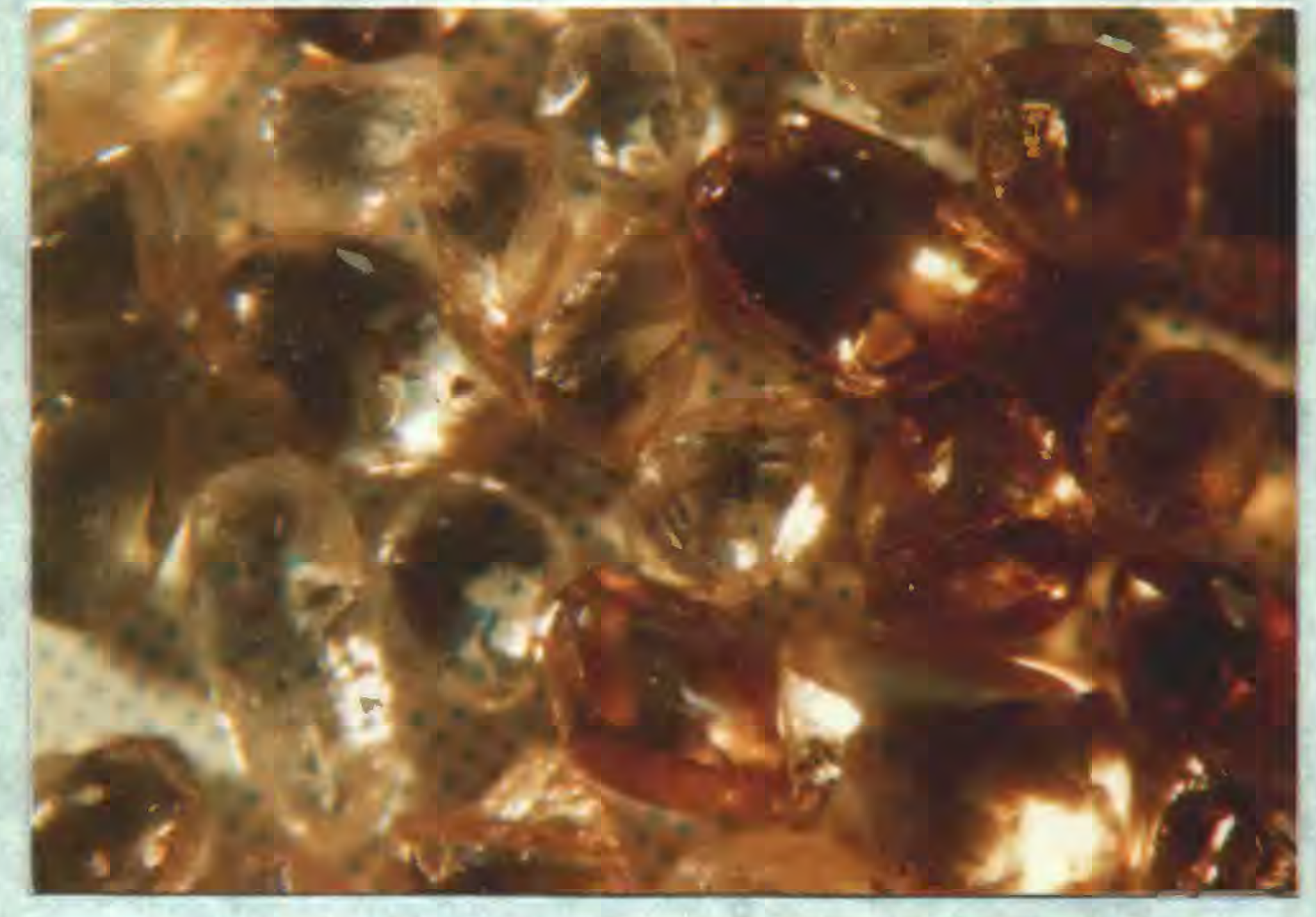
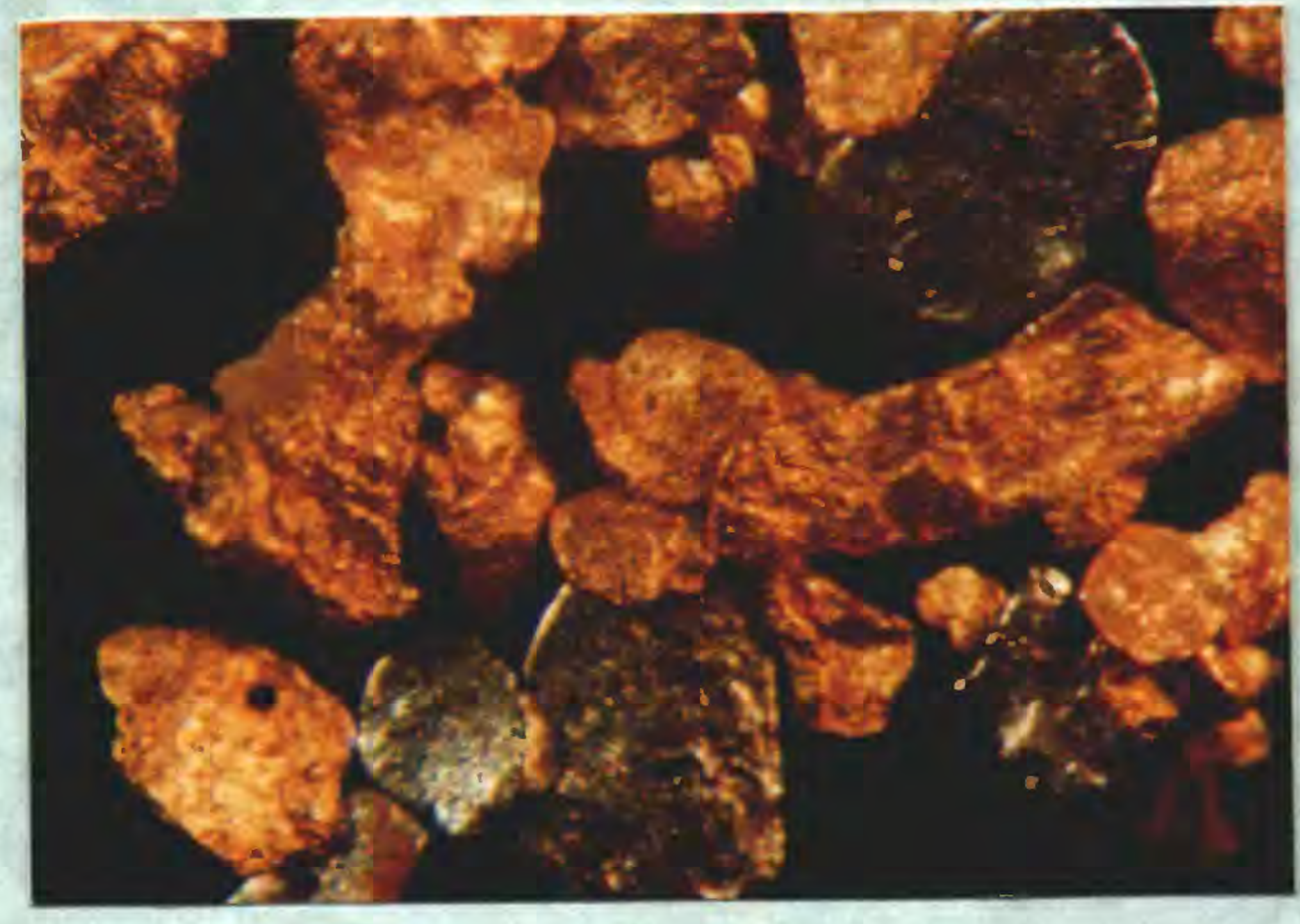


Figure 16. Photograph of flattened flakes of placer Au and PGM (gray) from the paleochannels near Cempaka, South Kalimantan.

Fig. 16



There is very little detailed information on these deposits. Generally, diamond, Au, and PGM occur both in terraces and in the modern alluvial deposits on the main trunk drainages (Riam Kanan or Riam Kiwa) but placer deposits are usually restricted to the channels of higher order tributaries. Diamonds, Au, and PGM from the S. Kusan appear to have been transported by long shore drift for approximately 50 km down the southest coast (at far south as the mouth of S. Satui).

Very general descriptions of the diamond-bearing deposits at Jambunau and Awangbakal were given by Burgath and Simandjuntak (1983). Burgath (1988) published some information on the PGM from Jambunau placer (Table 5) again showing a predominance of Pt-Fe alloy. However, he also showed that composition of the alloy was different than Pt-Fe alloy at S. Besar (Table 6), a placer on a tributary to the Cempaka-Danau Seran paleochannel. Test pits (representing 10,000 m^3 of sample) from young alluvial gravels, generally in the Riam Kanan drainage, contained 0.1 to 0.4 ct/m^3 diamond.

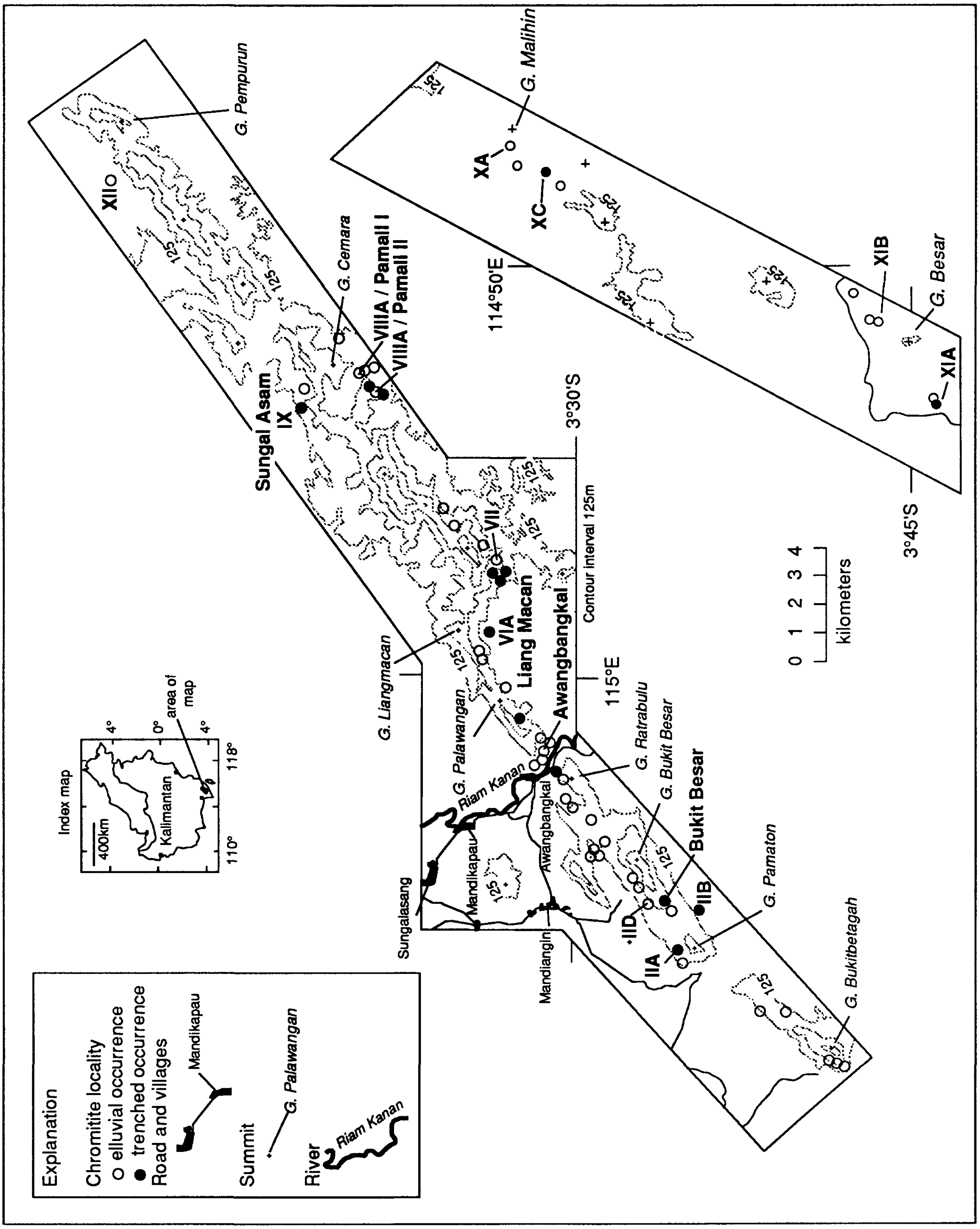
PGE analyses - Podiform chromitites of the Bobaris Range

In the vicinity of the transition from tectonized harzburgite to ultramafic cumulates in the Bobaris Range, at least 60 elluvial chromitite occurrences have been found on the southern flank from G. Cemara to G. Palawangan, the northern flank of G. Cemara, the northern flank from G. Ratrabulu to G. Pamaton, in the vincinity of G. Bukit Besar, and extending from G. Malihin to G. Besar (Figure 17). As part of a joint project by the Directorate of Mineral Resources and the Federal Institute for Geosciences and Natural Resources (BGR, Hannover, Federal Republic of Germany), 14 of these occurrences have been trenched or test pitted resulting in the location of 5 in-situ chromitite occurrences (Pamali I and II, Sungai Asam, Liang Macan, Bukit Besar; Simandjuntak and others, 1986). Samples of these in-situ occurrences, as well as eight of the elluvial occurrences provided by Wilher Simandjuntak were analyzed for PGE by the USGS to contribute to the assessment of the area (Table 7).

Table 7. PGE analyses of podiform chromitites, Bobaris and Meratus Range, South Kalimantan. [PGE determined by NiS fire assay - ICP mass spectroscopy; analysts: R.R. Carlson and A.L. Meier, USGS, Denver, Colorado]

SAMPLE LOCALITY		ELEMENT (ppb)				
ID	NAME	Pt	Pd	Rh	Ru	Ir
IIA-1	Pamaton	23	8.0	6.2	95	23
IIA-2	Pamaton	40	1.7	100	1300	380
IIB	Imban (Kiram)	3.9	1.7	28	130	74
IID	Bukit Besar	1.5	2.5	1.4	24	5.6
VIA	Liang Macan	32	5.5	9.9	100	89
VII	Batuditabang	1400	91	240	740	370
VIIIA-1	Pamali I	300	4.7	49	340	150
VIIIA-2	Pamali I	2.1	1.2	12	62	30
89INZ Pamali I	Pamali I, trench 1A	3.8	1.2	24	110	61
VIIIB	Pamali II	5.8	< 0.8	5.2	57	24
IX-1	Sungai Asam	25	1.9	34	190	73
IX-2	Sungai Asam - plagioclase bearing	1400	24	160	950	390
XA	Malachin	1200	58	370	1800	860
XC	Imban	2.3	1.6	6.0	90	25
XIB	Tanah Ambungan C-200	3.3	< 0.8	1.8	17	3.3
Kusan	Kusan, Meratus Range	10	2.3	8.8	22	9.3
89INZ PLWGN	Awangbangkal	1100	51	380	2100	970

Figure 17. Chromitite occurrences in the Bobaris ophiolite and location of analyzed samples, Banjar and Tanah Laut districts, southeastern Kalimantan, Indonesia.


Explanation
Chromitite locality
○ elluvial occurrence
● trenched occurrence
Road and villages
Mandikapau
Summit
G. Palawangan
River
Riam Kanan
Index map
400km
Kalimantan
area of map
110°
118°
4°
0°
4°
XII
G. Pempurun
G. Cemara
VIIIA / Pamali I
VIIIA / Pamali II
Sungai Asam
IX
VII
VIA
Liang Macan
Awangbangkal
G. Liangmacan
G. Palawangan
Riam Kanan
Sungaiasang
Mandikapau
Awangbangkal
Mandiangin
G. Ratrabulu
G. Bukit Besar
Bukit Besar
IID
IIB
IIA
G. Pamaton
G. Bukitbetagah
125
115°E
3°30'S
114°50'E
3°45'S
Contour interval 125m
0 1 2 3 4
kilometers
XA
XC
G. Malihin
XIB
G. Besar
XIA

The elluvial occurrences tend to be small. Typically, rounded pebbles or cobbles of chromitite (up to 50 cm in diameter) occur on the surface or in laterite over areas rarely exceeding 2500 m^2. The largest elluvial occurrence examined recently, Kampung Kiram, is found over an area of 60 x 100 m; test pitting has determined a resource of 150 tons. Van Bemmelen (1949) indicates a maximum of 10,000 tons of elluvial chromitite may occur near Gunung Batara Bulu (Gunung Ratrabulu).

The in - situ occurrences typically show layers or lenses of disseminated to massive chromite within olivine - rich segregations that occur in tectonized harzburgite. Lateral extension of mineralization at Pamali II, S. Murai, and Bukit Besar does not exeed 15 m; continuous mineralization over 30 m has been shown at Pamali I and a discontinuous rootless mineralization over 50 m in length is found at Liang Macan. Proved reserves at Pamali I are 50 tons. The small size and grades are similar to the minor podiform chromitite tonnage and grade models discussed by Singer and Page (1986).

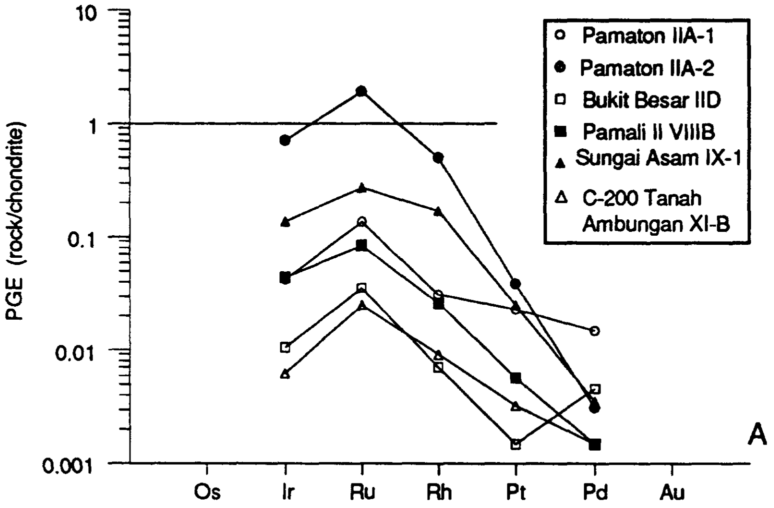
Cr_2O_3 contents of Bobaris chromitites vary from 25 to 54 weight percent. Cr /(Cr + Al) and Fe /(Fe + Mg) variations in chromite show the chromitites fall into two groups: one with Cr /(Cr + Al) between 0.4 - 0.5 and a second with Cr /(Cr + Al) greater than 6 (Burgath and Mohr, 1986). Cr/Fe and Cr/Al variations suggest a position of the occurrences either in the mantle - crust transition zone or in the upper most mantle section (Burgath and Mohr, 1986).

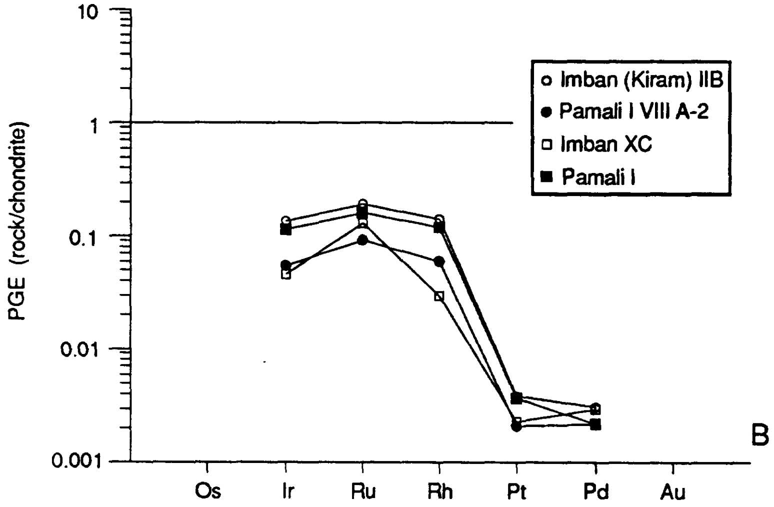
This group of samples shows amazing diversity in their degree of enrichment and the shape and form of their chondrite - normalized patterns; some groups of samples are quite unlike the pattern normally associated podiform chromitites elsewhere. Values for chondrite used in the normalization here and elsewhere in this report are 545 ppb Pd; 1020 ppb Pt; 200 ppb Rh; 690 ppb Ru; and 540 ppb Ir (Naldrett and Duke, 1980).

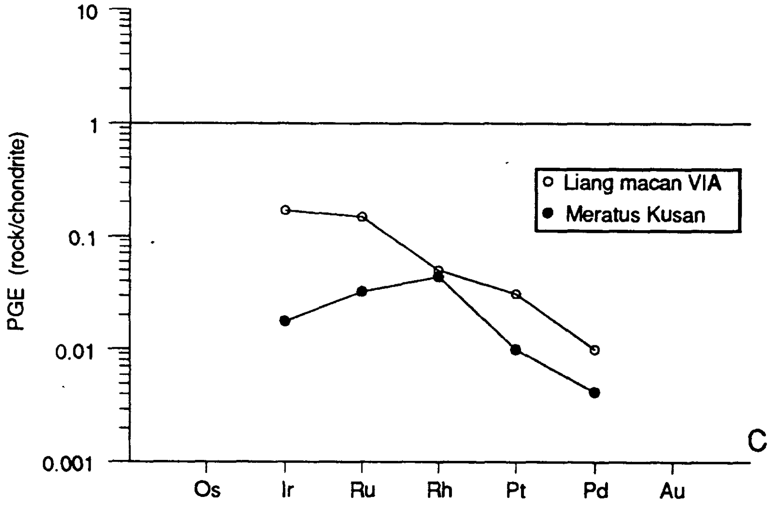
Previous investigations have shown that most podiform chromitites, regardless of size, grade, or tectonic setting, have chondrite - normalized patterns with a negative slope; typically Os, Ir, and Ru abundances are in the range 0.1 to 1.0 times chondrite and Pd and Pt abundances are about 0.01 times chondrite (Page and others, 1984, a,b; Page and others, 1982 a,b; Page and others, 1983; Page and Talkington, 1984; Page and others, 1986). Summary statistics presented by Page and others (1986) for a large sample population of California and Oregon podiform chromitites showed that only 50 percent of their analyses had Pt, Pd, Rh, Ru, and Ir exceeding 10, < 1, 7, 150, and 46 ppb respectively and only 10 percent had values exceeding 64, 10, 26, 320, and 170 ppb respectively. Studies of the platinum - group element minerals associated with podiform chromitites generally supports the Os - Ir - Ru enriched aspect of their geochemistry; the most common minerals are Os - Ir - Ru alloys, sulfides, and arsenides.

Twelve of the samples analysed have PGE geochemistry that is appropriate for what has been described for podiform chromitites elsewhere. Generally, for all samples illustrated in Figure 18, Ir and Ru are enriched relative to Pt and Pd yet they can be assembled into groups with slightly differing chondrite - normalized patterns. The samples in Figure 18A most resemble analyses and patterns previously described in literature for podiform chromitites. Ru is enriched relative to both Ir and Rh; Pt is enriched relative to palladium. Exceptions include the sample from Pamaton II which shows elevated Pd and Pt contents and Bukit Besar which has elevated Pd. The samples illustrated in Figure 18B differ from those in Figure 18A; Pt shows little or no enrichment relative to Pd. Samples in Figure 18C differ still. The sample from Liang Macan has elevated Ir, Pt and Pd relative to comparable patterns in Figure 18A. The sample from Kusan in the Meratus Range shows greatest enrichment in Rh. Presumably variations in Ir and Ru can be attributed to variations in the proportions and predominance of the various Os - Ir - Ru alloys, sulfides, and arsenides.

Figure 18. Chondrite normalized PGE profiles for (A) Pamaton, Bukit Besar, Pamali II, Sungai Asam, and Tanah Ambungan podiform chromitite occurrences; (B) Imban (Kiram), Pamali I, and Imban podiform chromitite occurrences; and (C) Liang Macan and Kusan podiform chromitites occurrences.


10
1
0.1
0.01
0.001
PGE (rock/chondrite)
Os
Ir
Ru
Rh
Pt
Pd
Au
○ Pamaton IIA-1
● Pamaton IIA-2
□ Bukit Besar IID
■ Pamali II VIIIB
▲ Sungai Asam IX-1
△ C-200 Tanah Ambungan XI-B
A


10
1
0.1
0.01
0.001
PGE (rock/chondrite)
Os
Ir
Ru
Rh
Pt
Pd
Au
○ Imban (Kiram) IIB
● Pamali I VIII A-2
□ Imban XC
■ Pamali I
B


10
1
0.1
0.01
0.001
PGE (rock/chondrite)
Os
Ir
Ru
Rh
Pt
Pd
Au
○ Liang macan VIA
● Meratus Kusan
C

The PGE geochemistry of the 5 samples illustrated in Figure 19A are unlike the majority of podiform chromitites. Elevated Pt and Rh contents typlify these samples resulting in a nearly flat or chondritic pattern for Ir, Ru, Rh, and Pt. Pd is depleted relative to chondrite. Values for Pt and Rh are 1 to 2 orders of magnitude higher than typical for podiform chromitites. We are aware of only three other examples of elevated Pt contents in podiform chromitites. The first are podiform chromitites from the Rattlesnake Creek terrain in northern California (Figure 19B; Page and others, 1986). Samples from the Tedoc group (39CAM81 and 49CAM81) and Pole Corral (42CAMB81) are enriched in Pt but not Rh. The analysis of the chromitite from the Western Chrome occurrence (47CAM81), though showing lower overall abundances, shows a nearly flat pattern for all elements, including Pd. PGE minerals at Pole Corral include Ru-Fe alloys, Os-Ir-Ru alloys, Pt-Fe alloys, laurite, and irasite-osarite-ruarsite group minerals (Moring and others, 1987). The second example is of podiform chromitites from the White Hills Peridotite, Newfoundland (Figure 19B; Talkinton and Watkinson, 1986). The third example is from the Cliff locality in the Unst ophiolite in Shetland (Prichard and others, 1986; Gunn and others, 1985). Sample from Cliff are extremely enriched in both Pt and Pd and exhibit chondrite normalized profiles with steep positive slopes analogous to the Merensky Reef (Gunn and others, 1985). PGE minerals at Cliff, in decreasing abundance, are Pt arsenides, Pd antimonides, hollingsworthite, laurite, irasite, native osmium, and potarite.

Naldrett and von Gruenewaldt (1989) have discussed the association of PGE with chromitite in layered intrusions and ophiolite complexes. They note that all chromitites appear to concentrate Ru, Ir, and Os regardless of setting. However, the noteable concentration of Pd, Pt, and Rh for the Upper and Middle Group chromitites in the Bushveld Complex and the A - chromitite of the Stillwater Complex are thought to result from the collection of these elements in a base metal - rich sulfide liquid. Arsenides, bismuthinides, or telluride minerals in these chromitites formed during crystallization of the sulfide liquid. Subsequent interaction between sulfide and chromite during cooling effectly reduce the amount of base-metal sulfide in the chromitites. Although this may be a viable model to explain the Pt, Pd, and Rh - enrichment of the Cliff deposit, the variable enrichment in Pt, Pd, and Rh (or in other words, the non correlation of these elements) for samples in the Bobaris Range and the Rattlesnake terrain do not suggest these elements were originally concentrated in the chromitites by a PGE - enriched base-metal sulfide liquid. Instead, the crystallization of differing combinations of various Pt, Pd, or Rh phases (arsenides, bismuthinides, tellurides, or alloys) directly from the magma may best explain these occurrences. Further work on the mineralogy of these occurrences is indicated.

Pt - enriched podiform chromitites in the Bobaris Range could conceivably be a source for some of the Pt - mineral dominated placers in southeastern Kalimantan. However, the small size of these podiform chromitites and the lack of spatial association with known PGM placers argue against their being the sole source for the extensive PGM placer deposits found in this region.

PGE analyses - Tanah Ambungan, Pigat, Riam Pinang

Fe-Cr-oxide concentrations, Tanah Ambungan

Tanah Ambungan is a body of clinopyroxenite that contains layers, masses, and lens of Fe-Cr-oxide minerals. Burgath and Simandjuntak (1983) conclude the oxide segregations form cumulus layers in the clinopyroxenite. Clasts of clinopyroxenite and modal layering in one of the oxide - concentrations was observed during a field trip in June, 1989. PGE analyses were performed by the USGS on 3 samples from Tanah Ambungan, two of the Fe-Cr-oxide concentrations and one of the host pyroxene. Results are listed in Table 8 and illustrated in Figure 20.

……

Figure 19: Chondrite normalized PGE profiles for (A) Batuditabang, Pamali I, Sungai Asam, Malachin, and Awangbangkal podiform chromitites occurrences; and (B) Tedoc group, Pole Corral, and Western Chrome podiform chromitites, Rattlesnake Creek terrain, California (Page and others, 1986) and White Hills Peridotite, Newfoundland (average of 8 analyses; Talkington and Watkinson, 1986).

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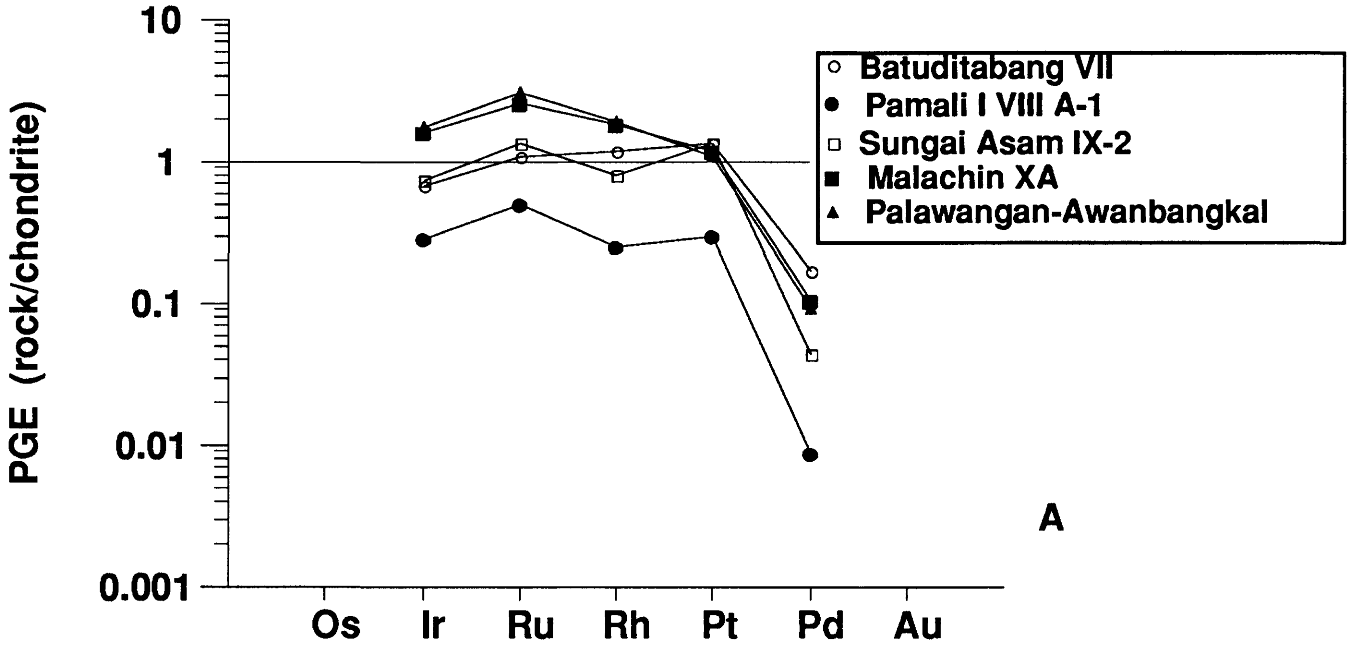
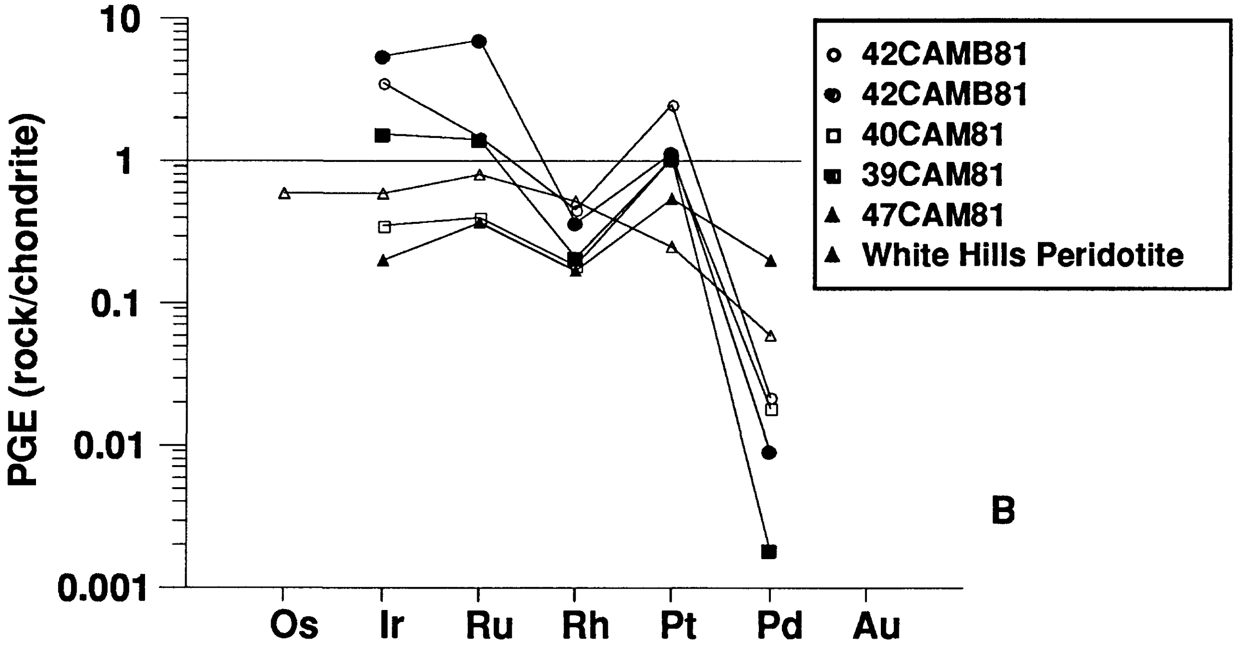

PGE (rock/chondrite)
10
1
0.1
0.01
0.001
Os
Ir
Ru
Rh
Pt
Pd
Au
○ Batuditabang VII
● Pamali I VIII A-1
□ Sungai Asam IX-2
■ Malachin XA
▲ Palawangan-Awanbangkal
A


PGE (rock/chondrite)
10
1
0.1
0.01
0.001
Os
Ir
Ru
Rh
Pt
Pd
Au
○ 42CAMB81
● 42CAMB81
□ 40CAM81
■ 39CAM81
▲ 47CAM81
▲ White Hills Peridotite
B

……

Figure 20. Chondrite normalized PGE diagram for analyses of magnetite-chromite ore and clinopyroxene, Tanah Ambungan, South Kalimantan.

……

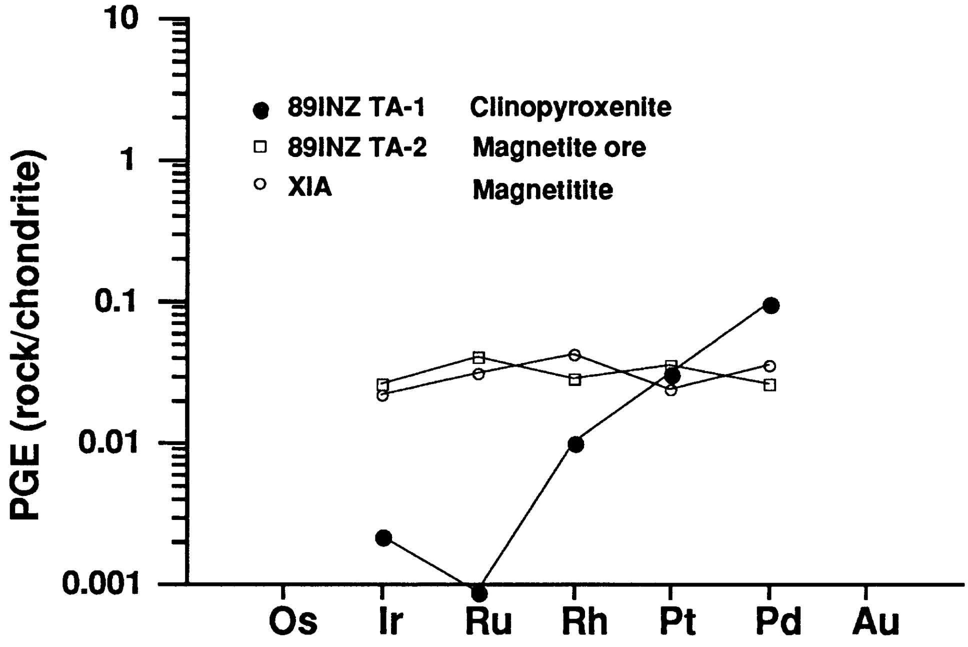

10
1
0.1
0.01
0.001
PGE (rock/chondrite)
● 89INZ TA-1 Clinopyroxenite
□ 89INZ TA-2 Magnetite ore
○ XIA Magnetitite
Os
Ir
Ru
Rh
Pt
Pd
Au

Table 8. PGE analyses of selected deposit types, South Kalimantan. [PGE determined by NiS fire assay - ICP mass spectroscopy; analysts: R.R. Carlson and A.L. Meier, USGS, Denver, Colorado. Au determined by graphite furnace atomic absorption spectroscopy; project leader: R.M. O'Leary, USGS, Denver, Colorado]

Sample ID	Location	Sample description	Pt (ppb)	Pd (ppb)	Rh (ppb)	Ru (ppb)	Ir (ppb)	Au (ppb)
89 INZ Pigat 1	Pigat	altered microdiorite	< 0.5	< 0.8	< 0.5	< 0.5	< 0.5	<8
89 INZ Pigat 2	Pigat	Au-mineralization in serpentinite	6.4	7.5	1.3	6.4	2.9	21200
89 INZ Pigat 3	Pigat	altered microdiorite	< 0.5	< 0.8	< 0.5	< 0.5	< 0.5	<8
89 INZ Pigat 4	Pigat	Au-mineralization in serpentinite	5.0	4.2	1.0	5.4	2.4	280
89 INZ Riam Pinang	Riam Pinang	massive magnetite, iron skarn	< 0.5	< 0.8	< 0.5		< 0.5	8
89 INZ TA-1	Tanah Ambungan	clinopyroxenite	31	53	2.0	0.6	1.2	--
89 INZ XIA	Tanah Ambungan	oxide - ore	24	19	8.3	21	12	--
89 INZ TA-2	Tanah Ambungan	oxide - ore	36	14	5.7	28	14	--

Marochkin and others (1963) summarized the exploration work conducted in the area. Numerous test pits and 19 boreholes outlined 132,200 tons of iron ore containing 31.72 percent Fe. Chemical analyses of 38 samples of the ore are summarized in Table 9.

Table 9. Summary of 38 chemical analyses of oxide-rich pyroxenite at Tanah Ambungan, South Kalimantan reported in Marochkin and others (1963).

	Weight percent		
	maximum	minimum	mean
Fe	40.39	17.49	33.15
SiO_2	13.71	1.32	5.70
Al_2O_3	32.24	6.15	23.44
TiO_2	0.65	0.29	0.47
Mn	1.57	0.34	0.93
S*	0.31	0.05	0.14
Cr_2O_3	30.59	3.0	7.64
Ni**	0.88	0.02	0.33

*29 analyses ** 20 analyses

The ore consists dominantly of magnetite, hematite, and chromite. Petrographic descriptions of ore samples in Simandjuntak and others (1986) indicated the presence of hercynitic spinel and exsolution structures in the magnetite. Disseminated oxide-minerals (up to 25 percent) occur in hornblende gabbro near Pajaringan.

High concentrations of cumulus magnetite are atypical of clinopyroxene cumulates of ophiolites but are a characteristic of Alaskan-type ultramafic intrusions (Findlay, 1969). Typically, the ores are titaniferous magnetites (rich in Fe-Ti-V). Smirnov (1977) describes PGE - lode and PGM placers from these types of oxide occurrences. PGE analyses were made of these rocks to see if they could represent a possible source of placer PGM.

Concentrations of the PGE are low, both for the magnetite ore and the clinopyroxenite (Table 8). Chondrite-normalized plots of these analyses show flat patterns for the oxide concentrations and Pt, Pd, and Rh enrichment for the pyroxenite. The patterns are unlike those for ophiolite. These are no comparable analyses for Alaskan-type ultramafic bodies. The Pt, Pd, and Rh enrichment suggest the presence of magmatic sulfides in the body and if present in sufficient quantities could be of interest. Although no anomalous PGE were found, additional investigations should be made to assess the PGE potential of this body and to understand its origin.

Serpentine-hosted Au mineralization, Pigat

Pigat is a 200 x 1500 m gold-prospect near G. Ratrabulu in the Bobaris Range. Au occurs in a sheared serpentinite adjacent to a dike-like body of altered microdiorite. The shearing is related to major fault nearby; the fault plane has been silicified, is not mineralized, and extends discontinuously nearly 40 km from near Tanah Ambungan to Palawangan. Au mineralization is associated with talc-carbonate alteration of the serpentinite (Anonymous, 1977). Au, with variable proportions of Cu and little Ag, is intergrown or associated with heazlewoodite or disseminated in talc. The composition of the Au from Pigat is illustrated in Figure 21. Ag is low, typically less than 2 percent; Cu content of the native Au is variable with two compositional groups evident (Cu < 5 percent and Cu > 20 percent). Grains with greater than 20 percent Cu have inclusions of Ag-rich native Au. High grade samples are enriched in Cu and Pb relative to low grade samples. Magnetite, chromite, heazlewoodite, covellite, galena, pyrrhotite, chalcopyrite, and chalcocite were observed in heavy liquid separates of Pigat ore. Analyses of one high grade ore sample yielded the following results: Au - 96.7 ppm; Ag - 5 ppm; Pt - < 0.005 ppm; Te - 2.0 ppm. Arsenic was below the detection limit of 50 ppm. Obviously, tellurides and arsenide minerals make a negligible contribution to the Au and Ag contents of the ore. High grade Au - ore may correlate with abundant calcite veinlets or calcite- cemented breccia and high sulfide content. Poor ore has < 5 ppm Au. Rich ore has Au ranging from 5 ppm to 1000 ppm; the average content is 14 ppm. The width of the high grade interval ranges from 20 cm to 1 m.

Hydrothermal PGM (Os-Ir - alloys) are known to occur in a sheared serpentinite in the Adamfield district in Tasmania (Mertie, 1969). Elsewhere, high Pt and Pd have been found in hydrothermal deposits cutting mafic and ultramafic rocks (New Rambler Wyoming; Rathburn Lake, Ontario; Peter Lake Complex, Saskatchewan; Hulbert and others, 1988). These occurrences are also enriched in copper sulfides. Two samples of Au - mineralization in the serpentinite and two samples of altered microdiorite were analyzed by the USGS to determine if PGE was mobilized with Au from the ultramafic host rock (Table 8 and Figure 22). The microdiorite has no detectable PGE. Au mineralization in the serpentinite has PGE in the low ppb range for all 5 elements. Apparently, PGE is not significantly mobilized in this hydrothermal setting.

Iron skarn, Riam Pinang area

PGE enrichments have been reported from some skarn deposits (Carr Fork, Utah; Singenggoe deposit, Kotanopan, Sumatra). One sample of massive magnetite from the Au-bearing iron skarn near Riam Pinang was analyzed for PGE; none were detected (Table 8). Additional samples of this skarn, or the one near Pontain, with higher sulfide mineral contents, should be analyzed before concluding no PGE occurs in these deposits.

Figure 21. Variation in the composition of native Au, Pigat prospect, South Kalimantan.

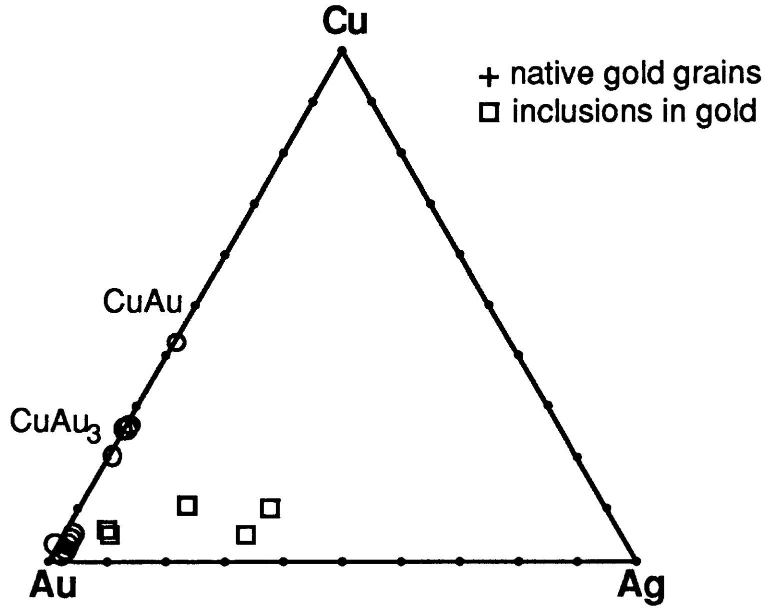
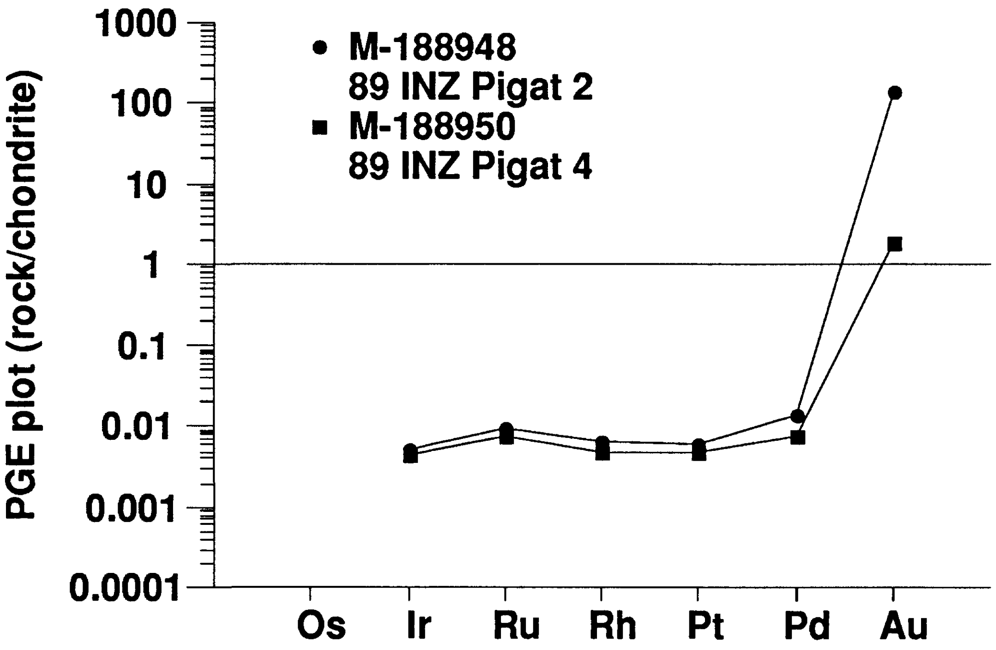

Cu
+ native gold grains
□ inclusions in gold
CuAu
CuAu3
Au
Ag

Figure 22. Chondrite normalized PGE diagram for analyses of serpentinite-hosted Au mineralization, Pigat Prospect, South Kalimantan.


PGE plot (rock/chondrite)
1000
100
10
1
0.1
0.01
0.001
0.0001
● M-188948
89 INZ Pigat 2
■ M-188950
89 INZ Pigat 4
Os
Ir
Ru
Rh
Pt
Pd
Au

MINERAL RESOURCE ASSESSEMENT OF SOUTHEASTERN KALIMANTAN

Introduction

The focus of the consultancy project was mutually decided to be a PGE resource evaluation for southeastern Kalimantan. Time constraints prohibited performing an assessment for all Indonesia. Southeastern Kalimantan was selected because numerous PGM occurrences are known in the area, significant prior placer production occurred in this area (over 60,000 oz PGM), and an opportunity existed for cooperative work with P.T. Aneka Tambang.

For the project, a geologic map and mineral occurrence map were compiled at 1: 100,000 (Plate 1 and 2). These were used to define 4 permissive areas for the occurrence of primary PGE deposits in this area. A detailed survey was conducted in one of these areas (Riam Pinang); the results of that work are described in another section. This section describes the work done to define the permissive areas.

Geology of southeastern Kalimantan

In southeastern Kalimantan, a pre-Tertiary accretionary complex and folded and faulted Eocene to Miocene sedimentary rocks are flanked by two Cenozoic sedimentary basins, the Barito basin to the west, and the Kutei basin to the northeast. Two small narrow Neogene basins lie offshore, east of the Meratus Mountains (Hamilton, 1979). The pre-Tertiary rocks consist of an Early to Middle Cretaceous accretionary complex, unconformably overlain by Late Cretaceous (Senonian) sedimentary and mafic volcanic rocks of the Manunggul Formation. Eocene to Miocene sedimentary rocks of mixed shallow marine, deltaic, and continental facies were deposited in stable shelf and epicontinental conditions over much of this area. After uplift of the Meratus Mountains, Pliocene and Pleistocene coarse, clastic sediments were deposited on the western and southeastern flank of the mountains.

PRE - TERTIARY ACCRETIONARY COMPLEX

Deep marine sedimentary rocks (cherts) and volcanic rocks; arc-related andesitic volcanic and volcanoclastic rocks; dioritic, tonalitic, and granodioritic plutons; discontinuous limestone bodies; graywackes and lithic sandstones, polymict breccias, siltstones and shales; ultramafic and gabbroic rocks that represent fragments of obducted ophiolites; and medium to high grade metamorphic rocks are all present in this area (Plate 2). Mapping in such a lithogically and tectonically complex terrain without the aid of radiometric dates or petrologic studies has resulted in a large number of described formations, often with conflicting descriptions and map distributions. It is not the purpose of this discussion to reconcile these differences; however a brief overview of some general characteristics of these rocks is necessary to establish the overall tectonic setting as related to mineral deposits, particularly near Martapura and Pleihari (plate 2). For more detailed information, the reader is referred to descriptions by Koolhoven (1935), van Bemmelen (1949), and various geologic maps of the area (Supriatna and others, 1981; Supriatna and others, 1986; Umar and others, 1982; Heryanto and Sanyoto, 1987; Rustandi and others, 1986; Sikumbang and Heryanto, 1986; Marochkin and Dudkinsky, 1964; Marochkin and others, 1964-1965; Anonymous, 1984; Laleno and Amirullah, 1988; Manurung and Laleno, 1986).

Metamorphic rocks occur in fault bounded areas and have not been mapped in detail. Quartzite, muscovite quartzite, hornblende schist, muscovite shist, actinolite schist, chlorite schist, amphibolite, biotite-chlorite schist, garnet- biotite (chlorite) schist, phyllite, tonalitic and granodioritic gneiss, and glaucophane schist are but a few of the metamorphic lithogies reported.

The descriptions suggest protoliths are principally metasedimentary and volcanic rocks intruded by tonalitic and granodioritic plutons. White mica from a glaucophane schist yields a K-Ar date of 114 ± 0.7 m.y. (Early Cretaceous), a probable age for the metamorphic event (Burgath and Mohr, 1986). Hornblende schist from the Arimo River in the Banjarmasin quadrangle yields a similar K-Ar date of 113 ± 1 m.y. (Sikumbang and Heryanto, 1986).

Volcanic, sedimentary, and plutonic rocks typical of subduction-related arcs underlies a relatively large area. The volcanic rocks are dominantly andesite porphyries and occur as flows, breccias, tuffs, and dikes. Analcite-bearing basalts in this sequence have a K-Ar date of 96.7 ± 4.8 m.y. (Yuwono and others, 1988). Andesite porphyry dikes cut all pre-Tertiary units. K-Ar ages of 72.2 ± 3.6, 79.9 ± 4.0, and 86.8 ± 4.4 m.y. have been reported for andesite and microdioite dikes that cut both these volcanic and sedimentary rocks as well as the Manunggul formation (see below) (Yuwono and others, 1988). The volcanic rocks may be interbedded with lithic sandstone and conglomerate, siltstone, claystone, and small lens-like bodies of limestone. At least some of these limestones contain *Orbitulina sp.*, a Mid Cretaceous (Cenomanian?) fossil. Other deposits contain Late Jurassic - Early Cretaceous gastropods (van Bemmelen, 1949). Sedimentary rock units typically consist of alternating graywacke, lithic sandstone, siltstone and shale sequences. Diorite, tonalite, and granodiorite plutons intrude the volcanic, sedimentary, and metamorphic rocks, forming iron-skarns when in contact with limestone. At least some of the plutonic rocks emplaced into the metamorphic rocks are unconformably overlain by *Orbitulina sp.* - bearing limestone. A K-Ar dates of 115 ± 1 m.y. and 119 ± 1 m.y. has been reported for granite emplaced into metamorphic rocks on the Balawayan River and microdiorite emplaced into metamorphic rocks near Mt. Karau in the Amuntai quadrangle (Heryanto and Sanyoto, 1987). These dates are comparable to those determined for the metamorphic rocks.

Deep marine sedimentary rocks have been mapped in the Kotabura quadrangle and have been described from the Banjarmasin quadrangle (Koolhoven, 1935; van Bemmelen, 1949). These rocks consist of radiolarian chert and siliceous shale. Melange consisting of graywacke, radiolarion chert, diabase, peridotite, serpentinite, and basalt in a scaly matrix have been mapped in a small area in the Kotabura quadrangle. There are no map descriptions indicating the presence of pillow basalts.

Ultramafic rocks and gabbro occur in several elongate belts in the area and are generally thought to be fragments of ophiolite complexes. Plagiogranite on the Riam Andungan, thought to be part of the ophiolite complex, has a K-Ar date of 96.7 ± 4.8 m.y. (Yuwono and others, 1988). Generally the rocks are poorly described. Rocks in the central Meratus range are largely tectonized harzburgite although exposures near the southern end of this mass near Riam Pinang are largely ultramafic cumulates. Rocks in the Bobaris Range occur close to the tectonized harzburgite-cumulate transition zone; over 60 podiform chromitite occurrences have been identified there. Gabbro and diorite have been mapped as plutons cutting the ultramafic rocks and have reported K-Ar dates of 86.4 ± 4.3 and 86.0 ± 4.3 m.y. (Yuwono and others, 1988). Cumulate gabbro may occur locally in the Bobaris Range. The mapped gabbroic plutons may be part of the arc plutonic suite; the ultramafic rocks are cut by numerous dioritic and intermediate composition plutons. Sheeted-dike complexes have not been mapped.

This group of rocks are unconformably overlain by the Late Cretaceous (Upper Turonian to Senonian; Yuwono and others, 1988) Manunggul Formation. The Manunggul Formation consists of polymict conglomerate, sandstone, shale, marl, and non-fossiliferous limestone. The conglomerates are poorly indurated and contain diamonds, Au, and PGM. The Paau member of this formation consists of andesitic/basaltic breccia, tuff, and lavas.

TERTIARY-RECENT DEPOSITS

A major unconformity seperates the pre-Tertiary rocks from the overlying Tertiary shelf deposits. During the Eocene, Oligocene, and Miocene, the Meratus Mountains existed only as a relative high that received thinner sediment layers than the flanking areas. The basal Eocene Formation, the Tanjung Formation, consists of sandstone, conglomerate, siltstone, and shale with intercolated limestone and coal. Continental deposits give way up section to brackish water and higher up section to marine depositional environments. Upsection from the Tanjung Formation, an Oligocene to lower Miocene shelf limestone (Berai Formation) was deposited over much of southern Kalimantan. This limestone can be traced eastward to the edge of the continental shelf and southward into the Java Sea. However, there is a facies change from limestone to sandstones and shales toward the northeast, north, and northwest. In the Kotabura, Sapanahan, and Balikpapan quadrangles to the north and east, the limestone facies changes into a time correlative shale and sandstone (Pamaluan Formation). To the north and west, the limestone facies changes to time-correlative sandstone, shale, and coal deposits (Montalat Formation). The facies changes indicate sources of clastic material to the north and west. Miocene sandstones and shale with intercalations of coal (Waruhin Formation) overlie the Berai Formation in the Meratus Mountains. To the east, Miocene Formations contain more limestone, again indicating a northwesterly or westerly clastic source.

Uplift of the Meratus Mountains must have occurred after deposition of the Miocene sandstones and coal. Along the east side of the Meratus Mountains and around the northern flank, the Eocene to Miocene sedimentary rocks are folded and cut by west-dipping reverse faults. Folding becomes more open and faulting less intense eastward. To the northeast, in the Mahakam Delta area, Kutei Basin, folds and west dipping reverse faults parallel to the coast (and the structures in the Meratus Mountains) affect Plio-Pleistocene deposits (Hamilton, 1979). The intensity of folding and the age of materials involved decreases eastwards. Folds appear to have grown currently with Late Tertiary and Quaternary sedimentation.

To the west of the Meratus Mountains, the Barito Basin began to form, perhaps as early as the Miocene. Late Neogene strata form a broad asymmetric basin, thinning westward and lapping up onto the platform of south-central Kalimantan. Deposits are thickest near the Meratus Mountains (approximately 6 km). Pliocene deposits of unconsolidated quartz sandstone, pebbly sandstone and shale, with some lignite (Dahor Formation) unconformably overlie the pre-Miocene rocks and extend around the perimeter of the Barito Basin and along the south coast of Kalimantan. Pleistocene deposits of sand, gravel, and clay (Martapura Formation) overlie the Dahor Formation along the southwestern flank of the Meratus Mountains. Paleochannels in these deposits are exploited for diamonds, Au, and PGM near Martapura.

A rise in sea level since the Pleistocene and continued subsidence in the Barito Basin has resulted in Holocene swamps covering the Dahor and Martapura Formation.

Basaltic sills (Kasale basalt) occur in Tertiary sedimentary rocks in the Buntok and Sampanakan quadrangles. They are estimated to be Oligocene in age and may be related to rifting that seperated Kalimantan from Sulawesi in the Mid-Tertiary.

Mineral resource assessment

MINERAL OCCURRENCE DATA

Mineral occurrence data for part of southeastern Kalimantan is shown in Plate 1. This information was derived from several published sources (Krol, 1920; Burgath, 1988), unpublished sources (Marockin and Dudkinsky,1964; Group Ophiolite, 1988; Simandjuntak and others, 1986; Burgath and Simandjuntak, 1983), and personal communications (Alwi Wikrama, P.T. Aneka Tambang).

The following mineral deposit types were recognized: 1) podiform chromitite, 2) iron - (Au) skarns, 3) Fe-Cr oxide segregations in clinopyroxenite and gabbro, 4) Mn deposits associated with jasparoid (?) in volcanic formations (epithermal Mn), 5) low sulfide Au-quartz veins, 6) Au in sheared serpentinite, 7) Au placers, 8) Au - PGM placers, and 9) diamond-Au-PGM placers.

Location of pan concentrate samples for which detailed petrographic descriptions were made are also plotted. Although these surveys were not necessarily conducted in search of PGM, routine, methodical observation of the mineralogy of the pan concentrate samples should have revealed the presence of white gold (platinum-iron alloy) but probably not other PGE minerals such as sulfides or arsenides. Locations where PGM were noted are highlighted.

MINERAL DEPOSIT MODELS

The objective of the map compilation is to conduct a mineral resource evaluation for deposits that contain PGE in southeastern Kalimantan, in order to identify those deposit types and permissive areas that may be the source for placer PGM in this area. The geologic and tectonic setting suggest these deposit types are pertinent PGM targets, most of which are described in Cox and Singer (1986):

Alaskan PGE
Placer PGE - Au
Synorogenic - synvolcanic Ni - Cu
Podiform chromitite
Limassol Forest Co - Cu - PGE
Acoje Ni - Cu - PGE (see Orberger and others, 1988 for description of this deposit type)
Noril'sk Cu - Ni - PGE (outside study area in Buntok and Sampanakan quadrangles).

As part of a resource assessment of an area, once deposit types permissive for the area are identified, tracts or areas permissive for the occurrence of the various deposit types would be delimited using whatever geologic information is available. Criteria that could be used for preliminary tract definition for the various deposit types listed above are tabulated below:

Deposit type	Criteria to delimit preliminary tracts
Podiform chromitite	Transition zone from tectonized harzburgite to cumulate ultramafic rocks in ophiolite complex
Acoje Ni-Cu-PGE	Cumulate ultramafic rocks in ophiolite complex
Synorogenic Ni-Cu	Gabbroic to dioritic plutons that are part of a compositionally diverse, generally intermediate-composition arc-related magmatic suite
Limassol Forest Ni-Co-PGE	Hydrothermally altered and fractured zones in gabbroic and ultramafic rocks of an ophiolite complex
Alaskan PGE	Alaskan-type ultramafic complexes emplaced into accretionary complexes at convergent plate margins
Placer PGE-Au	Drainages from areas with exposures of Alaskan-type ultramafic complexes
Noril'sk Cu-Ni-PGE	Basal portions of differentiated mafic sills emplaced in rift environment

Tract maps were not created for all the deposit types listed above because combined field and laboratory evidence indicates that the Alaskan PGE model is the most likely candidate for the primary source of placer PGM in this region; however, it is noted that placer PGM in the Manunggul Formation is a secondary and an immediate source for alluvial PGM in many of the drainages. Characteristics favoring the Alaskan PGE model are:

1) favorable tectonic setting,
2) small pluton size that could easily be overlooked or mapped as ophiolite in regional mapping programs,
3) placer PGM deposits consisting dominantly of Pt-Fe alloy with minor Os-Ir alloy and laurite are characteristically associated with Alaskan-type ultramafic complexes elsewhere,
4) mineralogy and composition of known PGM occurrences in East and South Kalimantan are identical to placer PGM derived from Alaskan - PGE deposits
5) textures and inclusion relationships in PGM indicate derivation from chromitite

6) chromitite is typically associated with only two of the primary deposit models listed above (Alaskan PGE and podiform chromitite); magmatic or hydrothermal sulfide deposits host the PGE in the other models listed
7) PGM associated with podiform chromitites (and derived placers) are dominated by laurite and Os-Ir alloys

Because of their obvious pertinence to the assessment, detailed descriptions of Alaskan - type ultramafic intrusions and their associated lode and placer deposits have been prepared (Appendices D and E). Descriptions of the other deposit models can be found in Cox and Singer (1986).

TRACTS PERMISSIVE FOR OCCURRENCE OF PRIMARY PGE DEPOSITS

Alaskan-type ultramafic complexes have not been mapped in southeast Kalimantan. Therefore the tracts were drawn based on the occurrence of alluvial PGM. The areas on the map represent regions that appear to be the source of known Au-PGM placer occurrences (with either the PGM minor or dominant) in areas not underlain by or with drainages originating in the Manunggul Formation, which is a secondary source of diamonds, gold, and PGM. Based on these criteria, four tracts were identified that may be the sources of placer PGM. On Plate 1, the tracts are numbered I to IV from south to north. Each tract is discussed below. All of the boundaries of the tracts are approximate.

Tract I in the upper drainage basin of the S. Sebuhur is defined by the extent of the drainage basin above the known PGM-Au placer deposits. No ultramafic rocks have been mapped in this tract; it is underlain predominantly by rocks mapped as the Alino Formation and consist of andesitic volcanic rocks. Most of the tract occurs in an area of low elevation and appears distal from a primary lode source for the PGM. The low topography and geology suggest that this tract may contain a secondary source for the PGM in raised terrace deposits.

Tract II includes part of the Pematang Kuliling Range and upper drainage basins of S. Kanaan and S. Tuyup. Its boundaries are defined by the major drainage divide on the east side and by the upper headwaters of drainage basins with PGM placers on the west side. The northern portion is poorly constrained because of the unknown extent of PGM in the S. Kanaan and S. Tuyup and their tributaries. The tract is largely underlain by ultramafic rocks. Detailed studies in the headwaters of the S. Tambanio, in the upper reaches of the S. Kineet and S. Riam Pinang suggest a platinum source in the southern part of Tract II in the Pematang Kuliling Range. All evidence implies there is a primary lode source in the tract and that this source has the characteristics compatible with the Alaskan PGE model.

Tract III covers an area in the headwaters of S. Banyumin and Betaga area. The eastern boundary coincides with a drainage divide and the area is extended southward to include the headwaters of the S. Karut and S. Tambanio in which there are known PGM. The tract is underlain by metamorphic rocks, schist and gneiss, with no mapped ultramafic rocks. The tract may contain as yet unrecognized ultramafic rocks which may be the primary source for the placer Au-PGM.

Tract IV includes part of the upper drainage basins at the S. Pihik, S. Jernih, and S. Batu Laki and is underlain predominantly by ultramafic rocks. The boundaries are poorly constrained, but the tract could contain a primary lode source for PGM.

Based on available information, further exploration for PGM lode sources appears most attractive for Tract II (particular its southern extent) followed by Tract IV, Tract I, and Tract III.

INVESTIGATIONS OF THE PLATINUM-GROUP ELEMENT PROSPECT, RIAM PINANG AREA, SOUTH KALIMANTAN

Introduction

Geologic investigations were conducted in the headwater tributaries of S. Tambanio near the village of Riam Pinang to try to locate the source of alluvial PGM found in S. Tambanio. Au - PGM placers were known to be present near Riam Pinang and are found downstream along the S. Tambanio for approximately 15 km. Discussions with local placer miners in June,1989 revealed that PGM are inhomogeneously distributed in the placers in this area; some placers contained only Au; others were dominantly PGM ("white gold"). This suggested that there was a good chance to locate a lode source for the placer PGM in the area.

Field work and office investigations

During September and October 1989, the DMR Platinum Exploration Team mapped and collected rock, pan concentrate, and stream sediment samples (Plate 3, 4, and 5). The sizes and number of Au and PGM in pan concentrate samples were systematically recorded (Appendix F).

Their work identified a small area (approximately 4 km^2) on the north side of S. Tambanio (S. Rambas area) where PGM appeared to be coming from bedrock. A detailed base map was prepared by tape and compass survey and the area was mapped and sampled in detail. A thin (< 200 m) sheared ultramafic rock unit that separates dioritic/tonalitic plutons intrusive into metasedimentary rocks on the south from schist and gneiss on the north was sampled and thought to be the primary source for PGM. Sheared ultramafic rock was pulverized in the field and panned; PGM were found in these "rock pan concentrates". Based on field observations, the DMR Platinum Exploration Team proposed that the PGM were hydrothermal in origin, forming as a result of the shearing and alteration of the ultramafic rock. Alteration features typical of sheared ultramafic rock (extensive serpentinization, magnetite veinlets, calcite veinlets) were all observed.

Zientek arrived in Indonesia October 24, 1989 to assist the Platinum Team in assessing the work done. All rock samples collected were examined and described (Appendix G), and the geologic maps were revised (Plates 6 and 7). The mineralogy of the pan concentrate samples were examined in the DMR laboratory and the mineralogy of PGM found in placer deposits and the "rock pan concentrates" were investigated in the USGS laboratory in Menlo Park, California. Samples were selected and submitted for assay and thin section. A site visit to Kalmantan to field check some of the interpretations was made in December. Based on the results of these investigations, two sources of PGM were recognized in the S. Rambas area: (1) elevated alluvial deposits, and (2) a lode source in discordant dunite bodies in clinopyroxenite. The hydrothermal model was rejected in favor of a primary magmatic association with chromitite. Assay results on pan concentrate samples suggested an area east of the S. Rambas area, Pematon Kuliling, also has potential for lode PGM.

The DMR Platinum Exploration Team returned to the field in February and March to continue investigations of the S. Rambas area. The mineralized sheared dunites were exposed in six trenches. Zientek returned to Indonesia in March, 1990 to review the field work and collect material necessary to complete the final report. The results were consistant with the proposed discordant intrusion model. In addition, a chromitite schlieren in dunite was exposed in one trench; analysis of this sample by the USGS shows elevated Pt content and a chondrite normalized pattern similar to mineralized chromitites in Alaskan type ultramafic complexes.

Geologic summary of the Riam Pinang area

S. Tambanio follows an important regional structure, a fault seperating medium grade metamorphic rocks (schists and gneiss) on the northwest from andesitic volcanic rocks, metasedimentary rocks, dioritic to tonalitic plutons, and ultramafic rocks to the southeast. Near Pleihari, this structure appears to be relatively simple but in the vicinity of Riam Pinang, the fault begins to splay. The geologic map of the Riam Pinang area shows multiple strands of this regional structure near the S. Tambanio generally separating blocks with very different bedrock characteristics (Plate 6). These structure also cut the younger andesitic rocks in the area, which have generally been assumed to be Cretaceous in age. In the northwest part of the map area, the metamorphic rocks are again in fault contact with ultramafic rocks (near Rinaat); these ultramafic rocks are part of the Bobaris range ophiolite. Pleistocene terrace deposits are developed on most of the principal drainages in this area.

METAMORPHIC ROCKS (Mms and Mmg)

The metamorphic rocks consist of both schist and gneiss. The schist protoliths vary from pelites to psammites to metavolcanic rocks. The rocks may have originally contained hornblende and biotite, however most of the ferromagnesian sites are now occupied by chlorite. Mineral assemblages observed include: quartz-chlorite (biotite); chlorite-garnet; quartz-garnet-spinel; chlorite-feldspar-quartz; chlorite-feldspar; and chlorite-quartz. Gneiss is medium-grained and generally has a tonalitic composition (feldspar-quartz-chlorite). Chlorite contents range from 3 to 25 percent; quartz contents generally are greater than 25 percent. Some samples of gneiss contain up to 10 percent disseminated pyrite. On the map of the S. Rambas prospect area (Plate 7), the gneiss forms a mappable unit within the schist; samples of metamorphic rocks from the Riam Pinang survey show that the majority were tonalitic gneiss, suggesting a fairly extensive gneiss unit in this area.

ULTRAMAFIC ROCKS (Mu)

Ultramafic rocks southeast of the metamorphic unit are dominantly cumulate; a few samples of olivine-augite cumulate show deformed pyroxenes. The cumulus rocks are olivine cumulate, layered olivine-augite cumulate, and augite cumulates. Olivine cumulates are nearly all adcumulates; pyroxene is absent or present as rare interstitial grains. Disseminated chromite (1-3 percent) is ubiquitous; phlogopite is present in trace amounts. Augite cumulates are also nearly adcumulate and range in size from fine - medium grained to medium grained. Disseminated opaque oxide minerals in the augite cumulates are not abundant; only a few samples have 3-5 percent disseminated oxides. The layered olivine-augite cumulates are dominated by fine scale modal and phase layering. Contacts between layers are generally sharp; very little modal grading was observed. Layers generally are either olivine-rich (< 3 percent pyroxene) or pyroxene-rich (< 10 percent olivine); layers with intermediate proportions of olivine and augite are rare. Tectonized websterites appear to be deformed olivine-augite cumulates that are olivine-rich and contain 1 - 25 volume percent deformed pyroxene (bent cleavage and kinked grains).

METASEDIMENTARY/METAVOLCANIC ROCKS INTRUDED BY DIORITIC/TONALITIC PLUTONS (Msvd)

A fault-bounded area separating the metamorphic rocks from the ultramafic rocks in the vicinity of Riam Pinang consists of metasedimentary and metavolcanic rocks intruded by dioritic/tonalitic plutons. Extensive skarn deposits formed adjacent to the pluton. The metasedimentary rocks include limestones, calcareous siltstones, sandstones or cherts, and mafic volcanic rocks. Limestone, typically very fine-grained, dark mudstones, are locally almost completely replaced by massive magnetite. They appear to be non-fossiliferous; silt filled burrows and a few sparry spots that may have been fossils were observed. The calcareous siltstones now occur as faintly layered fine grained calc-silicate hornfels (garnet-diopside? assemblages). Siliceous sedimentary rocks occur as quartz-chlorite hornfels. Metavolcanic rocks occur as fine-grained aphanitic greenstones with 1 to 3 percent garnet. Generally these rocks have no or a weakly developed penetrative fabric although they may be gently folded.

Samples of the intrusive plutonic rocks consist of fine-medium grained to medium grained biotite diorite (10-15 percent biotite), fine-medium grained hornblende diorite (15 percent hornblende), and fine-medium grained tonalite (10 percent hornblende, 5 percent biotite). Altered rocks show recrystallization and replacement of the ferromagnesian minerals and alteration of feldspars to clay or sericite. Altered rocks can contain 3 - 5 percent disseminated pyrite.

The iron-skarns found here were investigated by Russian geologists in the early 1960's. Ground magnetometer surveys, mapping, test pitting, and drilling were done in this area. The test pitting showed many of the magnetite-rich areas were elluvial deposits; drilling did locate in-situ skarn mineralization. Similar iron-skarns near Pontain contain 5 - 10 percent chalcopyrite and up to 10 ppm Au. Au was panned from a crushed sample of the iron-ore near Riam Pinang; it is probable that the skarn deposits are an important source for placer Au in S. Tambanio.

ANDESITIC ROCKS (Ka)

Andesitic rocks are the youngest rocks in the area; they occur as dikes in all units and as flows overlying the ultramafic rocks and the metasedimentary rock-diorite bedrock area. These rocks are aphanitic to porphyritic andesite, locally with vesicles and amygdules. Phenocrysts (up to 30 percent of rock) consist of following combinations: hornblende; hornblende+augite; hornblende+plagioclase; augite; augite+plagioclase. These rocks may be altered and mineralized; hornblende is replaced by very-fine grained ferromagnesian minerals and feldspars by clays and sericite. Altered rocks contain up to 20 percent disseminated pyrite. The rocks show no penetrative metamorphic fabric.

UNCONSOLIDATED ALLUVIAL DEPOSITS (Qal)

The terrace deposits adjacent to principle drainages are up to 1000 m wide and may be up to 7 m thick. They consist of unconsolidated deposits of reddish- brown clay, sand, and gravel. Au-bearing gravels being worked by local miners may be as thin as 20 cm but commonly are over a meter thick. Gravel deposits occurring up to 30 m above the terrace deposits along the modern drainages were also recognized but have not been mapped.

SITE STUDIES OF PGM WITH ULTRAMAFIC ROCKS (MU) IN THE S. RAMBAS AREA

The panning survey conducted in the area led the group to a 4 km area near S. Rambas as being the likely source of PGM in the headwaters of the S. Tambanio (Plate 8). A detailed survey was conducted in this area (Plate 9 to 11); the geologic map shows a small fault-bounded septum of sheared and altered ultramafic-rock separating the metamorphic rocks (Mms and Mmg) from the diorite/tonalite/meta- sedimentary-skarn package of rocks (Msvd - see below). Olivine-rich lithologies (dunites) occur as foliated serpentinites with abundant magnetite, serpentine, and calcite veinlets that appear to form discordant lenses in the host augite cumulate. Altered pyroxene-rich rocks (augite cumulate) are bleached, pale gray rocks with some calcite veinlets. Pyroxene is commonly completely altered to serpentine. The Platinum Exploration Team excavated sheared ultramafic rock, pulverized it and panned it looking for PGM. PGM were found in such pan concentrate samples at several locations along the length of the ultramafic exposure (Plate 12).

Seven trenches in the S. Rambas prospect area provided important insights on the origin of the dunite bodies in the clinopyroxenites and the controls on PGE mineralization. An intrusive origin is suggested for the dunite bodies based upon the irregular size and shapes of the bodies and the occurrence randomly oriented xenoliths of augite cumulate and augite-olivine cumulate in one exposure. A small (centimeter-sized) segregation of chromitite was found in a relatively undeformed dunite in Trench I; previous investigations of the PGM recovered from test pits in sheared dunite showed these minerals were intergrown with chromite. Visual examination of PGM recovered in this survey showed the presence of chromite inclusions in some of the particles. It is proposed that the PGM are associated with small chromitite concentrations in dunite, as found in Trench I. Economic evaluation of the PGE mineralization should focus on two subjects: 1) the size, distribution, and density of the chromitite segregations in the dunite, and 2) the size and shape of the dunite bodies.

.c4.Trench 1

A 29.7 m trench was excavated on S. Galagah I to document the geology and extent of mineralization in the vicinity of sample RMP89090RP, in which PGM were panned from sheared ultramafic rock (Figure 23). Variably altered and deformed adcumulate olivine cumulate was exposed in the southeastern two thirds of the trench. Augite cumulate was exposed in the northwestern end of the trench. The contact between these units was not exposed. Disseminated chromite with irregular centimeter sized concentrations of massive chromitite were found approximately three meters from the original test pit (Figure 24). The chromitite had no lateral continuity. PGM collected from the original test pit contain inclusions of chromite (see section on SEM investigations below).

Three pits were dug and the original test pit resampled. Two of the new pits and the original pit were sited in sheared rock, which is easy to pulverize and pan in the field. The fourth pit was put into more competent rock with intense, closely spaced magnetite veinlets. PGM were found only in the original pit and in a pit put into sheared olivine cumulate at the northwest end of the trench.

.c4.Trench 2

An 18 m trench was excavated on a side tributary of S. Gelagah I where a small area of gabbro/diorite float was found (Figure 25). The rocks exposed in the trench are augite cumulates cut by two dikes of diorite/gabbro. The northwestern most dike contains inclusions of augite cumulate. The diorite/gabbro in float was a lag deposit in a small channel. Test pits for PGM were not dug because rock was generally too competent. However, five locations of sheared rock were crushed and panned; no PGM were found.

.c4.Trench 3

A 19.6 m trench was excavated on a side tributary of S. Rambas to document the geology and extent of mineralization in the vicinity of samples RMP89087RP and RMP89206RP, in which PGM were panned from sheared ultramafic rock (Figure 26). Sheared olivine-rich ultramafic rock (adcumulate olivine cumulate) with numerous inclusions is in contact with augite cumulate in the northwest end of the trench. The inclusions in the sheared olivine-rich ultramafic rock are elliptical, up to one m wide, and unoriented and consist of augite cumulate and augite-olivine cumulate. Four test pits were put into sheared rock that could easily be crushed for panning. Two contained PGM. The particles from pit three were very angular and contained chromite inclusions.

.c4.Trench 4

A 20 m trench was excavated on a side tributary of the right fork of S. Kandanganan, on the northeast side of the reservoir on S. Kandanganan (Figure 27). The purpose was to document the geology and extent of mineralization in the vicinity of RMP89042P and RMP89204P, in which PGM were panned from sheared ultramafic rock. The rocks in the trench are dominantly sheared olivine-rich ultramafic rocks (olivine adcumulates?) in contact with augite cumulate near the northwest end of the trench. Three pits were dug in sheared rock that could be crushed for panning; two yielded PGM. The PGM in pit two were very angular and contained chromite inclusions.

.c4.Trench 5

A 20 m trench was excavated on the right fork of S. Kandanganan northeast of the reservoir to document the geology and extent of mineralization found in RMP89137RP, in which PGM were panned from sheared and altered ultramafic rock (Figure 28). The trench exposed very sheared and altered olivine-rich ultramafic rock (adcumulate olivine cumulate?) in fault contact with sheared and altered augite cumulate. The shear zone consisted of a fairly competent, maroon colored, well foliated gouge zone. For about 8 m away from the shear plane into the olivine-rich ultramafic rock, disseminated pyrite was noted on fracture and slip surfaces. The pyrite occurred either as euhedra or slickenslided, flattened grains. Seven pits were dug into the sheared olivine-rich ultramafic rock; PGM were found in pan concentrate samples of the crushed rock in three of the pits. Particles from pits two and five were very angular; the particle from pit five possibly contained an inclusion of chromite.

.c4.Trench 6

A 12 m trench was excavated east of the road that is east of and parallel to S. Gelagah I to test the lateral extent of olivine cumulate exposed in a grader ditch (Figure 29). Approximately 6 m of olivine cumulate in augite cummulate was exposed. Contacts with the augite cumulate were shears and dipped inwards toward the center of the dunite body. The rock was generally competent; no test pits for PGM were made.

.c4.Trench 7

A 16 m trench was excavated west of the road that is east of and parallel to S. Gelagah I to test the lateral extent of olivine cumulate exposed in a grader ditch (Figure 30). The trench consisted entirely of augite cumulate. No tests for PGM were made.

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Figure 23. Geology of Trench 1, S. Gelagah I, South Kalimantan.

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CROSS SECTION OF TRENCH # I OF S.GELAGAH I

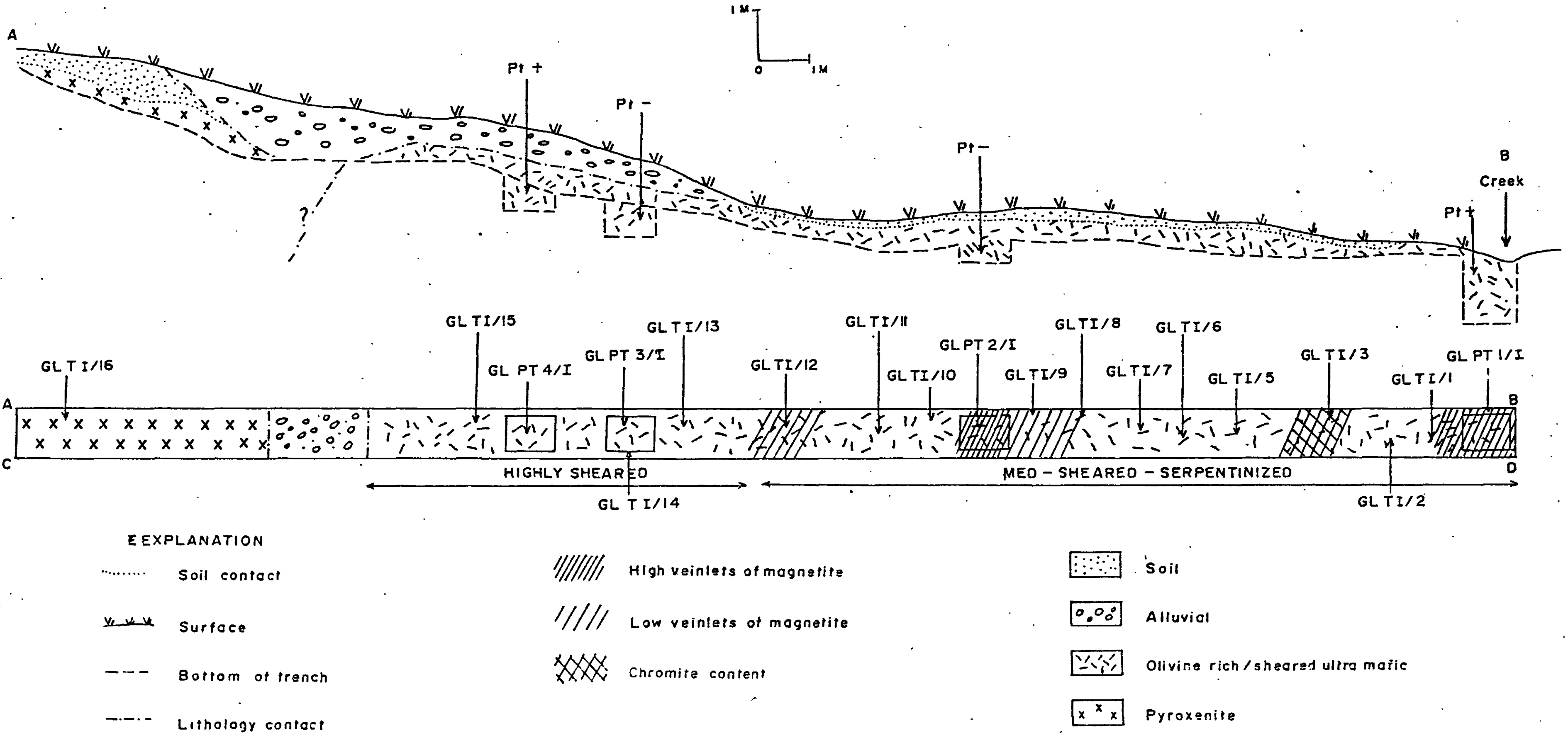

Figure 24. Sketch of chromitite segregation in sawn hand sample of altered olivine cumulate, 90GLT 1/3.

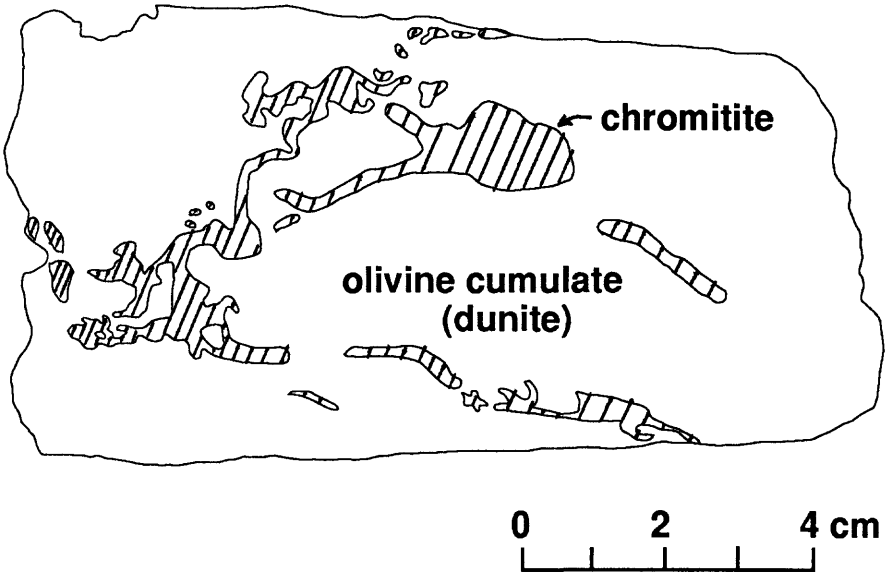
chromitite
olivine cumulate
(dunite)
0
2
4 cm

Figure 25. Geology of Trench 2, S. Gelagah I, South Kalimantan.

CROSS SECTION OF TRENCH # II OF S.GELAGAH I

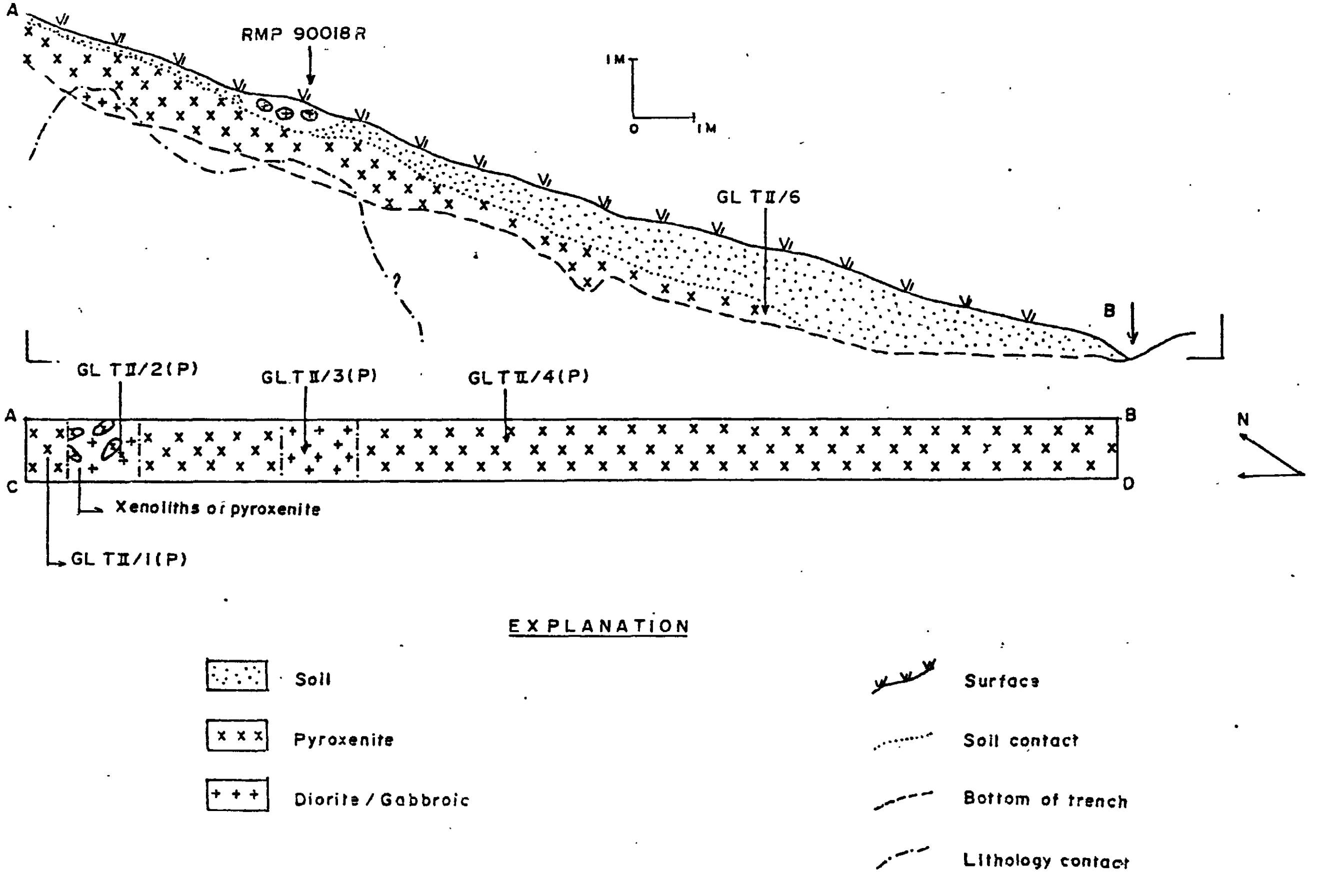

Figure 26. Geology of Trench 3, S. Rambas, South Kalimantan.

CROSS SECTION OF TRENCH # III OF S.RAMBAS

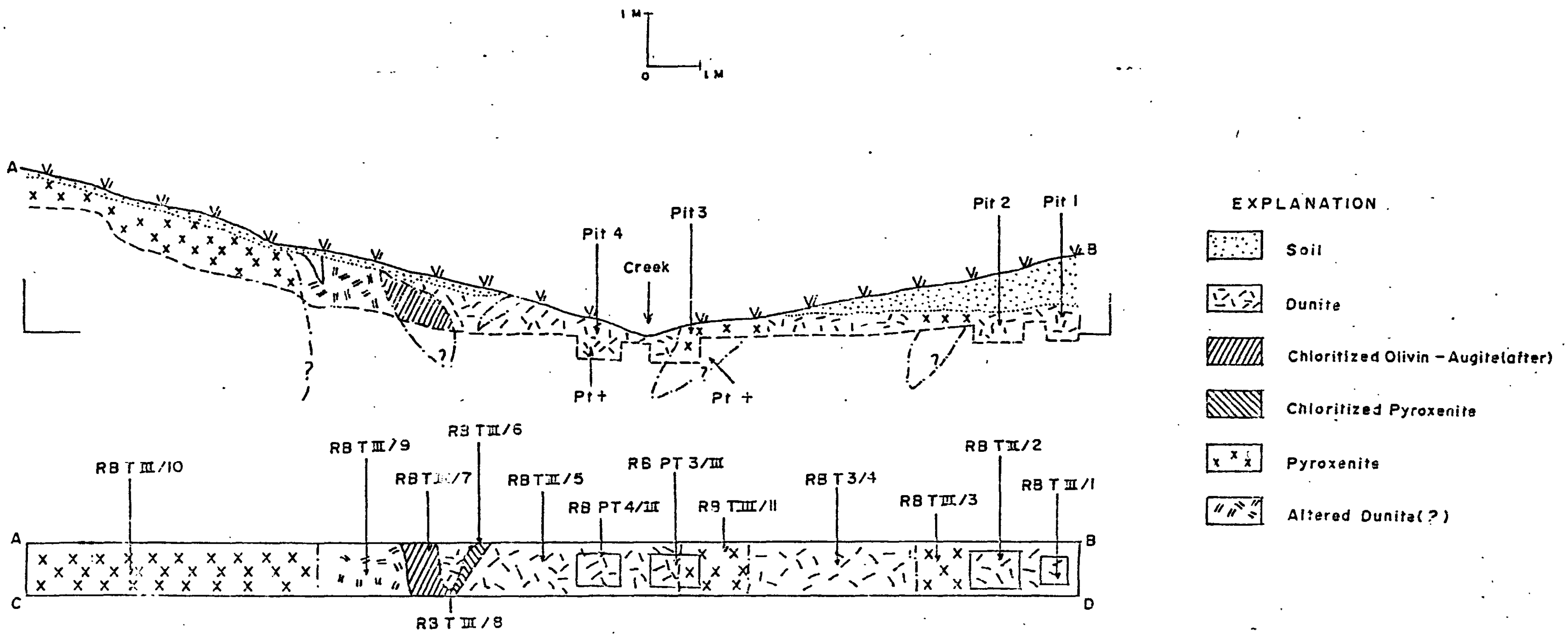

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Figure 27. Geology of Trench 4, S. Kandanganan, South Kalimantan.

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CROSS SECTION OF TRENCH # IV OF S.KANDANGANAN

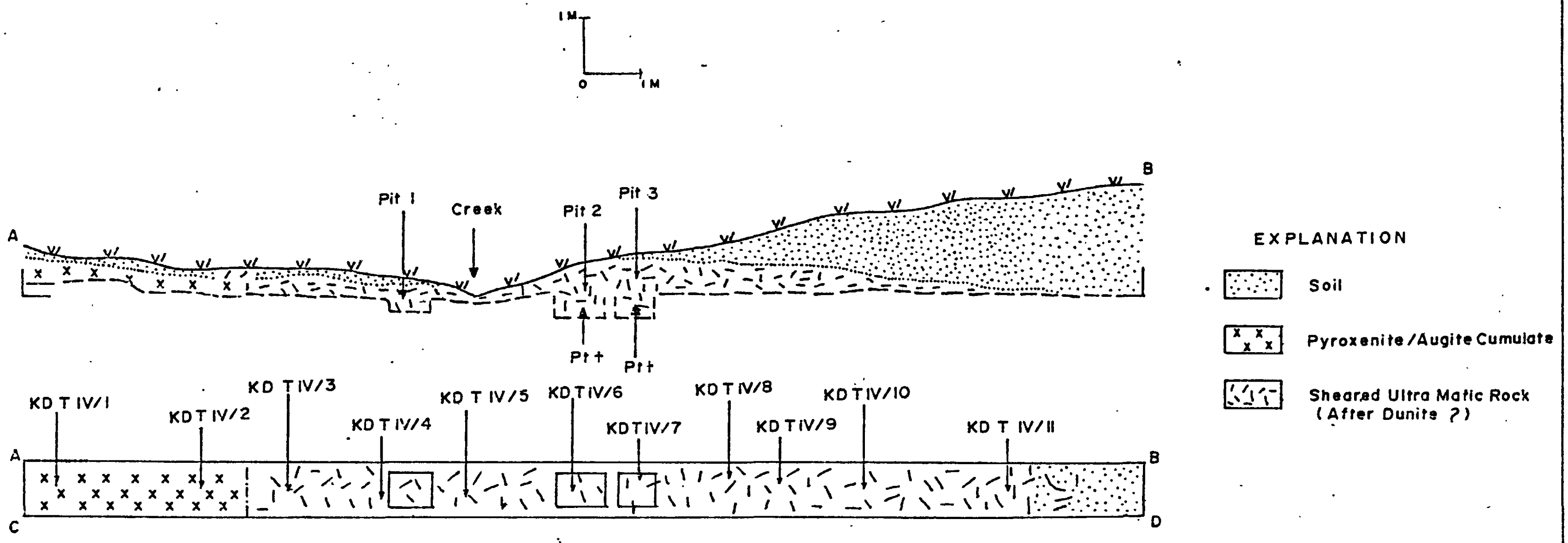

Figure 28. Geology of Trench 5, S. Kandanganan, South Kalimantan.

CROSS SECTION OF TRENCH # V OF S.KANDANGANAN

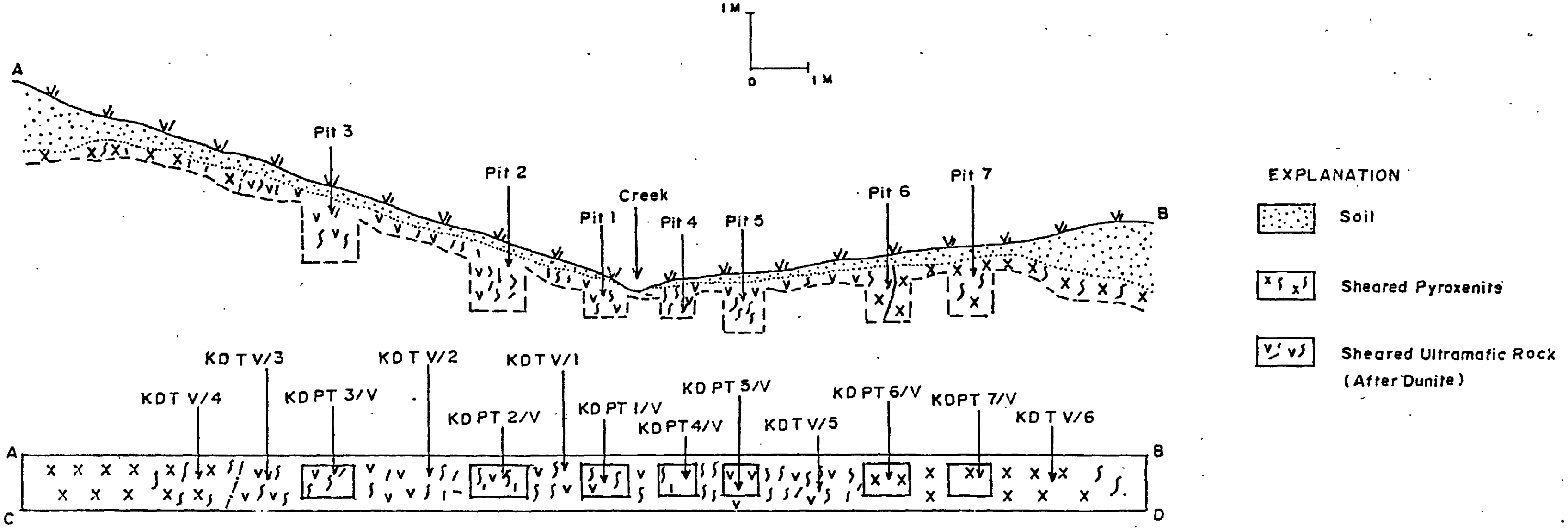

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Figure 29. Geology of Trench 6, S. Rambas, South Kalimantan.

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·CROSS SECTION OF TRENCH # VI OF RAMBAS AREA

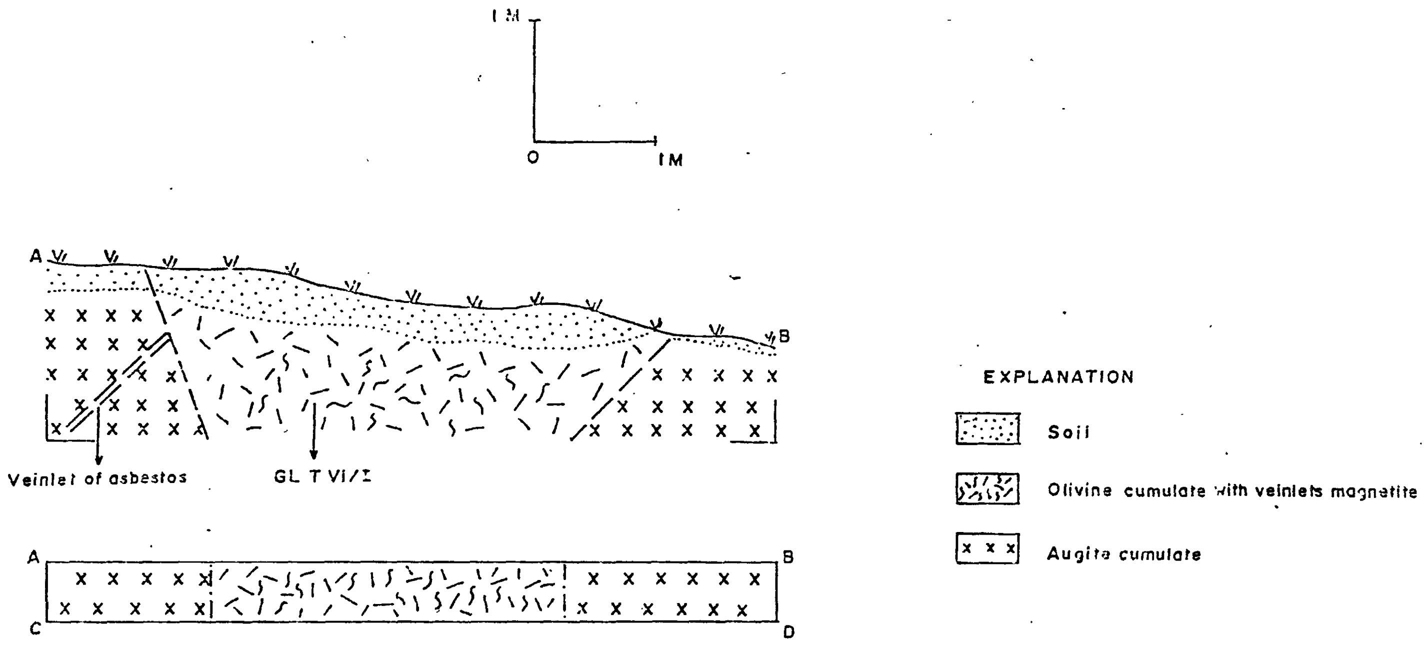
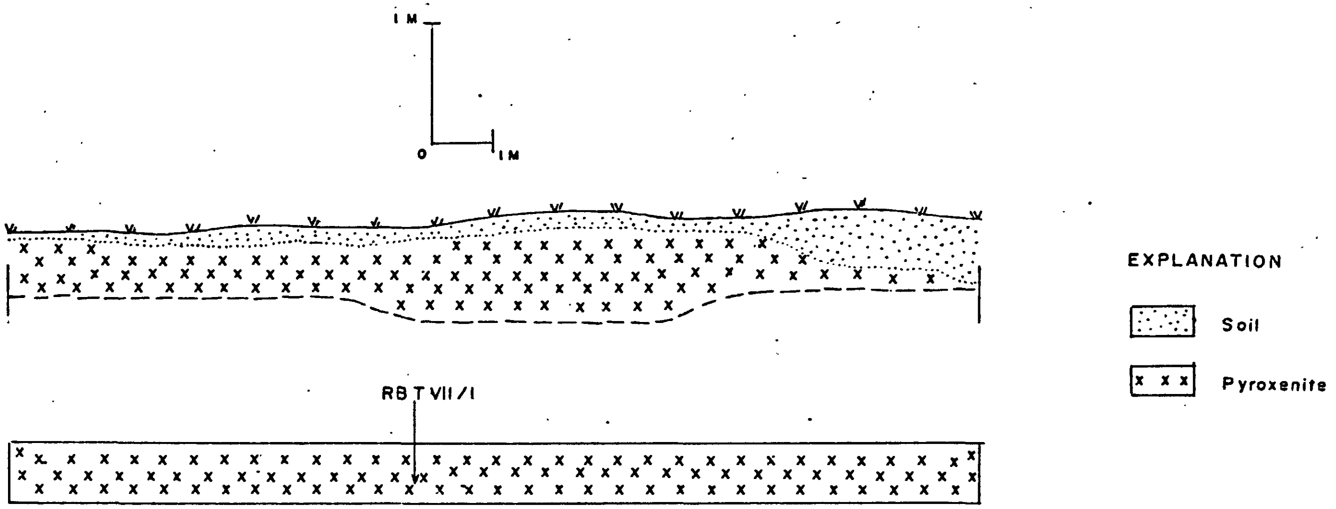


Figure 30. Geology of Trench 7, S. Rambas, South Kalimantan.

CROSS SECTION OF TRENCH # VII OF S. RAMBAS



SITE STUDIES OF PGM WITH UNCONSOLIDATED ALLUVIAL DEPOSITS (QAL)

When all the PGM occurrence data were plotted (including results of the microscopic study), it was observed that a large number of occurrences of PGM in pan concentrate samples were present in areas whose bedrock source was schist and gneiss. This is particularly evident on the ridge above (upstream of) the lode PGM occurrences in the ultramafic rock in the S. Rambas area. Olivine was also noted in a number of pan concentrate samples from this area; the proportions of magnetite, chromite, and ilmenite were also reported in the laboratory reports. Maps showing the percentage of olivine and the proportions of magnetite and chromite were prepared (Plates 13 to 15). The magnetite map was not useful but the olivine and chromite maps showed concentrations of these two minerals near the mapped septum of ultramafic rock, but also in the same area of the metamorphic rocks where PGM were found. Areas that are inferred to be the source of PGM, olivine, and chromite in pan concentrate samples for areas in the metamorphic rock unit are shown on the geologic map (Plate 8). The ridgelines where these areas occur are poorly exposed and deeply weathered; however there is no evidence for cultural contamination of the area in the road building activities. At the time the first field survey was conducted the nature of the source on the ridge in the schist and gneiss area was not known. Two possibilities were suggested. First, the area could could be underlain by a "dike-like" body of PGM - mineralized ultramafic rock. Second, the source could be a perched alluvial deposit that contains PGM, olivine, and chromite. Each possibility could account for the presence of PGM, olivine, and chromite in an area underlain by schist. There was evidence that indicated alluvial deposits were present; first, some of the PGM particles recovered from this area were well rounded, and second, a diamond was found in one pan concentrate (Figure 31). Additional field work in December 1989 identified perched alluvial deposits. Areas of poor exposure in the schist and gneiss where PGM, diamond, and olivine were noted in pan concentrate samples were examined in detail. Bedrock in the area examined was a medium-grained gneiss with segregations of white metamorphic vein quartz. Weathered bedrock could be identified in the lateritic exposures by the presence of a fabric consisting of flattened quartz grains supported in a red clay-rich matrix containing abundant weathered mica. The orientation of the metamorphic quartz veins in the weathered bedrock were undisturbed. In areas of poor exposure underlain by alluvial deposits, the soil consisted of a grain-supported matrix of rounded quartz grains surrounded by red clay with little weathered mica. The metamorphic vein quartz were present in these soil profiles as transported lag deposits near the contact with bedrock. The thickness of the alluvial deposits ranged from a few meters or less to over 10 meters . Numerous drainages in the S. Rambas area were noted to end upstream in a T-shaped junction (Plate 7). The drainages immediately downstream of the T-junctions were found to be deeply incised into thick perched alluvial deposits. The T-junction mark a morphological break where bedrock is exposed with little or no overlying perched alluvial deposits. These features suggest that young faulting and uplift may be important in this area.

A groundmagnetic traverse was conducted in the S. Rambas prospect area to test whether unexposed ultramafic rocks could be the source of alluvial PGM found in areas of metamorphic bedrock upstream of ultramafic rock exposures (Figure 32). The result of the survey supports field observations made in the December site visit which concluded that the source was alluvial gravel deposits. However, an attempt to model the magnetic data provided some interesting insights in the subsurface geometry of the rock units.

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Figure 31. Photomicrograph of gold, PGM, and diamond grains found in pan concentrate RMP 89042 P. The Au particles, right, is a flattened flake that has been rolled into a tube-like shape. The PGM particle, center, is rounded, suggesting considerable transport from site of origin. Grain at left is colorless diamond. Spacing between dots on grid 0.1 mm.

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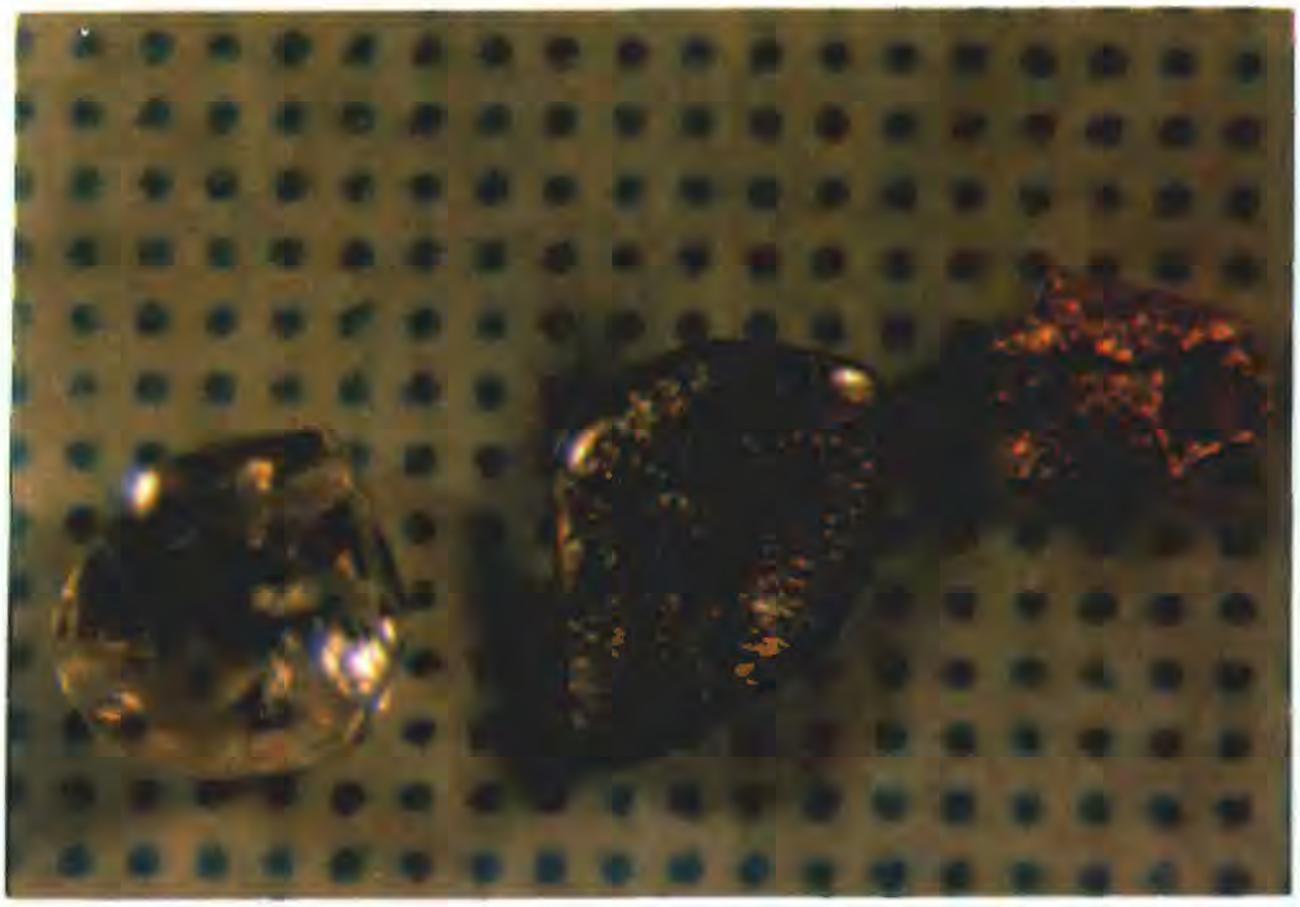
Fig. 31



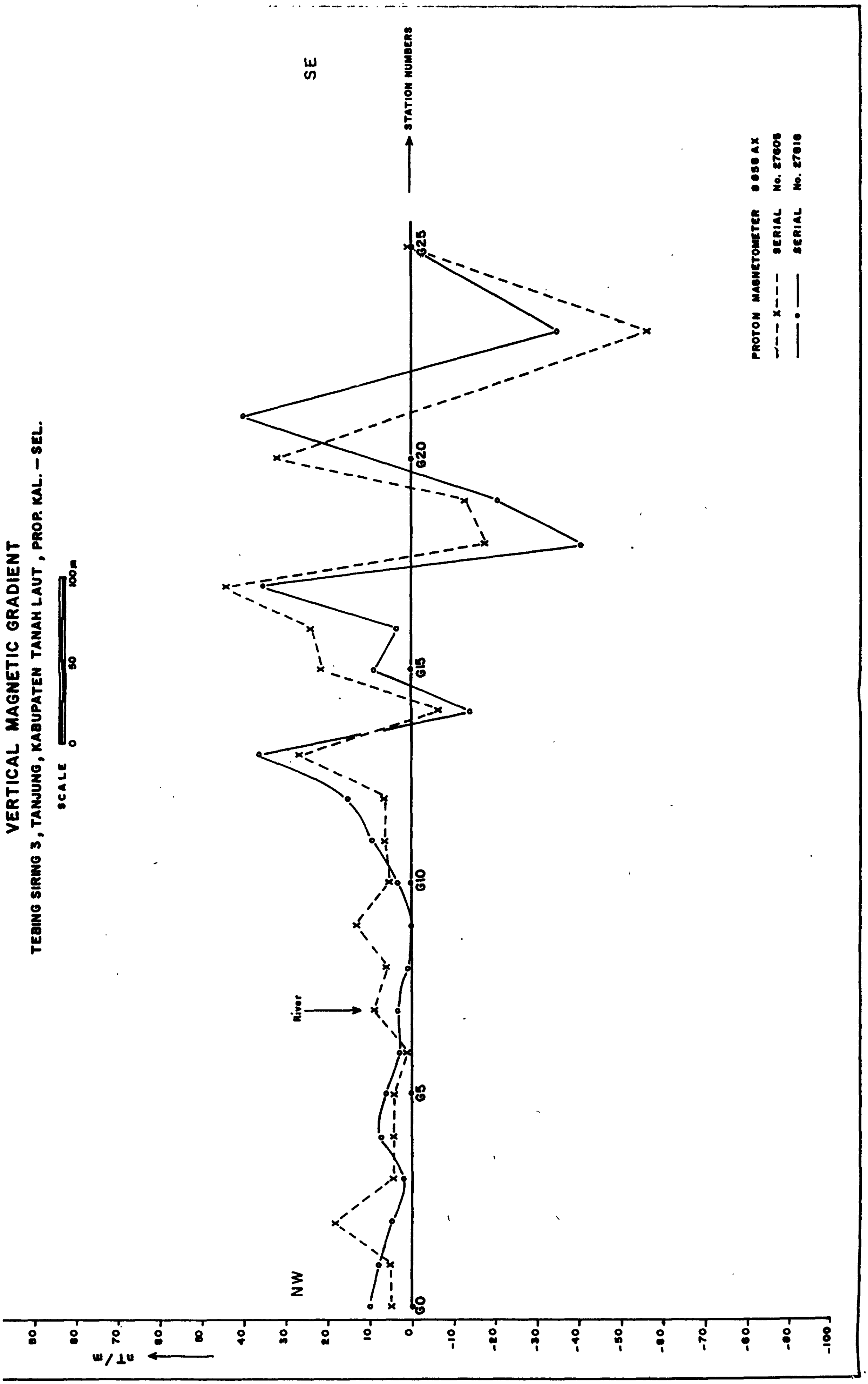
The location of the traverse is shown on Plate 7. The traverse began in the metamorphic rock unit, crossed the inferred source of alluvial PGM at station 5, continued through metamorphic rock through station 15, and was extended into exposures of ultramafic rock (largely augite cumulate) beginning at least by station 20. The vertical magnetic gradient for this profile shows no indication of ultramafic rock near station 5 which lies near the source of olivine and PGM in pan concentrate samples (Figure 32). Highly variable response, corresponding to the presence of ultramafic rock at depth, begins approximately at station 15. A magnetic anomaly model calculated for this profile shows the schist forming a north-westward thickening wedge (Figure 33). In the model, the vertical magnetic gradient was recalculated to a residual field assuming that ultramafic rocks principally make up the regional field. Bodies of schist and highly susceptable rock were modeled to account for variations in the residual. The area marked alluvium is essentially a void in the subsurface model with little or no susceptability. This model suggests the contact between the metamorphic and ultramafic units is a northwest-dipping thrust. Within the ultramafic unit, small bodies with high magnetic susceptability are used to model the variable residual magnetic profile southeast of station 15. These bodies would be analogous to dunite bodies known to occur in the augite cumulate.

The presence of elevated PGM bearing alluvial deposits may explain a number of scattered PGM occurrence in the study area. Laboratory studies showed PGM on one of the headwater tributaries of the S. Tambanio from an area underlain by metamorphic rocks. Local miners have recovered laurite from the main channel of the S. Tambanio upstream from the junction with the S. Irang. The source for these alluvial PGM is not known. Ultramafic rocks are not present in the areas drained by these channels. Understanding the distribution of elevated alluvial is essential because PGM occurrence locations is the primary information used in directing regional exploration in this area.

SEM investigations of PGM, Riam Pinang area and vicinity

Samples were sent back to the United States for SEM investigations by Robert Oscarson at the USGS in Menlo Park, CA with three objectives. The first was to determine the mineralogy of the PGM particles. The mineralogy of the PGM vary depending upon their source. For example, hydrothermal PGM from a sheared serpentinite in Tasmania are dominantly Os-Ir alloys. Those from Alaska-type ultramafic intrusions are Pt-Fe alloys with a small volume of intergrown Os-Ir alloy. The second was to identify the oxide mineral inclusions observed in the particles with a binocular microscope. If they happen to be magnetite with low Ti and V contents, the hydrothermal model would be supported. However, if they were chromite, a high temperature magmatic origin would be more likely. The third was to characterize the morphology of the particles. For samples of the rock pan concentrate samples, the reason was to see if the shapes of the particles were consistent with (1) formation in veins and as fracture coating in the serpentinites, (2) accumulation of alluvial particles trapped in fractures in the bedrock, or (3) occurrence as interstitial grains in the ultramafic rock. In addition, samples of alluvial PGM, up to 15 km downstream from the S. Rambas area were investigated to determine the degree of rounding that could be expected in alluvial transport. The two alluvial localities are S. Pirik (approximately 3 km from S. Rambas) and S. Danau Djingah (approximately 15 km from S. Rambas). X-ray energy spectrum of the PGM are presented in Appendix H.

Figure 32. Vertical magnetic gradient for ground magnetic traverse, S. Rambas area, South Kalimantan.

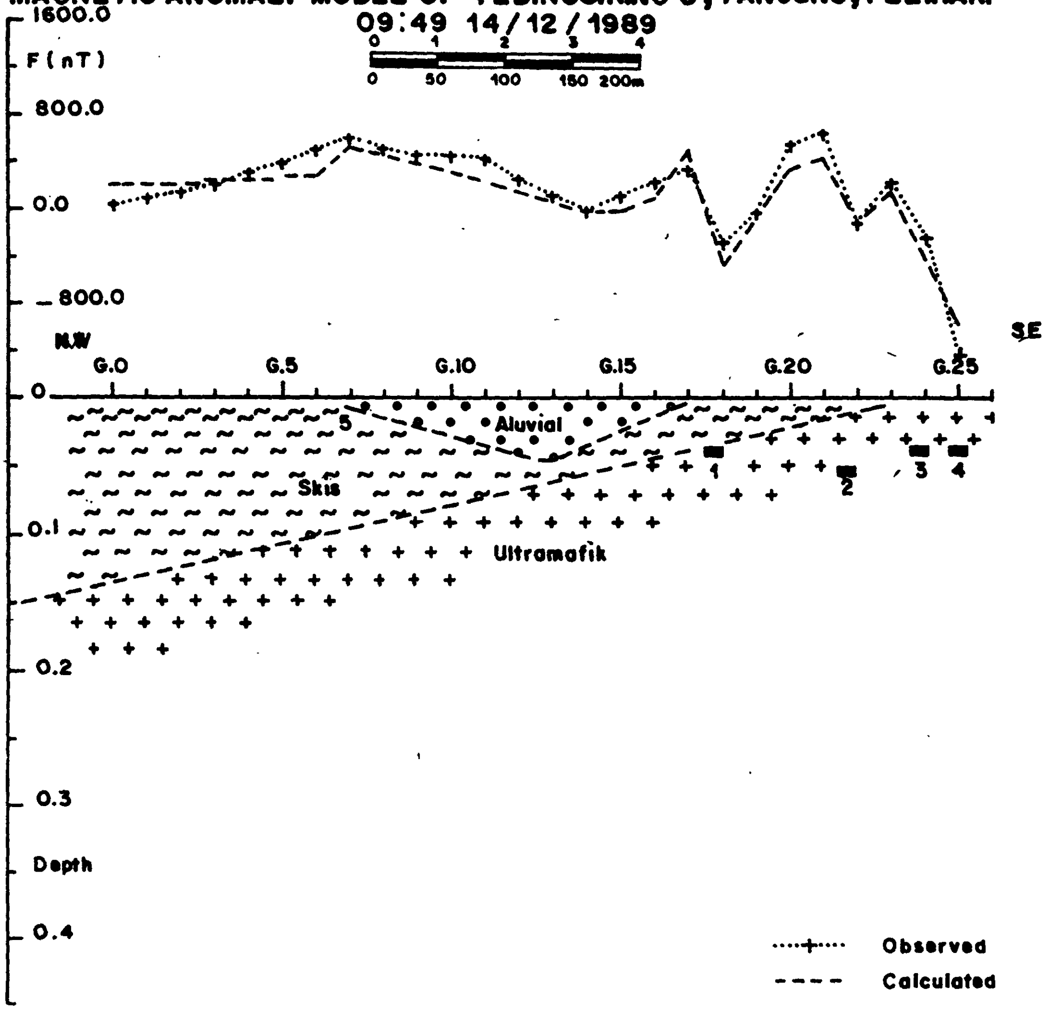


VERTICAL MAGNETIC GRADIENT

TEBING SIRING 3, TANJUNG, KABUPATEN TANAH LAUT, PROP. KAL. – SEL.

Figure 33. Magnetic anomaly model, S. Rambas area, South Kalimantan.

MAGNETIC ANOMALY MODEL OF TEBINGSIRING 3, TANJUNG, PLEIHARI



BODY Nº1	BODY Nº 2	BODY Nº 3	BODY Nº 4	BODY Nº 5
Shape :	**Shape :**	**Shape :**	**Shape :**	Metamorfic rock
Thickness = 10 m	Thickness = 10m	Thickness = 10 m	Thickness = 10 m	(skis)
Strike length = 10 m	Strike length = 10 m	Strike length = 10m	Strike length = 10m	
Height = 10 m	Height = 10 m	Height = 10 m	Height = 10 m	
Position :	**Position :**	**Position :**	**Position :**	**Susceptibility (k)**
Xr = 443 m	Xr = 541 m	Xr = 596 m	Xr = 624 m	K = – 0.0728 S.I
Yr = 0 m	Yr = 0 m	Yr = 0 m	Yr = 0 m	
Zr = 30 m	Zr = 34 m	Zr = 30 m	Zr = 30 m	
Susceptibility (k)	**Susceptibility (k)**	**Susceptibility (k)**	**Susceptibility (k)**	
K = 12.5 S.I	K = 12.5 S.I.	K = 12.5 S.I	K = 12.5 S.I	

MINERALOGY

The dominant PGM in the S. Rambas area (Table 10), and the S. Pirik and S. Danau Djingah alluvial occurrences (Table 11) is Pt-Fe alloy. Pt-Fe alloy at the S. Rambas area has inclusions of Ir-Os alloy, Ir-Os-Rh-Fe alloys, and Ru-Os sulfide (laurite?). One particle of sperrylite was found at S. Rambas area (Figure 34). Laurite occurs as discrete placer particles at S. Pirik (Figure 35) and has also been found in the main channel of the S. Tambanio upstream of the junction with S. Irang. Ir-Os alloy occurs as an inclusion in Pt-Fe alloy at S. Danau Djingah. The PGM mineralogy is typical for PGM-Au placers, many of which are derived from Alaskan-type ultramafic intrusions.

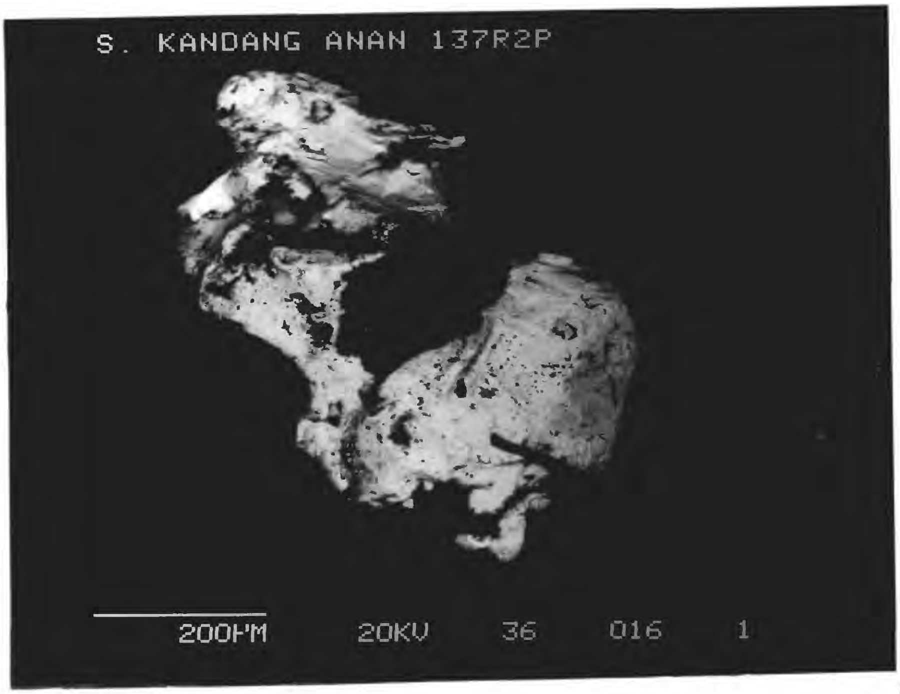
Table 10. Summary of scanning electron microscope investigations on PGM particles, S. Rambas area, South Kalimantan

Sample ID	Host Mineral (spectrum number[1]) size	Morphology of host	Inclusions (spectrum number[1]) size	Figure No.
S. Gelagah 1 90 RP	Pt-Fe alloy (SP0), 1070 μm	spherical, subangular, striated surfaces	chromite (SP1), 145 μm	--
S. Gelagah 1 90 RP	Pt-Fe alloy (SP4), 750 μm	subprismoidal, subangular, striated surfaces, high profile inclusions	4 grains of (Ru>Os>>Ir) sulfide (laurite) (SP2), 35 to 110 μm; Ir-Os alloy (SP3), 150 μm	36
Rambas alluvial 65 P	Pt-Fe alloy (SP6), 1720 μm	spherical, very angular, pitted, high relief edges on pits	2 grains of chromite in pits (SP5), 185 to 308 μm	37
Rambas alluvial 65 P	Pt-Fe alloy (SP7), 1040 μm	subprismoidal, subangular, smooth edges	none	39
S. Kandang Anan 137 R2P	Sperrylite (SP12), 640 μm	subprismoidal, subrounded	chromite (SP9), 100 μm; laurite (SP11), 44 μm; (Fe, Rh, Ir, Ni,Cu, Co) (S, P, As) (SP10), 33 μm	34
S. Kandang Anan 137 R2P	Pt-Fe alloy (SP13), 850 μm	subprismoidal, angular, high profile inclusion	chromite (SP8), 96 μm; Ir-Os-Rh-Fe alloy (SP14), 20 mm	38
S. Ayubat 166 P	Pt-Fe alloy (SP17), 1170 μm	subprismoidal, subangular, smooth edges	chromite (SP15), 102 μm; surface contamination (Al and Cl) on Pt-Fe alloy (SP16)	

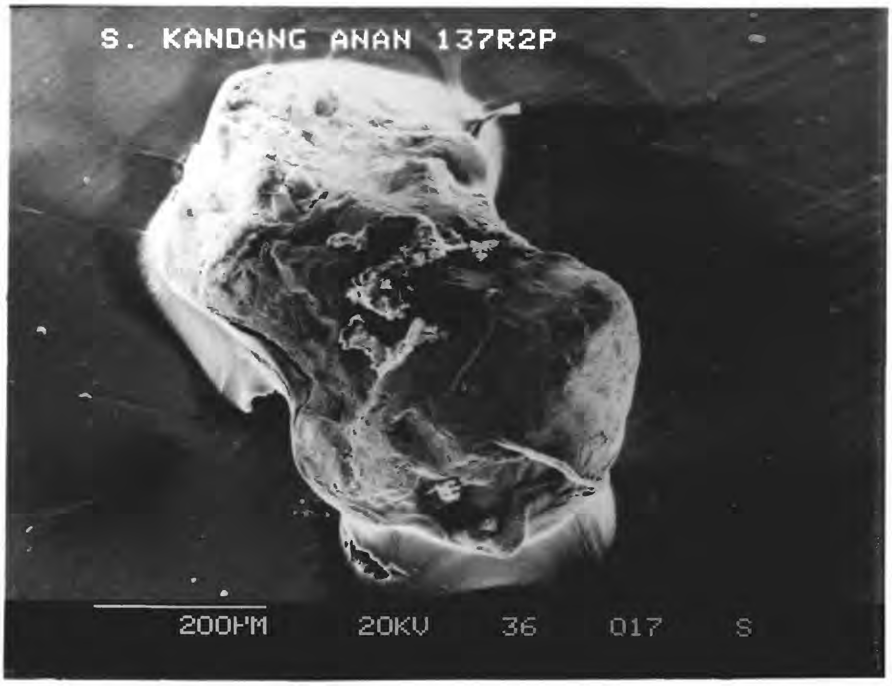
[1] X-ray spectrum for each grain in Appendix H.

Figure 34. Back scattered electron (A) and secondary electron image (B) of sperrylite (SP12) with inclusions of laurite (S11), chromite (SP9) and a (Fe, Rh, Ir, Ni, Cu, Co) (S, P, As) phase (SP10). Sample 137 R_2P, S. Kandang Anan, S. Rambas area.

Fig. 34A, B


S. KANDANG ANAN 137R2P
200PM 20KV 36 016 1

A


S. KANDANG ANAN 137R2P
200PM 20KV 36 017 S

B

……

Figure 35. Detrital laurite from the S. Pirik alluvial deposit. A). Back scattered electron (i), and secondary electron image (ii) of detrital laurite particle; B). Back scattered electron (i), and secondary electron images (ii) of broken grain of detrital laurite; C). Back scattered electron (i) and secondary electron (ii) images of detrital laurite particle. Note crystal faces (lower left). Dark areas on particle in back-scattered image are clay minerals and Fe-Mn oxides on the surface of the grain.

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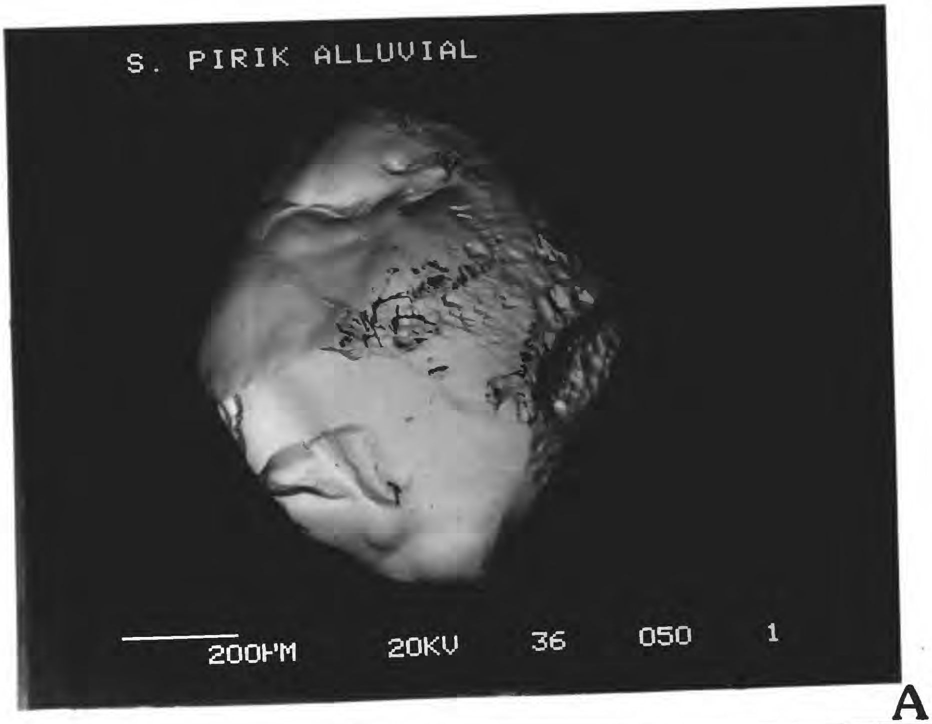
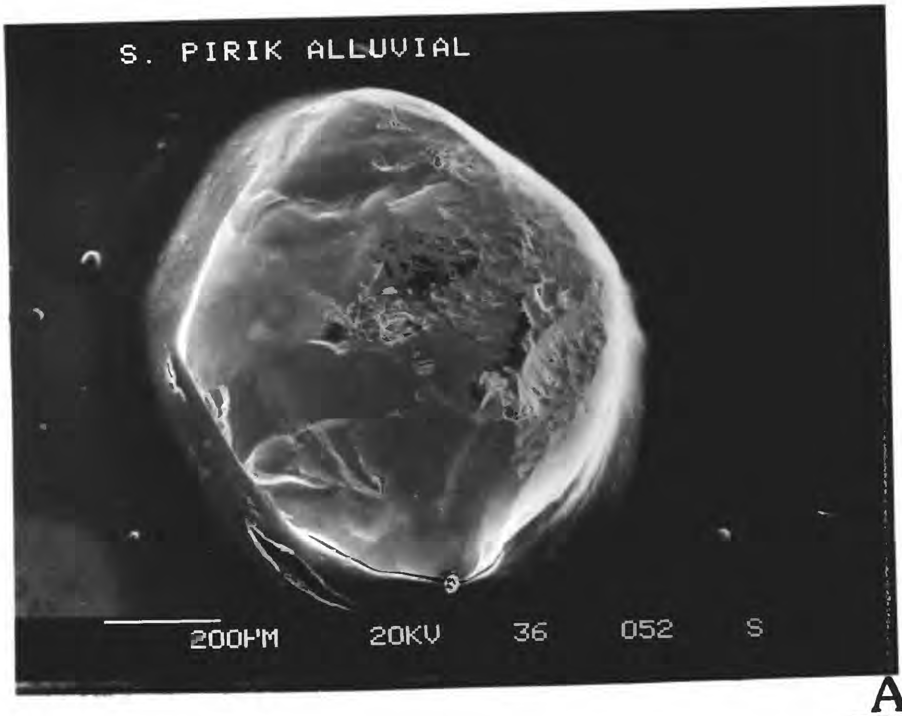
Fig. 35Ai, Aii

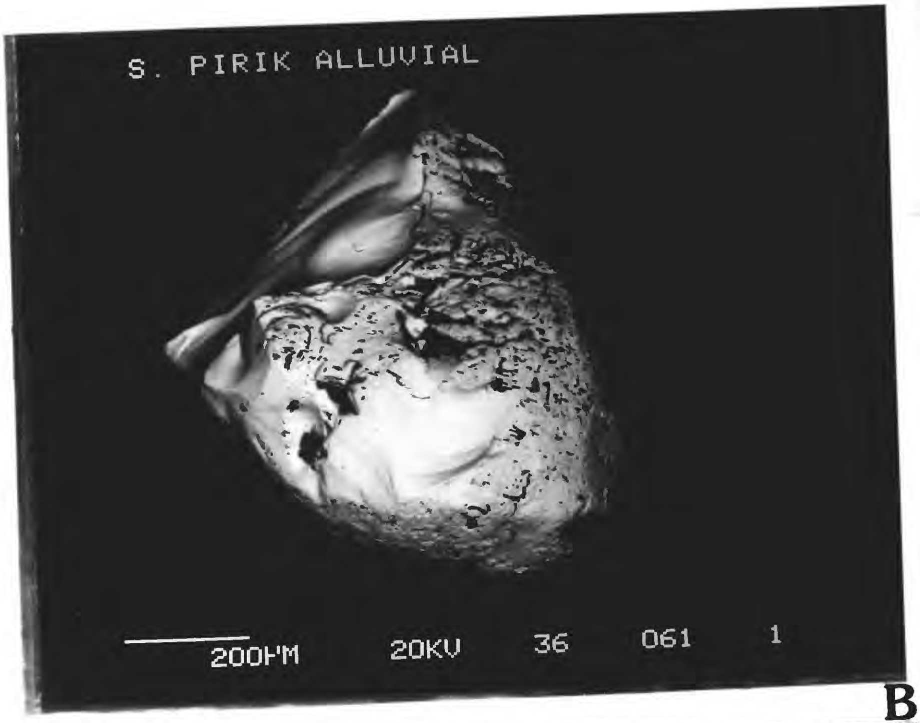


Ai

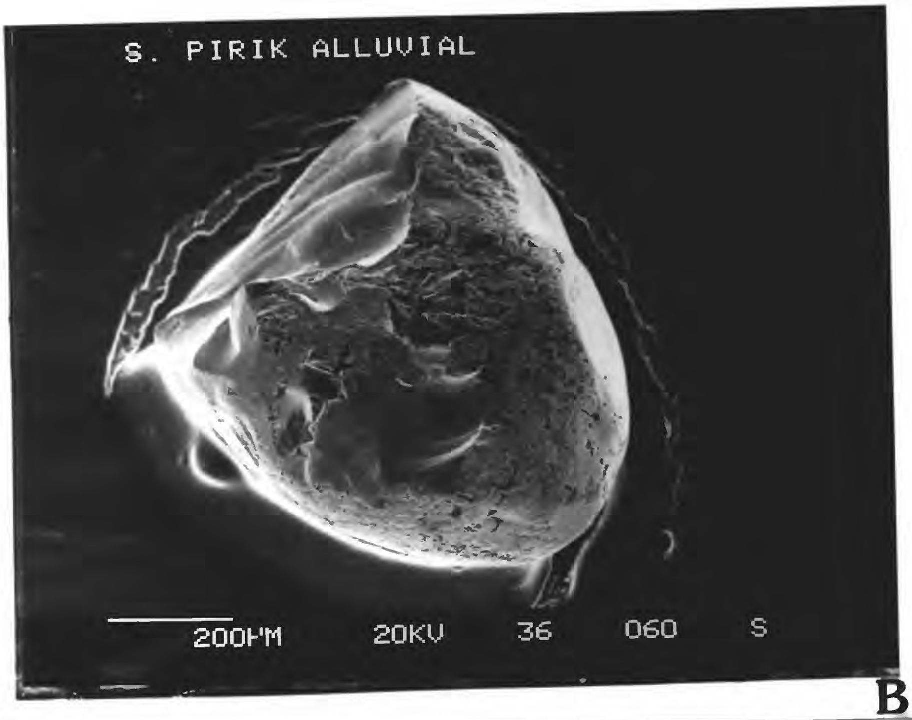


Aii

Fig. 35BI, BII

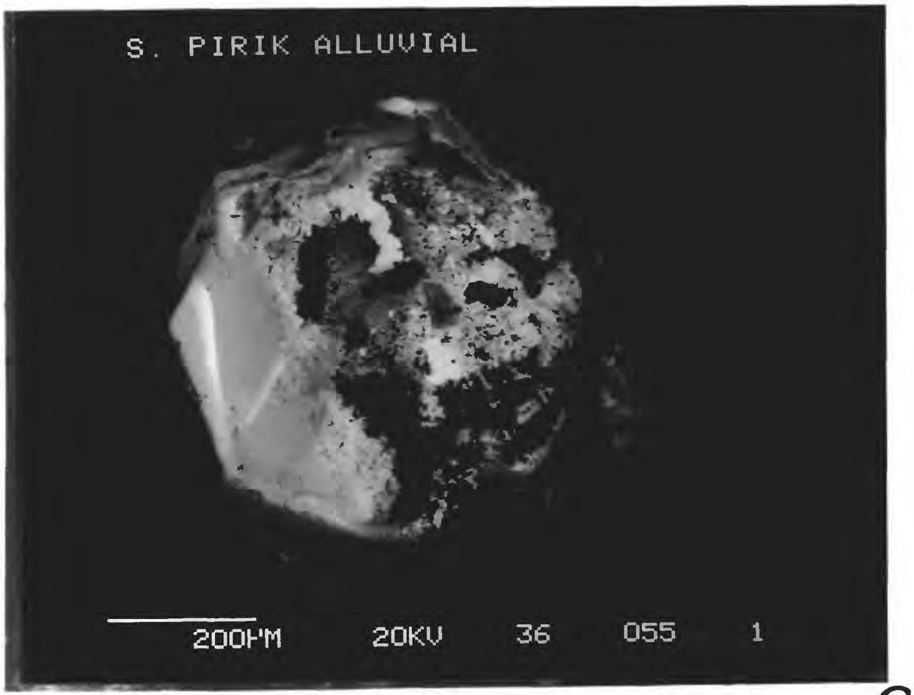


Bi

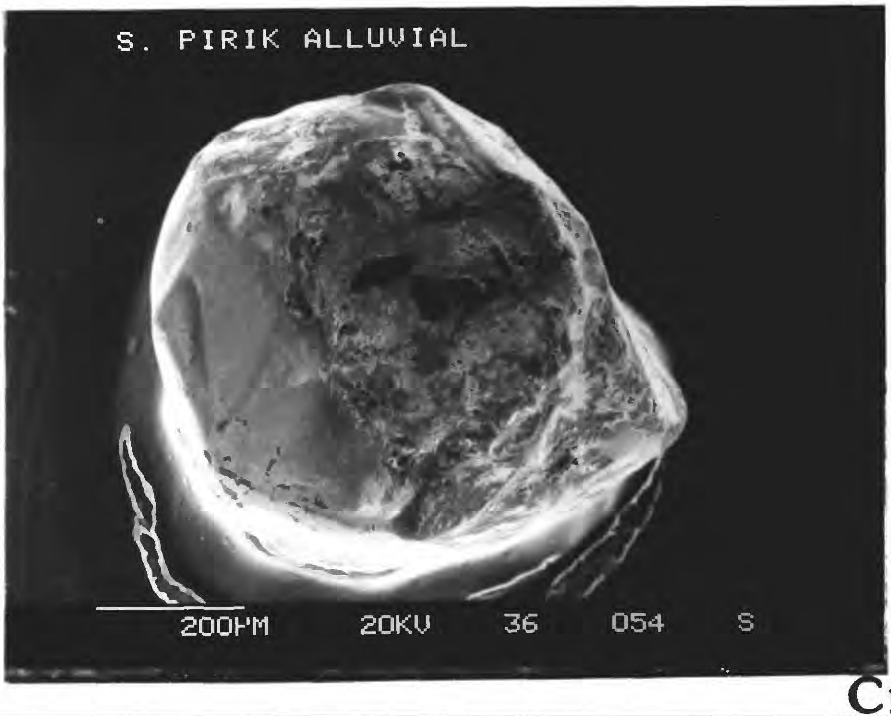


Bii

Fig. 35Ci, Cii



Ci



Cii

Table 11. Summary of scanning electron microscope investigation of PGM particles, S. Pirik and S. Danau Djingah alluvial deposits, South Kalimantan.

Area	Photo Numbers	Host Mineral (spectrum number[1]) size	Morphology of particle	Inclusions (spectrum number[1]), size	Figure No.
S. Pirik alluvial deposit	66/67	Pt-Fe alloy (SP32), 1057 µm	subprismoidal, angular	none	--
	68/69	Pt-Fe alloy (SP33), 954 µm	spherical, very angular	none	40 a, b
	71/72	Pt-Fe alloy (SP34), 955 µm	subprismoidal, subangular, cracked	none	40 c, d
	73/74	Pt-Fe-alloy (SP35), 683 µm	spherical, dimpled, subrounded	none	40 e, f
	75/77	Pt-Fe alloy (SP36), 854 µm	spherical, rounded, recti-linear cracks	none	40 g, h
	78/79	Pt-Fe alloy (SP37), 135 µm	---	---	---
	80/81	Pt-Fe alloy (SP41), 378 µm	subprismoidal, subrounded	none	
	50/52	laurite (SP29), 850 µm	spherical, subrounded, pockmarked	none	35A
	54/55	laurite (SP31), 68 µm	spherical, subrounded, crystal faces,deep pockmarks	none	35C
	58/59	laurite, µm	spherical, conchoidal fractured surface	none	---
	60/61	laurite, 830 µm	spherical, one end broken off	none	35B

Table 11. Summary of scanning electron microscope investigation of PGM particles, S. Pirik and S. Danau Djingah alluvial deposits, South Kalimantan (continued).

S. Danau Djingah alluvial deposit	30/31	Pt-Fe alloy (SP18), 305 µm	spherical to subprismoidal, subrounded, grooved	Ir-Os alloy (SP19), 67 µm	---
	33/34	Pt-Fe alloy (SP20), 609 µm	subprismoidal, subangular	none	41 a, b
	36/37	Pt-Fe alloy (SP22), 420 µm	subprismoidal, rounded, scratched	none	---
	38/39	Pt-Fe alloy (SP23), 615 µm	subprismoidal, subrounded	none	41 c, d
	40/41	Pt-Fe alloy (SP24), 457 µm	spherical to subprismoidal, subrounded, scratched	none	---
	42/43	Pt-Fe alloy (SP25), 418 µm	spherical, well rounded	none	41 e, f
	44/46	Pt-Fe alloy (SP27), 523 µm	subprismoidal, subangular	none	---

OXIDE INCLUSIONS

Oxide mineral inclusions in Pt-Fe alloy from the S. Rambas area (Table 10) were all high - Fe chromite. This, together with the Ir-Os alloy and laurite inclusions, suggests a high temperature of formation and an association with chromitite in the source for these particles.

MORPHOLOGY

The morphology of the particles from concentrates of the sheared ultramafic rock at the S. Rambas area varies from spherical to subprismoidal and very angular to subrounded (nomenclature after Powers, 1982). In general, the particles examined showed very little evidence of abrasion. The surfaces of some particles were striated (Figure 36), a feature resulting from growth of the particle (similar to stria on pyrite) or molding against adjacent silicate or oxide minerals. One grain was pitted (Figure 37); inclusions of chromite remained in some pits. Pits resulting from of plucking of grains included or intergrown with the PGM have delicate, high relief edges. Inclusions of laurite (Figure 36) and chromite (Figure 38) often showed very high profiles above the surface of the particle. The morphologies appear to be more consistant with PGM that formed at high temperatures interstitial to chromite and silicate minerals rather than in veins or on fracture surfaces. Rounding was limited to smoothing of edges on some particles (Figure 39). Particles from the rock pan concentrates show little or no evidence for alluvial transport. However, photographs of particles collected in routine pan concentrate samples appear to be more worn - generally appearing spherical and rounded (Figure 31).

Figure 36. Back scattered electron (A) and secondary electron (B) images of Pt-Fe alloy (SP 4) with inclusions of laurite (SP2), any Ir-Os alloy (SP3) in PGM particle, sample 90RP, S. Gelagah 1, S. Rambas area. Note striated surfaces on Pt-Fe alloy (upper left and lower right).

Fig. 36A, B

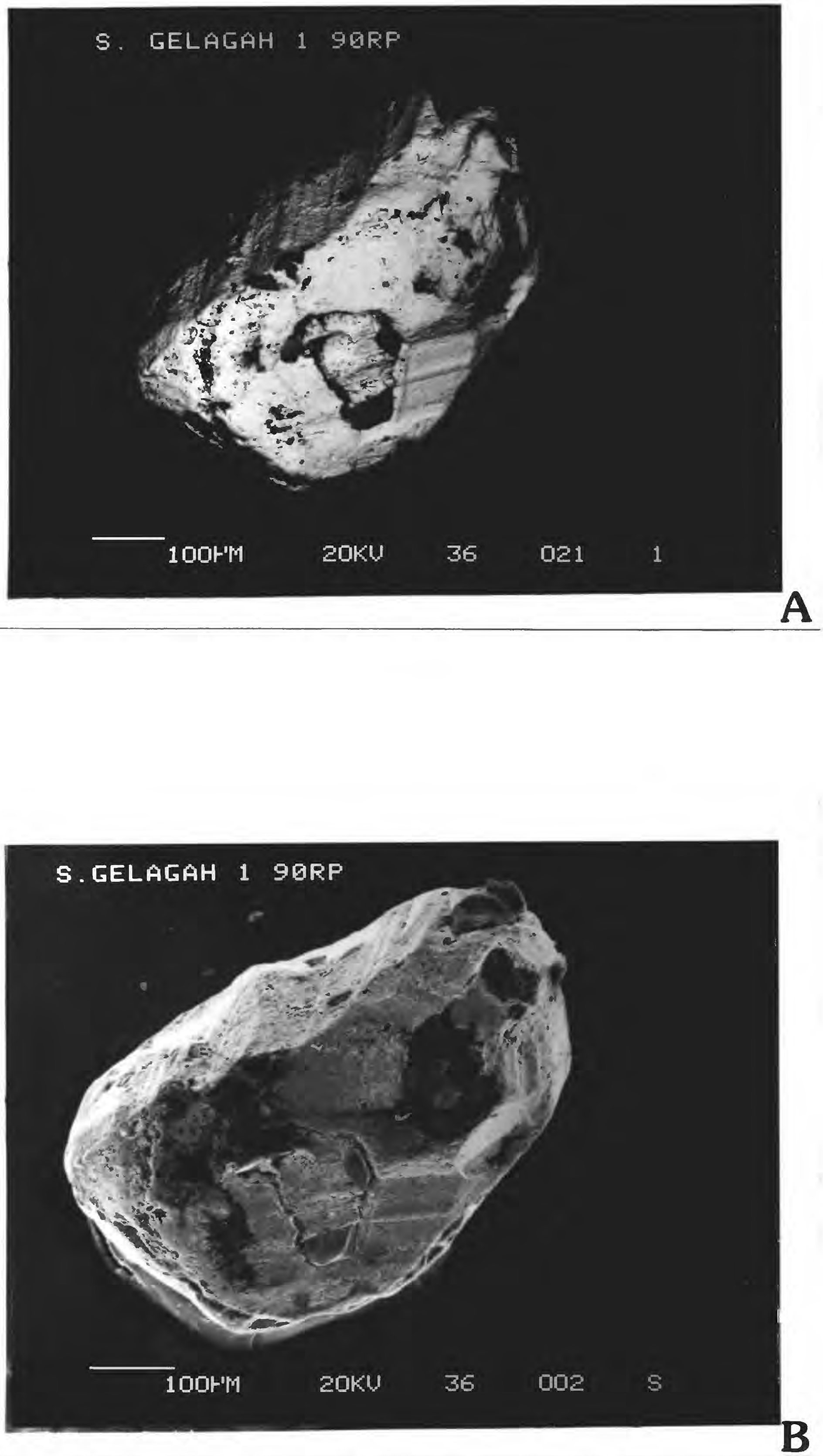
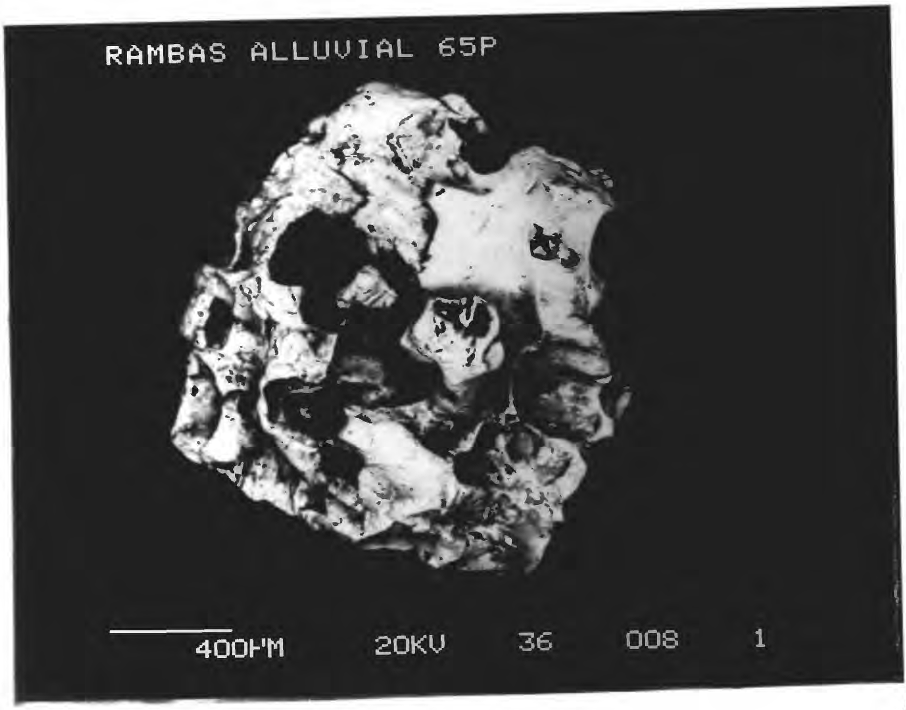
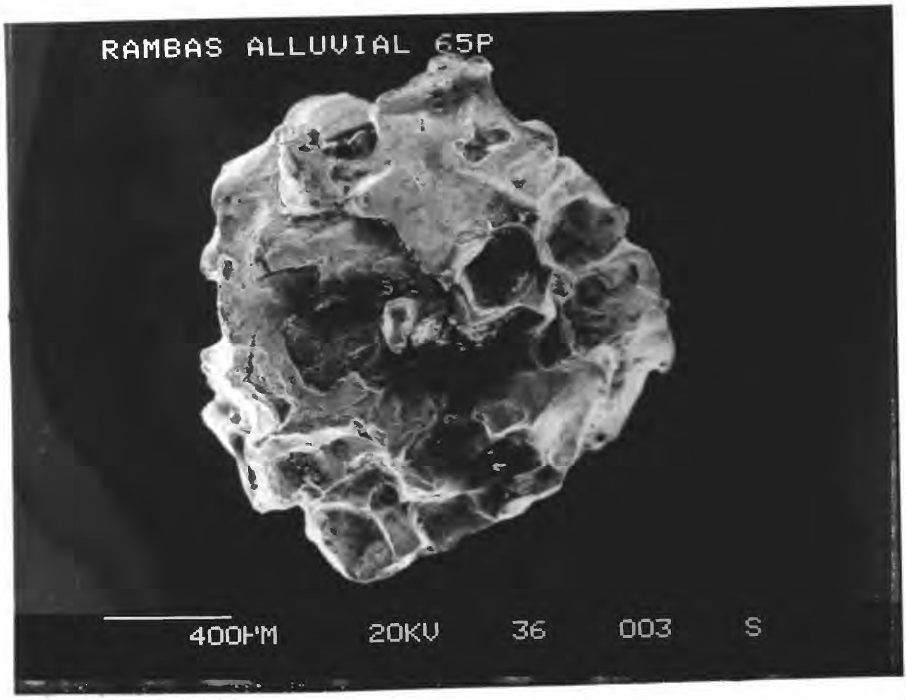

S. GELAGAH 1 90RP
100µM 20KV 36 021 1
A
S.GELAGAH 1 90RP
100µM 20KV 36 002 S
B

Figure 37. Back scattered electron (A) and secondary electron (B) images on deeply pitted PGM particle (Pt-Fe alloy-SP6), sample 65 P, Rambas alluvial, S. Rambas area. Inclusions of high - Fe chromite occur in some pits (SP-5).

Fig. 37A, B


RAMBAS ALLUVIAL 65P
400ᴾM 20KV 36 008 1

A


RAMBAS ALLUVIAL 65P
400ᴾM 20KV 36 003 S

B

……

Figure 38. Back-scattered electron (A) and secondary electron (B) images of particle of Pt-Fe alloy (SP13) with inclusions of chromite (SP8) and Ir-Os-Rh-Fe alloy (SP14), sample 137 R_2P, S. Kandang Anan, S. Rambas area.

……

Fig. 38

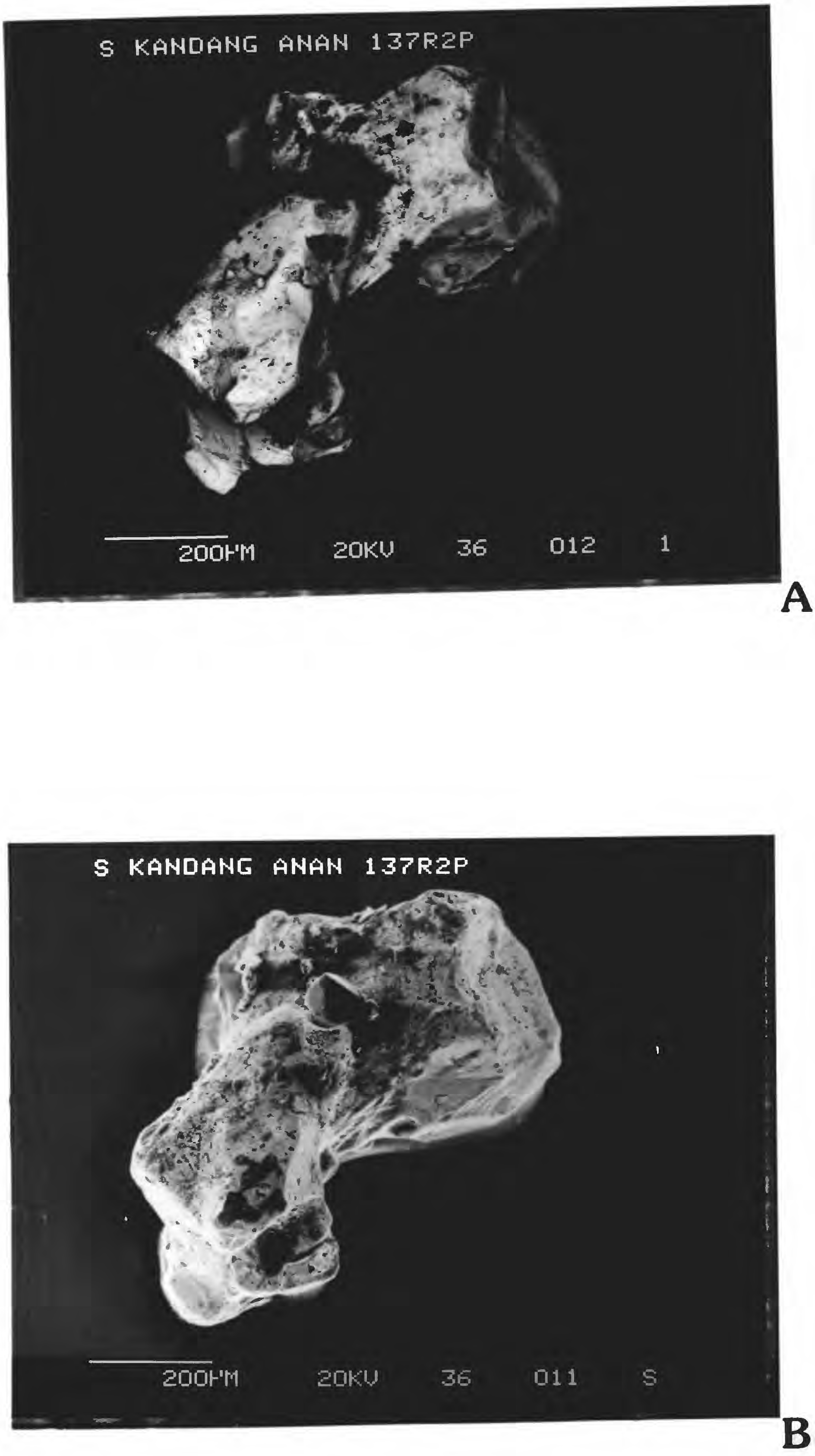
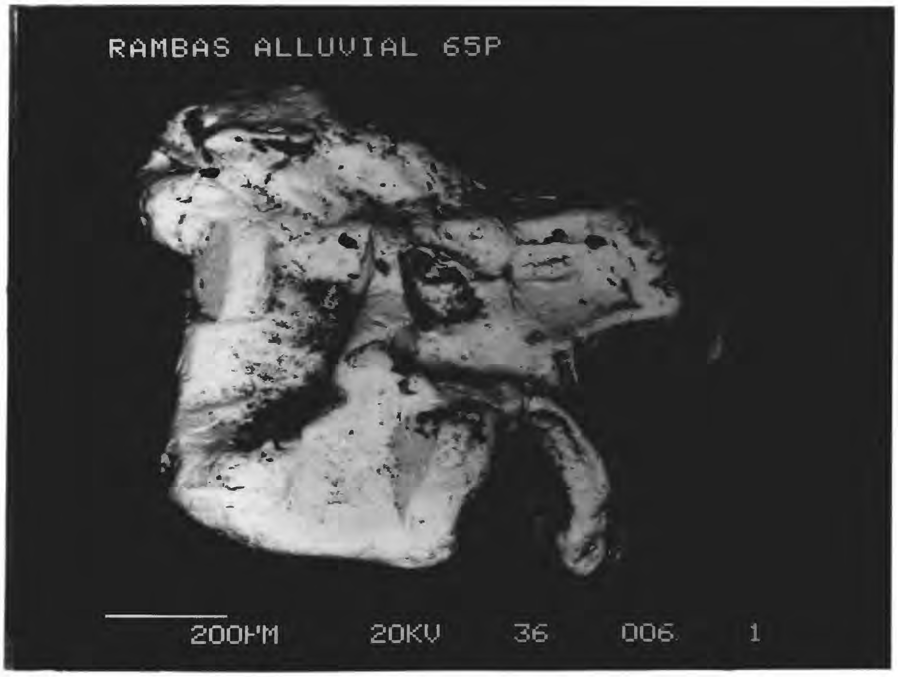

S KANDANG ANAN 137R2P
200µM 20KV 36 012 1
A
S KANDANG ANAN 137R2P
200µM 20KV 36 011 S
B

Figure 39. Back-scattered electron image of subangular particle of Pt-Fe alloy, sample 65 P, Rambas alluvial, S. Rambas area. Note slight rounding of edges of grain.

Fig. 39



The PGM particles from the S. Pirik alluvial deposit show more evidence for abrasion. The morphology of the particles varies from spherical to subprismoidal and very angular to rounded (Figure 40). There are no high profile inclusions on particles. More rounded and subrounded grains are present. Laurite occures as fairly large (600 - 850 µm) alluvial particles that are dark gray with a bright metallic or adamatine luster. Some laurite grains have crystal faces (Figure 35C),but most have smooth, slightly pockmarked surfaces (Figure 35A). Broken surfaces show conchoidal fractures (Figure 35B). A similar grain was found in a pan concentrate sample near Riam Pinang (RMP89147P).

The morphology of PGM particles from the S. Danau Djingah alluvial deposit varies from spherical to subprismoidal and subangular to well rounded and shows a greater extent of wear (Figure 41).

The degree of rounding varied considerably at each location, therefore it would be very difficult to estimate distance from a source by looking at only one or two grains. Although the PGM vary widely in roundness at each site, the ranges do not completely overlap and show a progressive increase in overall roundness downstream. Generally grains that are very angular, contain high profile mineral inclusions, and high relief edges may be a good indicator of a near source setting.

Grain size of particles also shows a decrease downstream. A statistical quantification of grain size was not done. Grains selected in the samples generally were the largest particles (easily to see and manipulate) so the measurements in Table 10 and 11 do provide some measure of the size of the larger particles. The mean size of the studied particles decrease downstream (mean size 1034 µm, 722 µm, and 478 µm for S. Rambas, S. Pirik, and S. Danau Djingah respectively).

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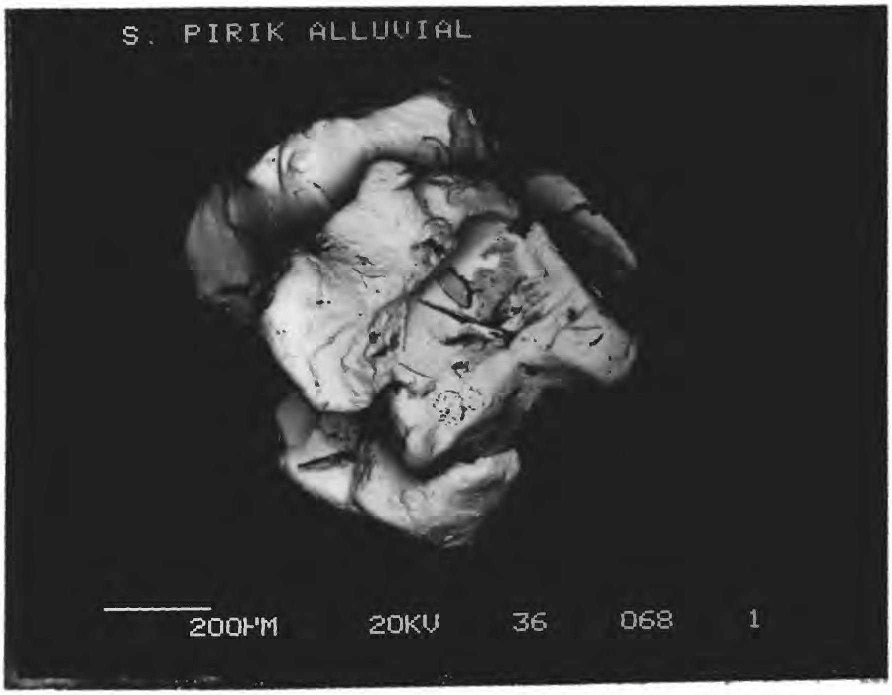
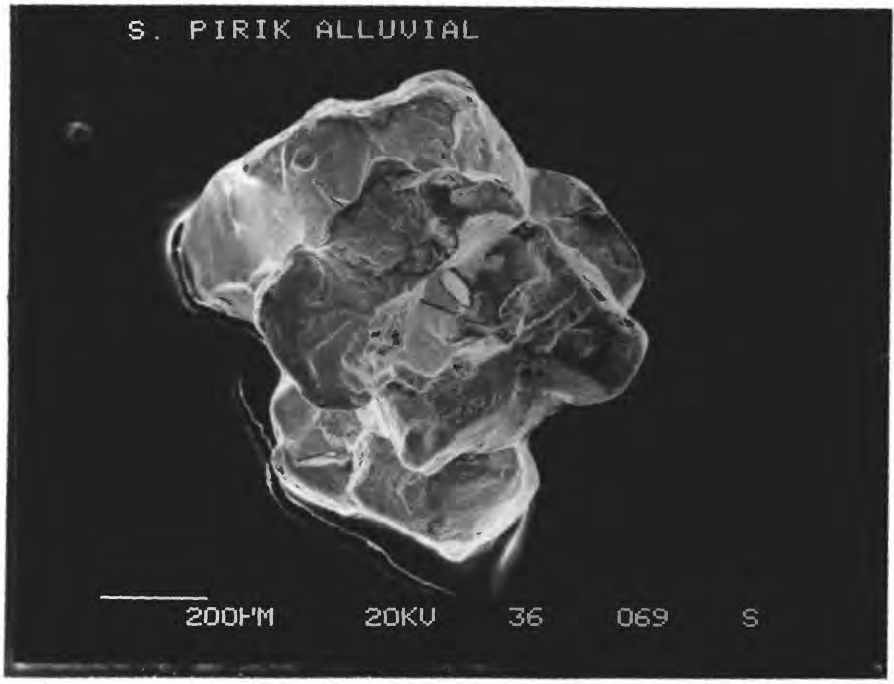
Figure 40. Back-scattered electron (BSE) and secondary electron (S) images of particles of Pt-Fe alloy snowing varying degrees of rounding, S. Pirik alluvial deposit. A) BSE and B) S - very angular; C) BSE and D) S - subangular; E) BSE and F) S - subrounded; G) BSE and H) S - rounded.

……

Fig. 40A, B

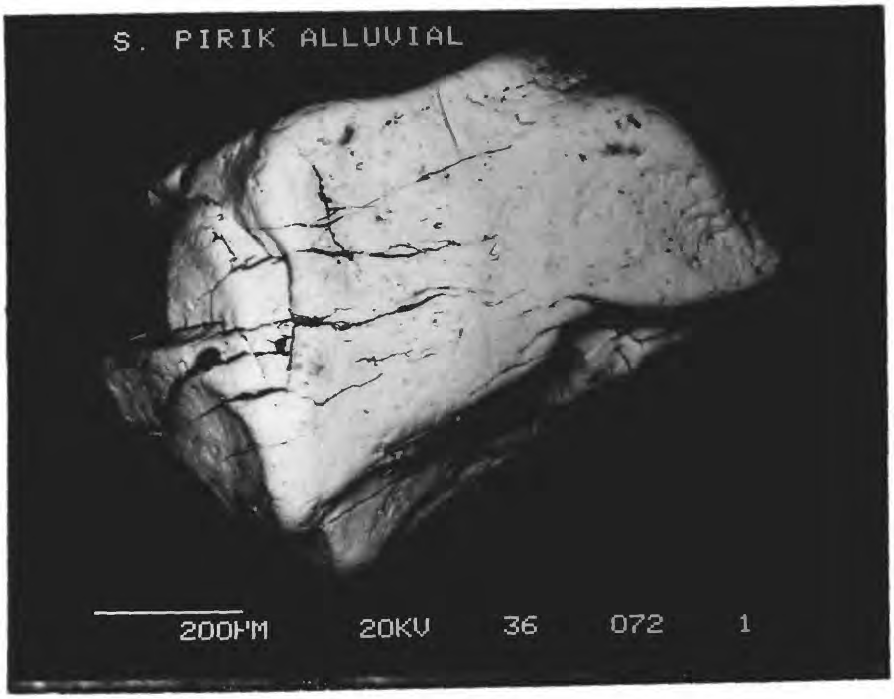

S. PIRIK ALLUVIAL
200НM
20KV
36
068
1

A

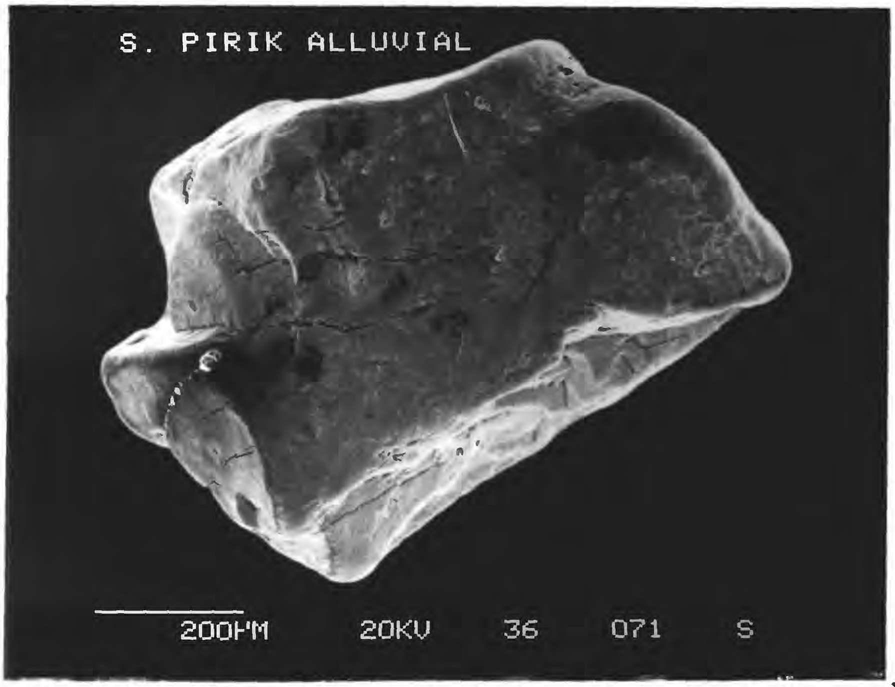

S. PIRIK ALLUVIAL
200НM
20KV
36
069
S

B

Fig. 40C, D


S. PIRIK ALLUVIAL
200µM 20KV 36 072 1

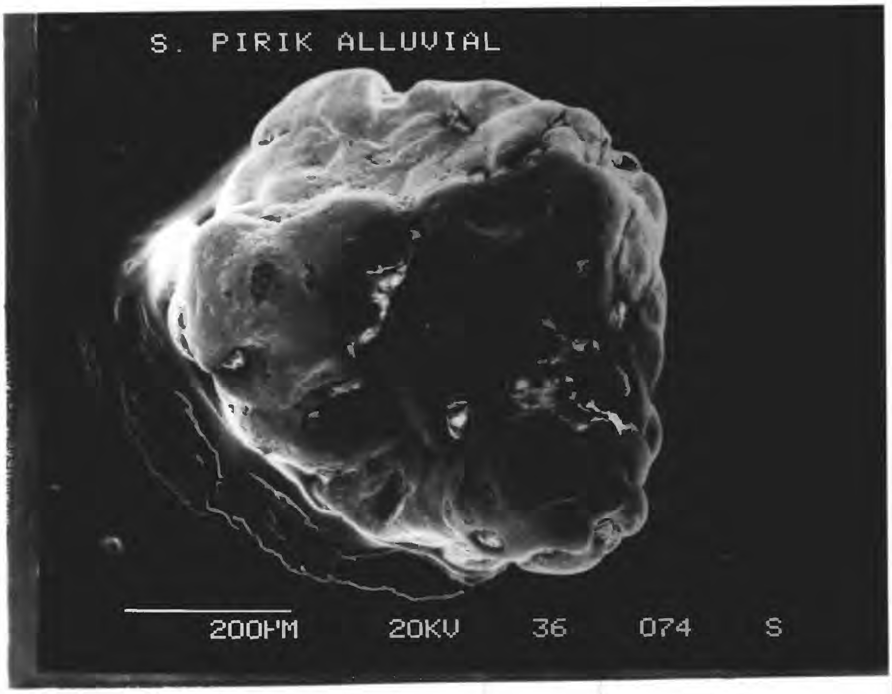
C


S. PIRIK ALLUVIAL
200µM 20KV 36 071 S

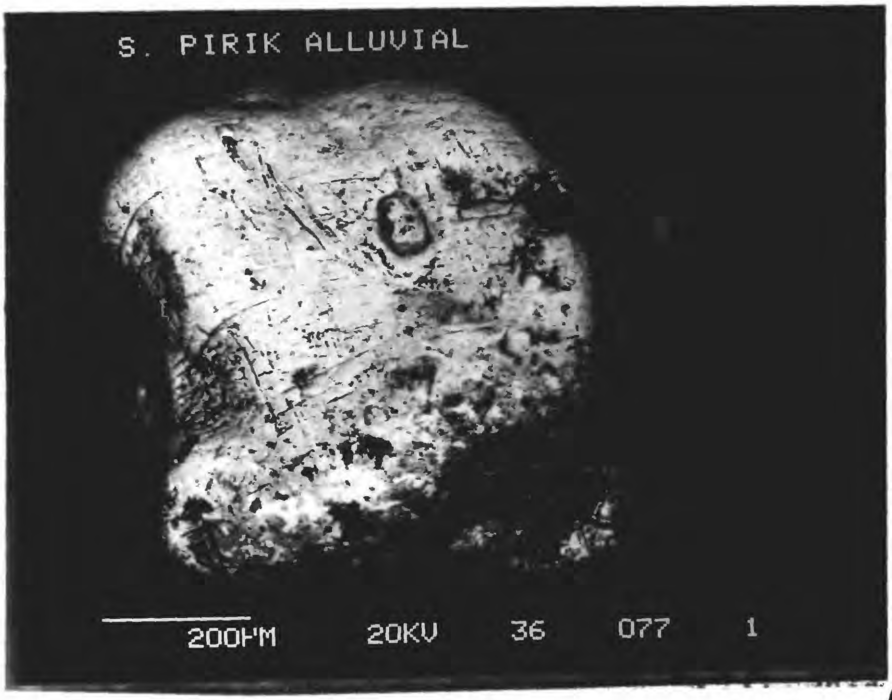
D


S. PIRIK ALLUVIAL
200PM
20KV
36
073
1

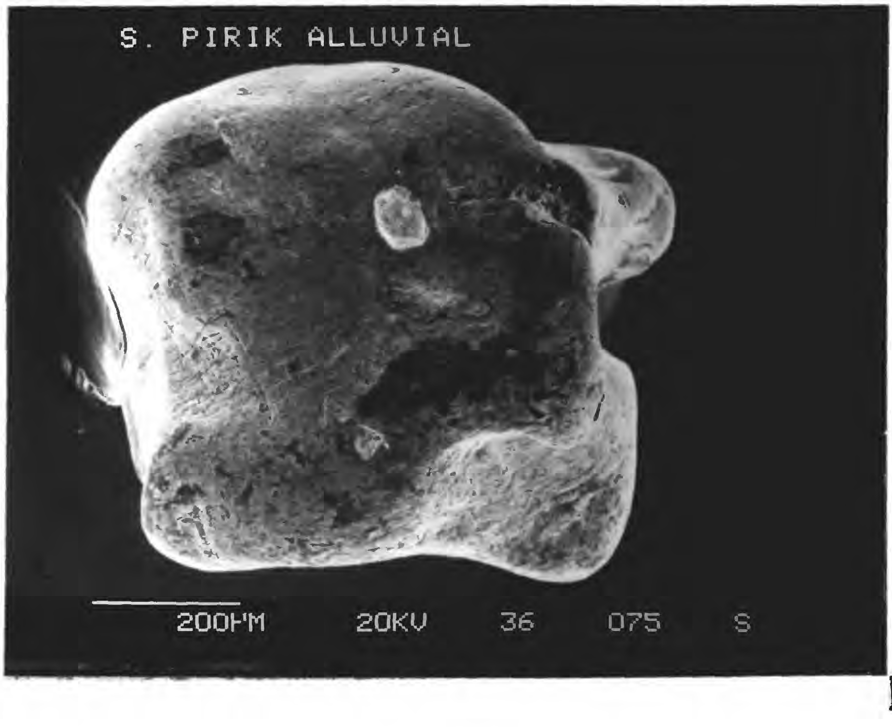
E


S. PIRIK ALLUVIAL
200PM
20KV
36
074
S

F


S. PIRIK ALLUVIAL
200µM 20KV 36 077 1

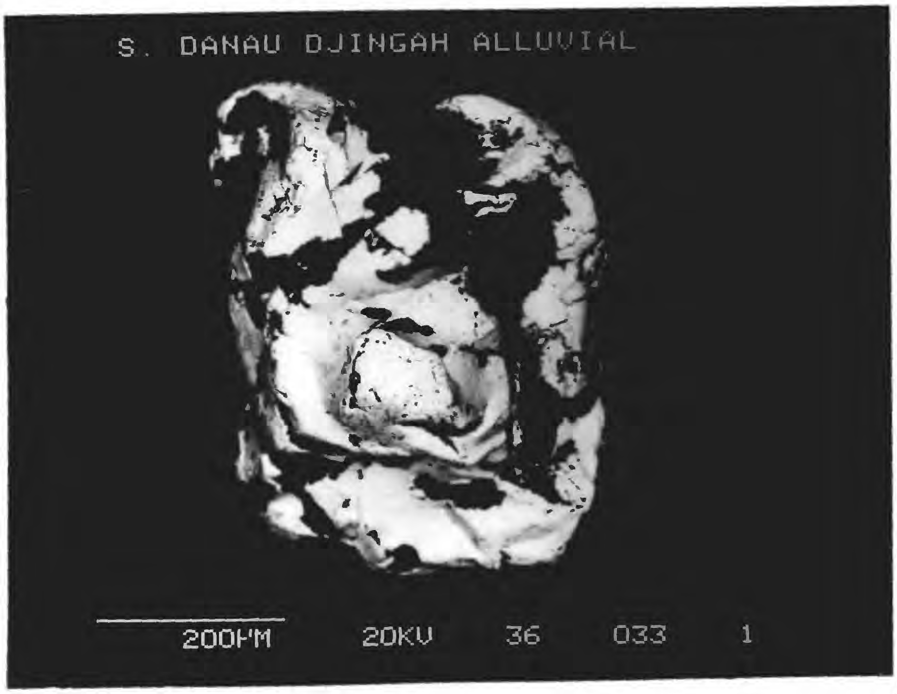
G


S. PIRIK ALLUVIAL
200µM 20KV 36 075 S

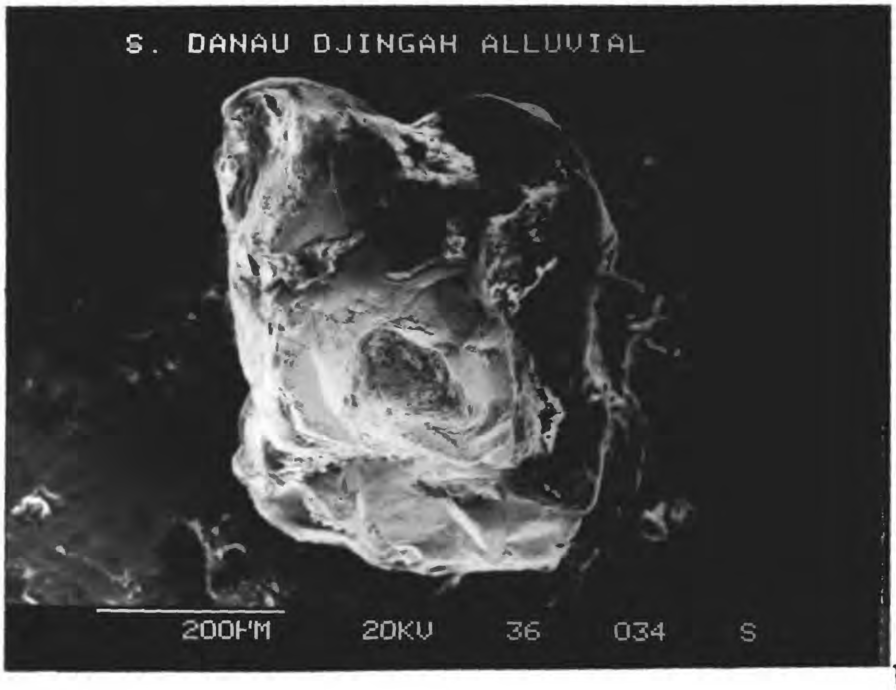
H

Figure 41. Back-scattered electron (BSE) and secondary electron (S) images of particles of Pt-Fe alloy showing varying degrees of rounding, S. Danau Djingah alluvial deposit. A) (BSE) and B) (S) - subangular; C) (BSE) and D) (S) - subrounded; E) (BSE) and F) (S) - well rounded.

Fig. 41A, B

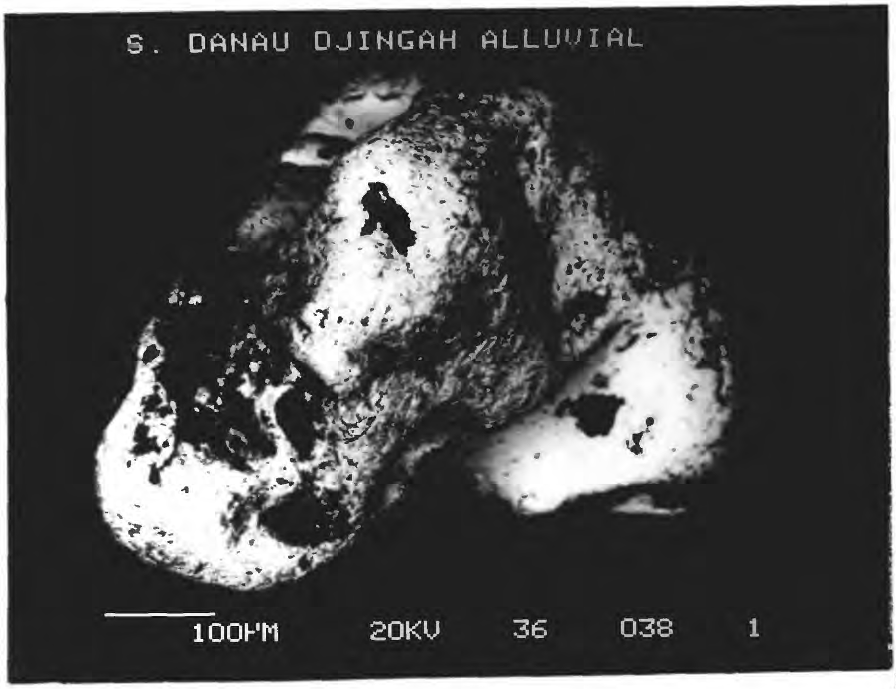

S. DANAU DJINGAH ALLUVIAL
200µM 20KV 36 033 1

A

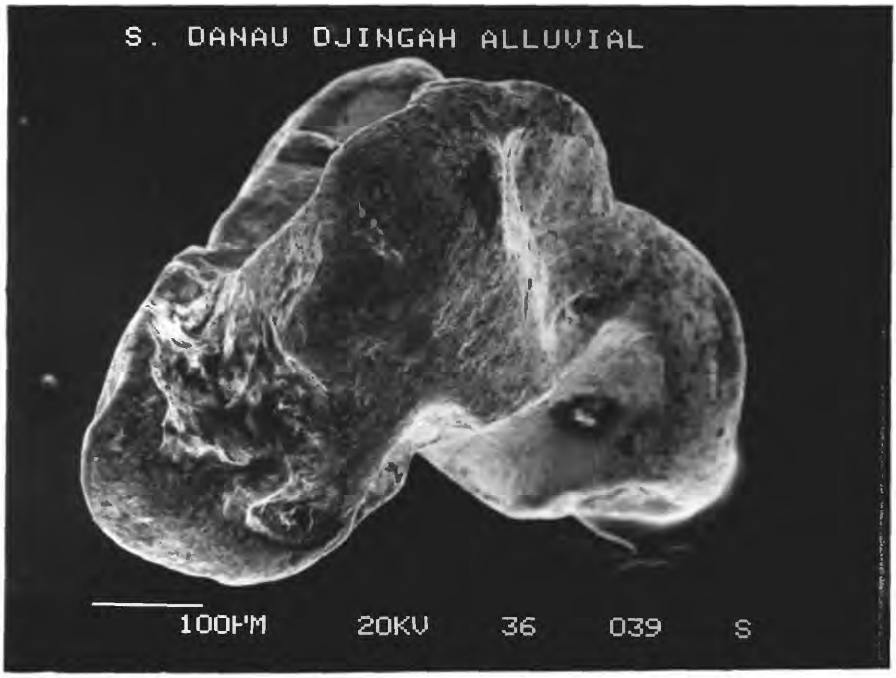

S. DANAU DJINGAH ALLUVIAL
200µM 20KV 36 034 S

B

Fig. 41C, D

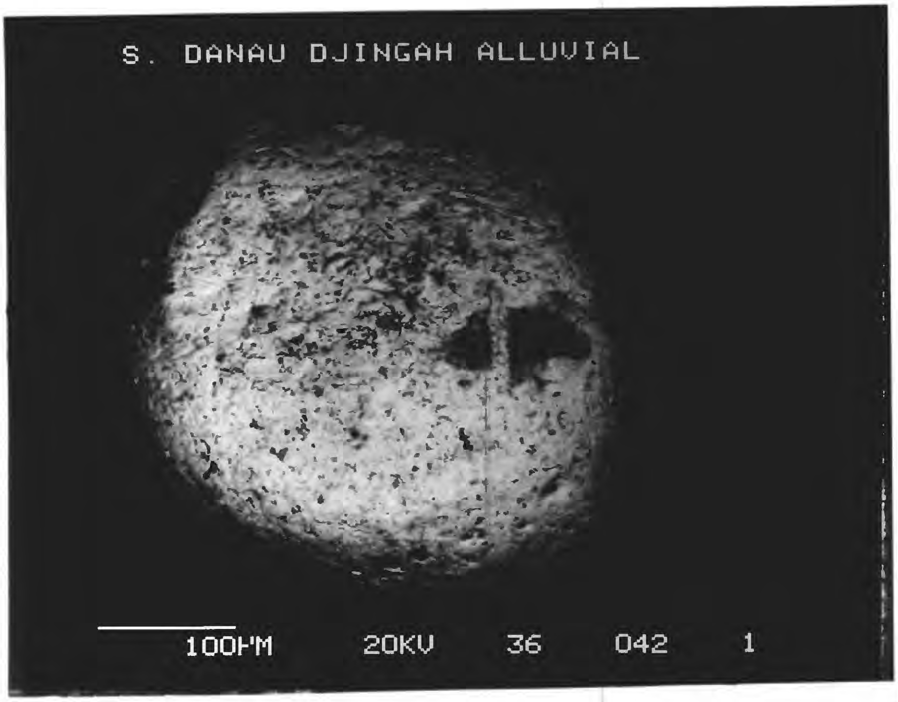

S. DANAU DJINGAH ALLUVIAL
100µM
20KV
36
038
1

C

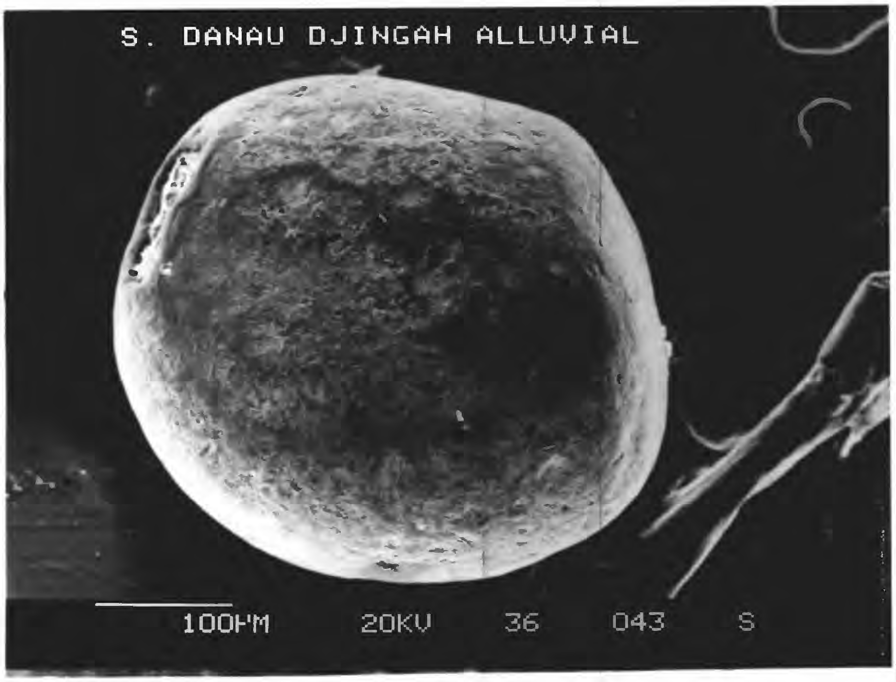

S. DANAU DJINGAH ALLUVIAL
100µM
20KV
36
039
S

D

Fig.41E, F


S. DANAU DJINGAH ALLUVIAL
100µM 20KV 36 042 1

E


S. DANAU DJINGAH ALLUVIAL
100µM 20KV 36 043 S

F

Pt, Pd, and Au analyses

Selected samples of rocks (31), pan concentrates (36), and stream sediments (24) were analyzed for Pt, Pd, and Au by P.T. Geoservices (LTD.) in Bandung (Table 12,13,and 14). Rock samples were selected primarily to determine if the crushed and sheared ultramafic rocks from which PGM could be panned had anomalous whole rock Pt contents. Stream sediment and pan concentrate samples were analyzed to see what type of response would be generated in both media in the areas where PGM had been observed in the field. A single sample of chromitite schlieren in dunite found in trench one was analyzed for Pt, Pd, Rh, Ru, and Ir by the USGS in Denver, Colorado with the idea that such chromitites are likely sources for the PGM found in the rock pan concentrate samples.

The rock samples can be grouped into sheared ultramafic rocks from which PGM had been panned (serpentinites after olivine-rich lithologies and pyroxenites); undeformed cumulate ultramafic rocks (complete lithologic range from olivine cumulate to augite cumulate); the schlieren chromitite sample; and a variety of mineralized rocks (andesites, tonalite/diorite, gneiss) that could be a source for Au and possibly PGM. In addition, two of the samples of the sheared ultramafic rock from which PGM had been found in "rock pan concentrates" were split prior to analysis to help interpret whether the PGM occurred in situ the rock or in the fines (possibly representing trapped alluvial particles in fractures in the sheared bedrock). One sample split was submitted as collected in the field; the other was washed to remove all adhering mud, soil, clay, and gouge from the rock fragments, which were then submitted for analysis. The rationale would be as follows: (1) if results for both samples were high in Pt, the PGM were likely to be in the rock, or (2) if the unwashed sample had high Pt and the washed sample had low Pt, then the PGM were in the fine fraction - either an particles in the gouge or trapped alluvial particles.

Table 12. Platinum, palpadium, and gold analyses of rock samples, Riam Pinang area, South Kalimantan. [Analyses by P.T. Geoservices, Bandung]

SAMPLE	Au (ppb)	Pt (ppb)	Pd (ppb)	SAMPLE DESCRIPTION
RMP 89029 R	7.0	24	21	tectonized websterite
RMP 89050 R	2.8	7	5	tectonized websterite 1-2 mm pyrrhotite veinlets
RMP 89002 R	5.4	11	7	olivine cumulate
RMP 89145 R	2.1	28	4	olivine cumulate
RMP 89056 RD	11.4	24	24	layered olivine cumulate/olivine-augite cumulate with chromitite lens
RMP 89177 R	8.6	22	2	olivine-augite cumulate
RMP 89091 R	< 0.1	8	4	fine-medium grained augite cumulate
RMP 89064 R	1.6	35	4	crushed sample of friable, sheared serpentinite. PGM found in pan concentrate
RMP 89087 R	6.2	23	3	crushed sample of sheared serpentinite PGM found in pan concentrate
RMP 89090 RA	1.1	24	3	crushed, washed sample of sheared serpentinite. Thin section shows rock was dunite. PGM found in pan concentrate
RMP 89090 RB	< 0.1	28	1	unwashed crushed sample of sheared serpentinite
RMP 89137 R2A	0.6	10	4	crushed, washed sample of serpentinite after dunite
RMP 89137 R2B	1.9	< 5	4	unwashed crushed sample of sheared serpentinite
RMP 89206 R	2.1	32	2	crushed sample of sheared serpentinite after dunite; 3% disseminated chromite

Table 12. continued.

SAMPLE	Au (ppb)	Pt (ppb)	Pd (ppb)	SAMPLE DESCRIPTION
RMP 89094 R	4.8	21	3	very altered medium grained augite cumulate
RMP 89095 R	6.8	38	8	very altered medium grained augite cumulate
RMP 89136 R	0.7	18	4	altered medium grained augite cumulate
RMP 89141 R	4.0	< 5	11	slightly sheared "pyroxene peridotite/pyroxenite"
RMP 89163 R	3.2	14	2	extremely altered augite cumulate
RMP 89173 R1	< 0.1	9	9	crushed sample of sheared augite cumulate
RMP 89047 R	35.0	< 5	4	hornblende andesite porphyry with 5-10% pyrite
RMP 89058 R	9.4	< 5	3	silicified dioritic rock whitish green, fine-grained, with disseminated pyrite
RMP 89166 R	16.7	21	12	augite-hornblende andesite porphyry with 3 - 5% disseminated pyrite
RMP 89093 R	0.8	90	3	fine-medium grained tonalite; altered feldspar and ferromagnesian minerals; coated with black and red hematite
RMP 89104 R	49.6	< 5	4	very altered and weathered tonalite?
RMP 89056 RC	10.2	< 5	4	coarse-grained hornblendite from tonalite/ultramafic contact
RMP 89054 RF	10.1	< 5	6	spongy Fe-oxide concretions from soil developed on small skarn occurrence; Au panned from crushed rock.
RMP 89071 R	7.3	< 5	3	quartz-chlorite-(garnet) schist with 2-3% disseminated pyrite (local areas to 30%)

Table 13. Platinum, palladium, and gold analyses of stream sediment samples, Riam Pinang area, South Kalimantan. [Analyses by P.T. Geoservices, Bandung]

SAMPLE	Au (ppb)	Au (ppm)	Pt (ppb)	Pt (ppm)	Pd (ppb)
RMP 89008 S	63.3	---	10	---	8
RMP 89009 S	98.9	---	24	---	13
RMP 89011 S	52.0	---	25	---	11
RMP 89020 S	88.0	---	10	---	5
RMP 89021 S	61.1	---	26	---	12
RMP 89023 S	87.0	---	37	---	16
RMP 89027 S	85.5	---	< 5	---	4
RMP 89037 S	50.3	---	40	---	22
RMP 89038 S	50.7	---	35	---	19
RMP 89039 S	92.0	---	30	---	18
RMP 89041 S	51.1	---	19	---	13
RMP 89042 S	30.6	---	> 200	0.394	8
RMP 89044 S	61.2	---	100	---	4
RMP 89051 S	74.4	---	42	---	16
RMP 89057 S	96.9	---	14	---	3
RMP 89058 S	78.9	---	7	---	2
RMP 89065 S	23.8	---	9	---	2
RMP 89067 S	18.1	---	< 5	---	3
RMP 89068 S	10.6	---	< 5	---	1
RMP 89091 S	95.4	---	138	---	8
RMP 89100 S	9.8	---	5	---	1
RMP 89147 S	> 100.0	0.121	< 5	---	2
RMP 89166 S	79.5	---	< 5	---	23
RMP 89084 S	> 100.0	0.130	44	---	21
Detection limit	0.1	0.005	5	0.005	1

Table 14. Platinum, palladium, and gold analyses of pan concentrate samples, Riam Pinang area, South Kalimantan. [Analyses by P.T. Geoservices, Bandung]

SAMPLE	Au (ppb)	Au (ppm)	Pt (ppb)	Pt (ppm)	Pd (ppb)
RMP 89008 P	> 100.0	0.584	10	---	7
RMP 89009 P	2.4	---	6	---	6
RMP 89011 P	5.6	---	< 5	---	3
RMP 89020 P	> 100.0	18.300	16	---	4
RMP 89021 P	69.0	---	7	---	6
RMP 89023 P	24.1	---	> 200	0.255	11
RMP 89027 P	> 100.0	34.500	12	---	4
RMP 89037 P	> 100.0	0.126	15	---	5
RMP 89038 P	1.2	---	< 5	---	2
RMP 89039 P	> 100.0	0.383	> 200	72.100	33
RMP 89041 P	> 100.0	1.210	> 200	1.250	22
RMP 89042 P	> 100.0	1.430	> 200	85.900	7
RMP 89043 P	58.3	---	110	---	11
RMP 89044 P	> 100.0	13.400	> 200	0.344	5
RMP 89045 P	> 100.0	1.960	80	---	4
RMP 89046 P	> 100.0	31.400	136	---	14
RMP 89051 P	62.6	---	5	---	2
RMP 89057 P	> 100.0	0.224	< 5	---	4
RMP 89058 P	> 100.0	3.660	> 200	1.380	2
RMP 89065 P	> 100.0	2.070	> 200	5.300	4
RMP 89066 P	> 100.0	1.440	> 200	3.420	1
RMP 89067 P	> 100.0	4.370	> 200	0.813	1
RMP 89068 P	> 100.0	6.650	143	---	< 1
RMP 89076 P	> 100.0	291.30	7	---	2
RMP 89088 P	> 100.0	41.400	> 200	0.264	< 1
RMP 89089 P	> 100.0	0.136	75	---	< 1

The sheared ultramafic rocks have low Pt, Pd, and Au contents, indistinguishable from the undeformed ultramafic lithologies (Table 14). Pt, Pd, and Au contents are appropriate for unmineralized ultramafic rock (Gray and others, 1986). Pt, Pd and Au analyses for the other sulfide-bearing hydrothermal occurrences in the area are also low. These results initially suggest that the sheared ultramafic rocks are not anomalous in their Pt contents. Alluvial entrapment of placer PGM in cracks or fractures in the ultramafic bedrock also is unlikely. The particles from the bedrock show no sign of alluvial transport and geologic investigations in December, 1989 show the particles occur at least 1 m below the bedrock surface. Alluvial deposits being tested by local miners a few 10's of meters from the rock pan concentrate pit did not contain PGM - only Au.

The chromitite schlieren from Trench 1 (90GLT 1/3) was anomalous in Pt (Figure 24). Analysis by NiS fire assay - inductively coupled mass spectroscopy yielded the following results: Pt - 580 ppb; Pd - 3.4 ppb; Rh - 10 ppb; Ru - 9 ppb; and Ir - 21 ppb. The chondrite normalized PGE pattern for this rock is characterized by elevated Pt and Ir contents and is similar to chromitites found in Alakan-type ultramafic intrusions (Figure 42). Chromitite schlieren made up approximately 11 percent of the analyzed rock sample; concentrations of Pt in the chromitite alone may exeed 5 ppm.

Table 15. Maximum, minimum and mean Pt, Pd and Au contents of rock samples from the Riam Pinang area, South Kalimantan.

Rock type	Number of samples	Pt (ppb)			Pd (ppb)			Au (ppb)			ID of samples in group
		max	min	mean	max	min	mean	max	min	mean	
Ultramafic rocks											
Tectonized websterite/ deformed olivine-augite cumulate	2	24	7	---	21	5	---	7.0	2.8	---	29R, 50R
Olivine cumulate	2	28	11	---	7	4	---	5.4	2.1	---	2R, 145R
Olivine/olivine-augite cumulate with chromitite	1	24	---	---	24	---	---	11.4	---	---	56Rd
Olivine augite cumulate	1	22	---	---	2	---	---	8.6	---	---	177R
Augite cumulate	1	8	---	---	4	---	---	< 0.1	---	---	81R
Sheared ultramafic rocks											
Serpentinite after olivine-rich rocks	7	35	6	22	4	1	3	6.2	< 0.1	2.2	64R, 87R, 90RA, 137RA, 174R1, 204R, 206R
Altered pyroxenites	6	38	< 5	17	11	2	5	6.8	< 0.1	3.3	94R, 95R, 136R, 141R, 163R, 173R1
Mineralized porphyries	3	21	< 5	10	12	3	6	35	9.4	20.4	47R, 166R, 58R7
Altered tonalites	2	90	< 5	---	4	3	---	49.6	0.8	---	93R, 104R
Gabbro	1	21	---	---	1	---	---	2.5	---	---	110R
Quartz-chlorite-(garnet) schist with disseminated sulfide minerals	1	< 5	---	---	3	---	---	7.3	---	---	71R
Hornblendite	1	< 5	---	---	4	---	---	10.2	---	---	56Rc
Weathered skarn	1	< 5	---	---	6	---	---	10.1	---	---	54Rf

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Figure 42. Chondrite normalized PGE diagrams for sample 90GLT 1/3, chromitites, and placer concentrates from mafic and ultramafic rocks. A.) Sample 90GLT 1/3 (this report) and chromitite from Tulameen Complex (Talkington and Watkinson, 1986). B.) PGM concentrates from Goodnews Bay, Alaska and Big Flat, Choco district, Columbia (Mertie, 1969). C.) Pt-enriched A-chromitite, Stillwater Complex, Montana (Talkington and Lipin, 1986). D). UG-2 chromitite, Bushveld Complex, South Africa (Gain, 1985). E.) Podiform chromitites, Bobaris Range, Kalimantan (this report). F.) Pt-enriched podiform chromitites, Bobaris Range, Kalimantan (this report). G.) Pt-enriched podiform chromitites, Rattlesnake Creek terrane, California (Page and others, 1986) and White. H.) Pt-enriched podiform chromitite, Unst ophiolite, U.K. (Prichard and others, 1986).

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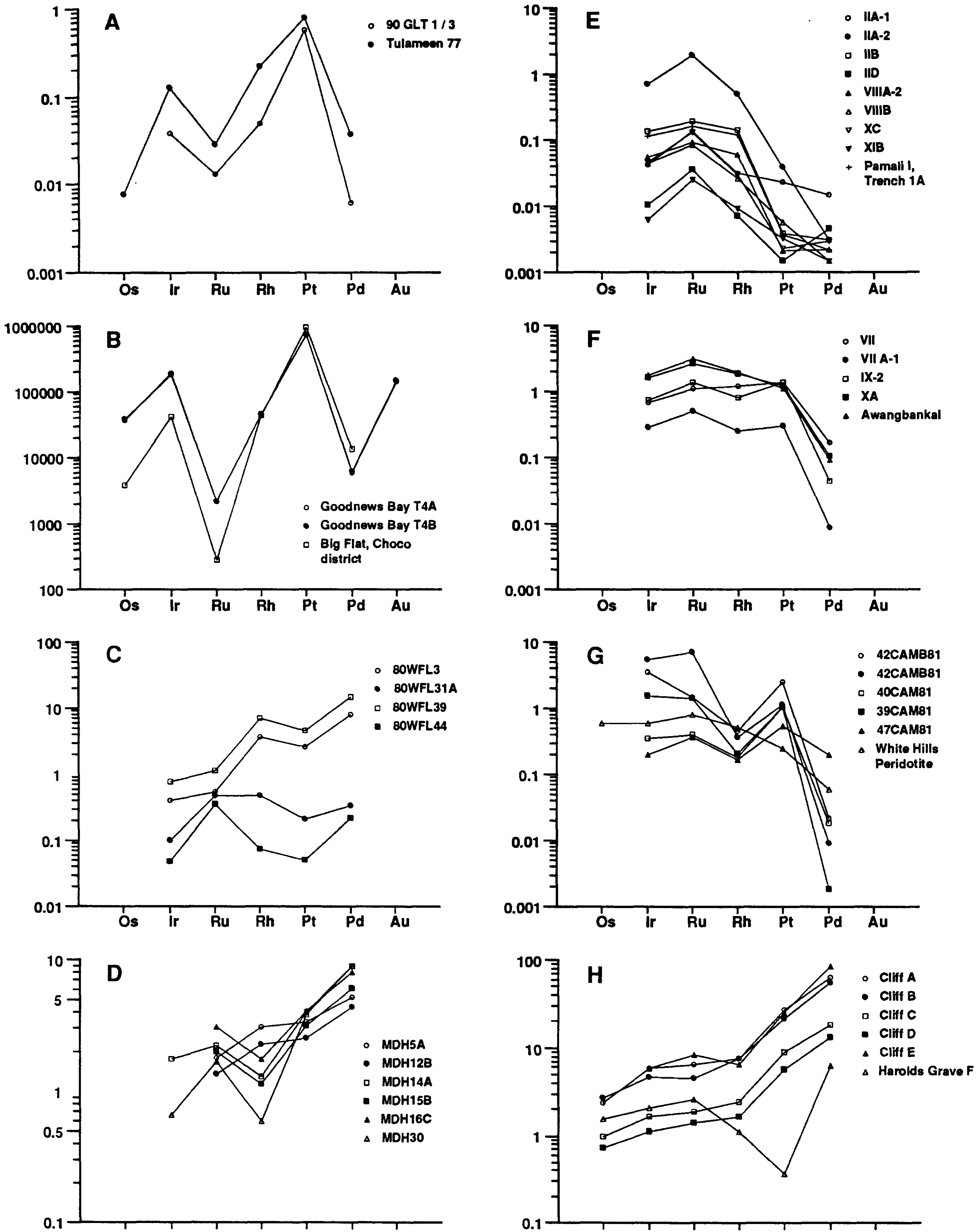
A
1
0.1
0.01
0.001
Os
Ir
Ru
Rh
Pt
Pd
Au
○ 90 GLT 1 / 3
● Tulameen 77
B
1000000
100000
10000
1000
100
○ Goodnews Bay T4A
● Goodnews Bay T4B
□ Big Flat, Choco district
C
100
10
1
0.1
0.01
○ 80WFL3
● 80WFL31A
□ 80WFL39
■ 80WFL44
D
10
5
1
0.5
0.1
○ MDH5A
● MDH12B
□ MDH14A
■ MDH15B
▲ MDH16C
△ MDH30
E
10
1
0.1
0.01
0.001
○ IIA-1
● IIA-2
□ IIB
■ IID
▲ VIIIA-2
△ VIIIB
▽ XC
▼ XIB
+ Pamali I, Trench 1A
F
10
1
0.1
0.01
0.001
○ VII
● VII A-1
□ IX-2
■ XA
▲ Awangbankal
G
10
1
0.1
0.01
0.001
○ 42CAMB81
● 42CAMB81
□ 40CAM81
■ 39CAM81
▲ 47CAM81
△ White Hills Peridotite
H
100
10
1
0.1
○ Cliff A
● Cliff B
□ Cliff C
■ Cliff D
▲ Cliff E
△ Harolds Grave F

These results suggest that the PGM in the sheared ultramafic rocks in the S. Rambas prospect are associated with small chromitite schlieren such as found in Trench 1. The PGM found in the rock pan concentrates probably were derived from chromitite schlieren in the dunite that were disaggregated by shearing. The low Pt assays for samples of the sheared ultramafic rock from which PGM are consistently panned most likely represent a sampling problem created by the very large size of the particles and their inhomogeneous distribution in the rock. Very large PGM particles (>1 mm) create sampling problems when splits are taken of the rock for assay. High values for Pt would result only if one or more of the large particles end up in the split to be analyzed. Second, the PGM are not uniformly distributed in the rock. They appear to be concentrated in thin chromitite lenses or schleiren which random samples of rock do not adequately represent. This indicates that it will be very difficult to determine the average concentration of PGE in the rock Panning approximately 0.03 m^3 of crushed material yielded several mm^3 of PGM. This would suggest grades on the order of a ppm; much higher than the 10's of ppb determined by analysis of the sheared ultramafic rock and close to the value determined for the rock sample containing the chromitite schlieren. Reconciliation of this problem by additional sampling and analysis is necessary. It is suggested that large rock specimens be collected, weighed, and crushed to less than 0.5 mm. This crushed rock could then be panned and the concentrate observed, weighed, and sent for assay. Approximate grades could be calculated from the weight/volume relationships. The purpose of such an exercise is to preconcentrate the coarse PGM from a large sample into a small enough sample that could be analyzed without splitting.

Only three of the stream sediment samples are slightly anomalous in PGE (the highest containing 394 ppb Pt, followed by 138 and 100 ppb, Table 13). The rest of the samples have less than 44 ppb Pt and 23 ppb Pd. Au values are typically higher, averaging 90 ppb, with a high value of 130 ppb.

The results for the pan concentrate samples are more informative (Table 14 and Plate 17). Pt contents ranged from < 5 ppb to 85.9 ppm. Fifty percent of the samples had more than 107 ppb Pt; 25 percent had greater than 1250 ppb Pt. Au contents ranged from 1.2 ppb to 291.3 ppm. Fifty percent of the samples had greater than 1.43 ppm Au; 25 percent had greater than 13.4 ppm Au. There is not a one to one correspondence of high Pt and Au (as would be expected if they come from different sources). Pd contents are all low, less than 33 ppb.

Generally, high concentrations of Pt were present in pan concentrate samples from the S. Rambas area. However, two samples with Pt values in the upper 25 percent of the population occur outside the S. Rambas area, in streams that flow westward from ultramafic cumulates exposed in the Pematang Kuliling range. The samples did not contain visible PGM in the field. Follow-up surveys were conducted in three other drainages in this area to extend areal coverage of samples: 1) a tributary of S. Irang from which an anomalous sample was previously collected, 2) a tributary of S. Riam Pinang that is subparallel to and the next drainage north of S. Kineet, and 3) the upper reaches of S. Buluhlembox. The geology observed in 2) was consistent with previous interpretations. However, no dioritic rocks were found in the upper part of S. Beluhlembox and no ultramafic outcrop or float was found in the tributary of S. Irang. PGM were also not observed in the six pan concentrate samples collected. Results for these pan concentrate samples are pending.

A pan concentrate sample anomalous in Pt came from the tributary with S. Irang, alluvial lanrite has been recovered by local miners from the main channel of S. Tambanio just upstream of S. Beluhlembox, and placer PGM has been observed in pan concentrate samples in the S. Tambanio upstream of S. Irang. With the geologic observations made in the S. Irang tributary , there apparently are no exposures of ultramafic rock in the drainage basins north of the intersection of S. Buluhlembox and S. Tambanio. The source for the PGM in these drainage basins is unknown.

Comparison of exploration methods, Riam Pinang area

Four methods were used to collect information about the distribution of PGM in the Riam Pinang area: (1) recording size and number of particles of PGM in pan concentrate samples as seen in the field, (2) microscopic investigation of the mineralogy of the pan concentrate samples and recording the number and sizes of PGM and Au particles as well as determining the percentages of all other minerals, (3) Pt, Pd, and Au analyses of stream sediment samples, (4) Pt, Pd, and Au analyses of pan concentrate samples. The two most valuable methods are recording the PGM seen in pan concentrate samples in the field and Pt, Pd, and Au analyses of pan concentrate samples.

The report on microscopic investigation of the pan concentrate samples gave useful but mixed results. The results are useful because PGM were seen in some concentrates in which none were noted in the field and the other mineralogical information (presence of olivine, diamond, chromite) were crucial to recognizing the elevated alluvial source area in the area mapped as schist and gneiss. The results are disturbing because the petrographer saw PGM in only 20 percent of the pan concentrate samples in which PGM were seen in the field. In the 20 percent of the samples where the field investigator and petrographer both saw PGM, the petrographer saw fewer grains (Figure 43). Results for Au generally were more consistent between field and laboratory observations. One reason for this discrepency could be the processing steps used in studying the pan concentrate samples. The concentrates are divided into strongly magnetic, moderately magnetic, and non-magnetic fractions using a hand magnet. The non-magnetic fraction is where Au and some of the PGM are concentrated. If the strongly magnetic fraction were not carefully examined (generally because it consists solely of magnetite) ferromagnetic PGM would be overlooked. The implications of missed PGM go beyond this study. DMR has conducted numerous mineral surveys in many areas. Although the surveys were not done for PGM, detailed mineralogical reports of pan concentrate samples could identify new occurrences of PGM. However, if the reports are likely to miss 80 percent of the PGM, then they can only be used as a positive indication when PGM are reported. The absence of PGM in the pan concentrate sample laboratory reports could not be used to rule out areas.

The stream sediment data generally were less informative than that for the pan concentrate samples. Practical experience has shown stream sediment samples to be more useful than pan concentrate surveys for gold because of the fine grain size of gold in many deposits and lack of entrapment of the small particles. Studies of disseminated Au deposits in Nevada show that in unoxidized (sulfide-bearing) ore; the Au is difficult to extract by leach methods; in part because it is still "locked up" with the sulfide minerals. In oxidized ores, the Au particles occurs in Fe-oxides - the oxidation product of the sulfide minerals. The Au is available for leaching and also could be transported as free gold particles of very small size in alluvial settings. Panning would not concentrate these small particles efficiently, therefore analyses of stream sediment samples are more likely to detect the presence of Au. However, what we know about the PGM in south Kalimantan suggests that they occur as larger particles or when very small, occur as inclusions in chromite. Chromite is quite stable in the alluvial and weathering environment thus abundant, small micron size free particles of PGM are less likely to be present. Panning would concentrate both the coarser-grained PGM particles as well as chromite which may contain the smaller 10's of micron sized PGM.

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Figure 43. Comparison of PGM and Au observed in pan concentrate samples in the field and the laboratory.

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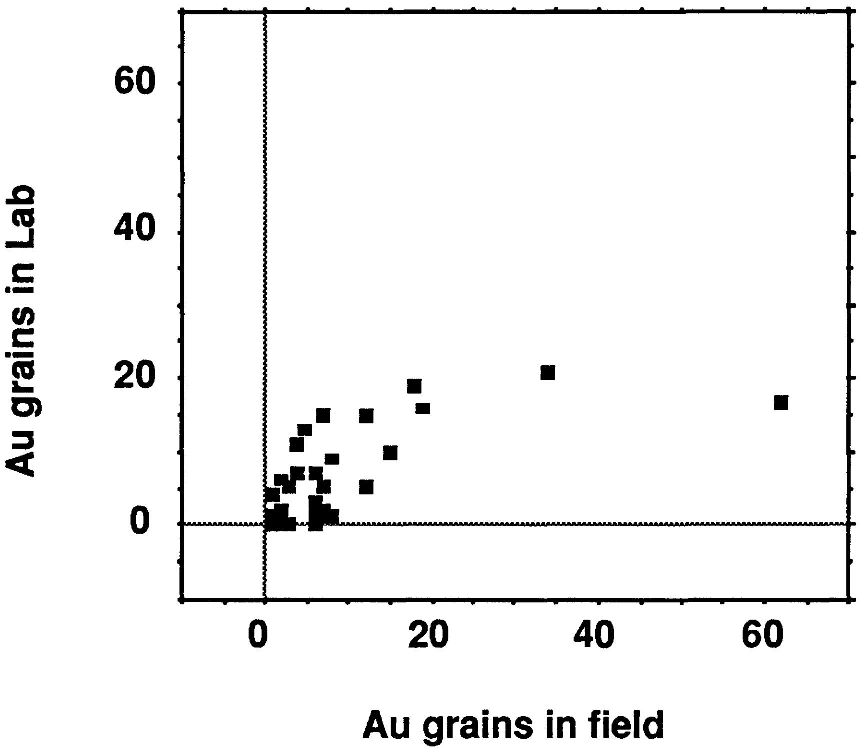
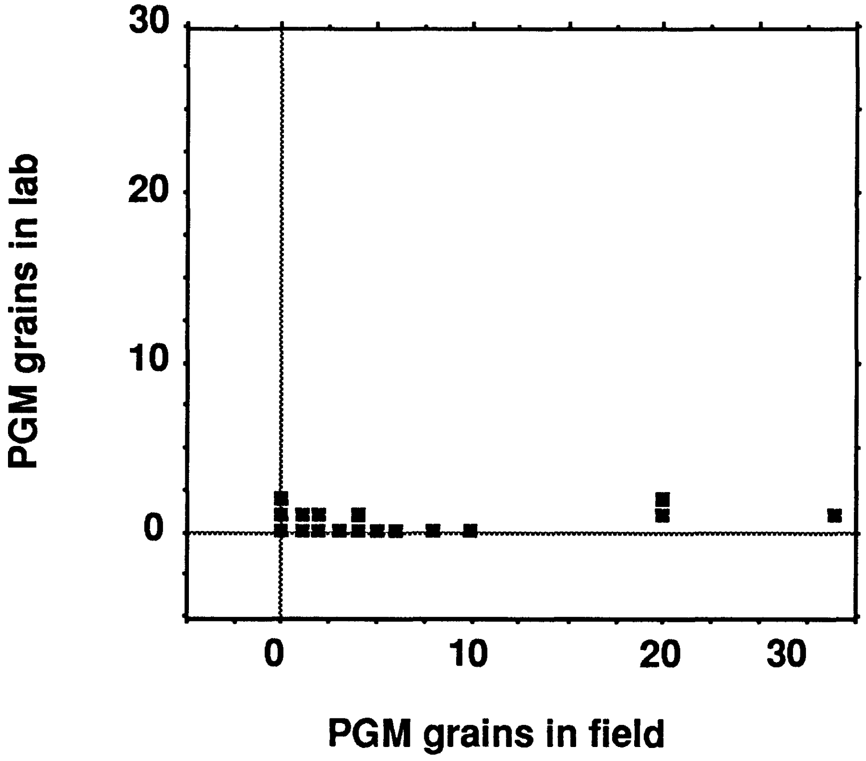

Au grains in Lab
60
40
20
0
0
20
40
60
Au grains in field


PGM grains in lab
30
20
10
0
0
10
20
30
PGM grains in field

The nature of the PGM mineralization in the S. Rambas prospect area is still not clearly defined. This results from poor exposure in the prospect area, biased sampling, and few analyses of rock. What is currently known is that millimeter sized PGM can occasionally be found in olivine-rich ultramafic rock that is sheared enough to be crushed and panned. The few samples of sheared pyroxenite that have been panned do not yield PGM. The PGM are very angular, commonly with pitted or molded surfaces, and commonly contain inclusions of euhedral chromite. One small chromitite segregation found in relatively undeformed olivine cumulate is enriched in Pt. Analyses of the sheared ultramafic rocks indicate very low Pt contents (10's of ppb). The probable origins and controls of the mineralization are summarized in order to direct future investigations.

HOST ROCKS

PGM has only been recovered from sheared olivine-rich ultramafic rock. The shearing probably have nothing to do with the formation of the PGM but only facilitates sampling and panning. The olivine-rich ultramafic rocks appear to form discontinuous lenses in the augite cumulates. The geology in the vicinity of Trenches 6 and 7 clearly show these dunites do not form continuous cumulus layers but instead form discontinuous bodies. In the cumulus succession exposed on the west flanks of Pematon Kuliling, olivine cumulate grade upwards into a succession of layered olivine-augite cumulates which in turn are overlain by augite cumulates. The lack of layered olivine-augite cumulates in the contacts between olivine cumulate and augite cumulate in the S. Rambas area also argues against the dunites being part of a layered cumulus succession. An intrusive origin is supported by the relations seen in Trench 3, in which the olivine cumulate contains numerous unoriented inclusions of augite cumulate and olivine-augite cumulate. The latter lithology is not exposed in situ in any nearby outcrops. A likely interpretation is that the olivine-rich ultramafic rock represent a discordant intrusions carrying xenoliths of older pyroxenite and wehrlite. Auger-drilling or test-pitting on a regular spacing would be required to establish the shape, size, and position of these intrusive olivine cumulates.

PGM ASSOCIATION

It appears that the PGM are located in the dunite bodies most likely concentrated in chromitite schlieren. From textural studies of the PGM, it is obvious they were associated with chromite when in situ. Concentrations of chromite have only been found in Trench 1, and it was clearly a small, discontinuous segregation. More chromite concentrations may be present but obscured by the serpentine coatings on fracture and slip surfaces. The anomalous Pt assay for the chromitite schlieren justifies the assumption that the PGM are associated with chromite segregations and that these segregations are small and widely and irregularly dispersed throughout the olivine cumulates. The presence or absense of PGM in the sheared ultramafic rock would be related to whether or not small chromitite segregates were present or not. Analyses of the sheared ultramafic rock would only run high Pt if the small sample collected happened to contain one of the segregations or a large PGM associated with the chromitites. The next task will be to establish the size, shape, and pattern of distribution of chromitite segregations in the dunite. This can be established by continuous channel sampling with PGE and, perhaps, Cr analyses of the samples. Determining the grade of the rock is complicated by sampling problems. One approach to determine the tenor of the rock would be to take relatively large rock samples, measure their size/weight, crush the rocks, create a heavy mineral concentrate, measure the weight/volume of the concentrate, and analyze the concentrate for PGE. Then use the weight/volume relations to calculate the actual tenor in the rock.

With all the information collected to date, this prospect most closely resembles the PGE-enriched chromitite segregations known to occur in olivine cumulates of Alaskan-type ultramafic complexes.

One problem remaining is the source of alluvial PGM found in the gravels overlying the metamorphic rocks northwest of the in-site PGM occurrences at S. Rambas, and the alluvial PGM, particularly laurite, found in S. Tambanio north of the intersection with S. Beluhlembox. The PGM particles are rounded, suggesting significant transport. Higher olivine and chromite in pan concetrate samples suggest an ultramafic source. Laurite, of the size found, is not known from the in-situ occurrences in the S. Rambas prospect area. The solution to the problem probably will require a detailed geologic and geomorphic analysis to determine the distribution, origin, and provenance of elevated gravel deposits such as found at S. Rambas.

Summary and Recommendations for Additional Work in the Riam Pinang Area

The PGM in the S. Rambas area appear to be associated with chromitite schlieren in discordant olivine cumulate intrusions in augite cumulate; the occurrence has many similarities to deposits found in Alaskan-type ultramafic intrusions. The interpretation of a hydrothermal, shear zone associated, primary PGE deposit in the S. Rambas area was not supported by follow-up investigations. Future investigations should focus on the distribution of the olivine-rich intrusions in the pyroxenite, the distribution of chromitite schlieren in the olivine-rich intrusions, and overcoming sample problems in order to determine the tenor of the rock

A poorly exposed and highly weathered area within the schist and gneiss unit yielded PGM, olivine, chromite, and one diamond in pan concentrate samples. This area is upstream from the sheared ultramafic rock and is a likely secondary source of the PGM. Investigations should be undertaken to determine the nature and areal extent of this source, which appears to be PGM-bearing alluvial gravels occuring on the ridge, approximately 25 - 30 m above the terraces near the modern drainage. In terms of planning regional exploration programs for PGM at the other 4 permissive areas defined in the resource assessment, it is critical to know how widespread are the elevated gravels that are contributing PGM to pan concentrate samples on the ridge in the S. Rambas area. Further investigations should establish the extent and grade of these deposits by mapping, auger drilling or test pitting in the area.

Anomalous samples outside the detailed S. Rambas area should be validated and followed up by geologic mapping and more extensive sampling.

OTHER PERMISSIVE AREAS

In a reconnaissance survey, samples of PGM-bearing concentrates should be obtained from each of the drainages suspected to contain Au-PGM placers. This would verity the occurrence and provide material for mineralogical investigation (PGE mineralogy, degree of rounding, inclusion relationships). Seven element PGE analyses of concentrates may again be used to fingerprint the source. Surveys of the other permissive areas should be planned in accordance with the results of the follow-up work at S. Rambas area and the reconnaisance studies outlined above.

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APPENDIX A: OUTLINE OF LECTURE NOTES FOR A COURSE IN PLATINUM-GROUP ELEMENT DEPOSITS AND ENVIRONMENTS

M.L. Zientek, N.J Page, D.L. Mosier, J.A. Peterson, and R.R. Carlson

U.S. Geological Survey

DAY 1: Introduction to platinum-group elements as commodities, their chemical behavior, mineralogy, and geochemical cycle

I. Design of course, purpose, and content

II. Definition of PGE vs PGM

- A. Conversion data:
  1 troy ounce (tr. oz) = 31.103481 gram (g)
  1 kilogram (kg = 32.150742 tr. oz.
  1 part per billion (ppb) = 0.001 part per million (ppm)
  1ppb = .000032 oz/ton
- B. Chondrite normalized data:
  1. Old values used in literature: Pd = 1200 ppb; Pt = 1500 ppb; Rh = 200 ppb; Ru = 1000 ppb; Ir = 500 ppb; Os = 700 ppb (Naldrett and Cabri, 1976a)
  2. New values used in literature: Pd = 545 ppb; Pt = 1020 ppb; Rh = 200 ppb; Ru = 690 ppb; Ir = 540 ppb; Os = 514 ppb; Au = 152 ppb (Naldrett and Duke, 1980)
- C. Properties: resistance to corrosion and oxidation at elevated temperatures, electrical conductivity; superior catalytic activity

III. Discovery (Collender, 1987)

1748, Choco district, Colombia
1748-1750, Brownrigg and Watson
1805, Wollaston; Smithson Tennant
1827, Osann
1845-1847, Klaus

IV. Early Mining History (Collender, 1987)

1748, Colombia
1824, Urals
1831, Kalimantan (Borneo)
1887, Canada
1892, South Africa, Os-Ir
1925, South Africa, Merensky Reef
1987, Montana, USA, JM Reef

V. Production

1774-1950, Quiring (1962)
1950-1987, U.S. Bureau of Mines Mineral Yearbook
1977-1986, Robson (1987)

VI. Demand

1977-1988, Smith (1989)

VII. Prices

Smith (1989), U.S. Bureau of Mines Mineral Yearbooks

VIII. Physical Properties of PGE - Westland (1981)

IX. Uses

- A. Chemical and laboratory
- B. Electrical/Electronic
- C. Jewelry and decoration
- D. Dental and medical

X. Estimated resources and reserves. USBM/USGS Commodity Summaries (1988)

XI. Chemical properties
A. Thermodynamic properties (Westland, 1981)
B. Reactivity toward common reagents
C. PGE and oxygen
D. Simple compounds
E. Solution species

XII. PGE complexes in hydrothermal fluids (Wood, 1987; Mountain and Wood, 1988)
A. Unlikely complexes for transport-carbonate, bicarbonate, sulfate, phosphate, fluoride, Br^-, I^-, CN^-, NO_2^-, SCN^-, $S_2O_3^{-2}$, SO_3^{-2}, polysulfides
B. Likely complexes-chloride, hydroxide, ammonia, bisulfide
C. Solubility of Pt and Pd sulfides, selenides, tellurides, arsenides
D. Aqueous chemistry of Ru, Rh, Os (Westland, 1981)
E. Volatility of PGE in fluids at magmatic temperatures (Wood, 1987)

XIII. Phases and phase relations of PGE (Berlincourt and others, 1981)
A. Uniary phases
B. Binary phases
C. Ternary and Quaternary phases
D. Solubility of PGE in other minerals (Makovicky and others, 1986)

XIV. Mineralogy of PGE (Cabri, 1981)
A. Post 1959 expansion in the number of known minerals
B. Alloys (Cabri and Feather, 1975; Harris and Cabri, 1973)
C. Sulfides (Cabri and others, 1978)
D. Tellurides
E. Arsenides
F. Antimonides
G. Bismuthides
H. Stanides
I. Arsenic-sulfur
J. Arsenic-antimony
K. Antimony-tellurium
L. Bismuth-tellurium
M. Bismuth-arsenic
N. Mercury-tellurium
O. Selenides
P. Lead
Q. Mercury

XIX. General geochemical cycle
Mantle-rocks-oceans-biosphere

DAY 2: Mineral deposit models (Cox and Singer, 1986)

I. Model concept
    Various types: genetic, descriptive, splitters and lumpers

II. Descriptive ore deposit model
- A. Name for type of deposit
- B. Synonyms
- C. Reference
- D. Description of environment of the deposit
  1. Host rocks
  2. Associated rocks
  3. Tectonic setting
  4. Associated mineral deposits
- E. Description of the deposit
  1. Mineralogy
  2. Texture of ore
  3. Alteration
  4. Ore controls
  5. Effects of weathering
  6. Geochemical and geophysical signature
- F. Examples

III. Geologic environments used in classification of models

IV. Grade-tonnage models
- A. Construction techniques
- B. Uses

V. Purposes of models

VI. Other types of models - Mineral deposit density, exploration, and discovery models

DAY 3: Mineral resources assessment process

I. Introduction-based on a course developed by W. Menzie, W. Bagby, N. Page of USGS
  A. Viewpoint from economics, statistics, geology
  B. Concentrate on undiscovered resources
  C. Basic concept-three-step assessment
  D. Relation of assessment to exploration

II. What is a mineral-resource assessment?
  A. An estimation of the amounts of mineral resources in an area
  B. Many methods (Singer and Mosier, 1981)

III. Geologically-based resource assessment
  A. Assessment process parallels exploration
  B. Three-step assessment
  C. Mineral resource map
  D. Domain delineation

IV. Delineation of ore deposits in accreted tectonostratigraphic terranes
  A. Definitions: accretion, tectonostratigraphic terrane, stratigraphic terrane, disrupted terrane, metamorphic terrane
  B. Identification of accreted terranes
    1. Discriminating terranes-characteristics
    2. Terrane boundaries
    3. Features
  C. Temporal development of terranes
    1. Pre-accretion-ophiolites, island arcs, other assemblages
    2. Syn- and post-accretion-subduction, intrusive igneous rocks development, associated hydrothermal systems, overlying volcanic fields, erosion
  D. Deposits associated with accreted terranes
    1. Pre-accretion
    2. Syn- to post-accretion
    3. Post-accretion
  E. How to delineate by deposit types

V. Estimation of number of undiscovered deposits
  A. Factors that affect estimations-use, available data, exploration
  B. Expert judgment methods-subjective probability
    1. Pitfalls
    2. Success of forecasters
    3. How to do
  C. Mineral deposit density
    1. Number of deposits per unit area with restricted geologic criteria
    2. Low sulfide-gold-quartz veins (Bliss and others, 1987)
    3. Podiform chromite (Page and Johnson, 1977)
  D. Statistical methods
    1. Frequency distributions
    2. Regression methods
    3. Discriminant analysis
    4. Problems with statistical approaches

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DAY 4: Overview of mafic and ultramafic igneous rocks

- I. Classification of mafic and ultramafic rocks
  - A. Modal
    - 1. Streikeisen/IUGS (Streikeisen, 1973; Streikeisen, 1980)
    - 2. Cumulus nomenclature (Jackson, 1967; Irvine, 1982)
    - 3. Felsic rocks associated with massif anorthosites (Dewaard, 1969)
    - 4. Alkaline rocks (Sorensen, 1974)
  - B. Chemical
    - 1. General
      - a. Silica content (Williams and others, 1954)
      - b. SiO_2 vs K_2O (BVSP, 1981)
      - c. SiO_2 vs. $Na_2O + K_2O$ (Cox and others, 1979)
      - d. Alumina saturation (Shand, 1951)
      - e. Peacock's alkali-lime index
      - f. Streikeisen/IUGS (Streikeisen, 1976)
      - g. Irvine and Baragar (1971)
    - 2. Basalts
      - a. Basalt tetrahedron (Yoder and Tilley, 1962)
      - b. SiO_2 vs. $Na_2O + K_2O$ - tholeiitic vs. alkaline (Macdonald and Katsura, 1964)
      - c. Chayes (1966) - tholeiitic vs alkaline
    - 3. Alkaline rocks (Sorensen, 1974)
    - 4. Komatiites = ultramafic volcanic rocks (Arndt and Nisbett, 1982; Jensen, 1976)

- II. Textures of mafic and ultramafic rocks
  - A. Igneous (Barker, 1982)
    - 1. Degree of crystallinity
    - 2. Grain size
    - 3. Variations in grain size
    - 4. Grain shape
    - 5. Arrangement of nonequant grains
    - 6. Specialized jargon
      - a. Glomeroporphyritic
      - b. mortar texture
      - c. Poikititic
      - d. Interstitial
      - e. Intergranular
      - f. Ophitic/subophitic
  - B. Ores
    - 1. Abundance of sulfide or oxide minerals (Page, 1979)

- III. Structures within mafic and ultramafic igneous intrusions
  - A. Glossary of terms for layered intrusions (Irvine, 1987)
  - B. Primary or depositional structures
  - C. Post-depositional structures (Lee, 1981)

- IV. Igneous and tectonic associations of mafic and ultramafic rocks and associated ore deposits
  - A. Other classifications
    - 1. By geologic setting of the mafic/ultramafic rocks (Naldrett, 1979; Naldrett, 1982; Page and others, 1982; Naldrett, 1989)
    - 2. By the context of the mineralization in the host rock (Cabri and Naldrett, 1984; Hulbert and others, 1988)

B. This course
  1. Extensional or rift related magmatism
    a. Archean and Early Proterozoic greenstone belts (Windley, 1977; BVSP, 1981)
    b. Intracratonic rifts (BVSP, 1981)
    c. Accreting plate margins - mid-ocean ridges and back-arc basins (Coleman, 1977; BVSP, 1981)
  2. Subduction related or synorogenic magmatism
    a. Synorogenic intrusions (Read, 1982)
    b. Alaskan-type ultramafic intrusions (Irvine, 1974)
  3. Intracratonic or intraplate-related magmatism
    a. Stratiform intrusions (Vermaak and von Gruenewaldt, 1986; von Gruenewaldt and others, 1985; Czamanske and Zientek, 1985)
    b. Massif anorthosites (Emslie, 1985,1986)
    c. Alkaline complexes (Mutschler and others, 1985)
    d. Intrusion related to meteor impact (Pye and others, 1984)

V. Review of igneous processes relevant to the formation of magmatic PGE deposits
  A. Processes involved in the formation and development of layered igneous rocks (Irvine, 1987)
  B. Sulfide liquid exsolution and crystallization (Naldrett, 1989; Buchanan, 1988)
  C. Partitioning of chalcophile elements between sulfide and silicate melts (Naldrett, 1989)
  D. Controls on compositional variations of magmatic sulfide ores
    1. Internal zoning of deposits
      a. Compositional variability that is imposed upon a deposit (Naldrett, 1989)
    2. Relation between composition of ore and host magma (Naldrett, 1981)

DAY 5: Stratiform Mafic Intrusions

I. Bushveld Complex provides 46% of the world's supply of PGE, 72% of the world's production of Pt, and 82% of the world's resources of PGE (Wyllie, 1987; Naldrett and others, 1987, Sutphin and Page, 1986)

II. Bushveld Complex South Africa (Vermaak and von Gruenewaldt, 1986; von Gruenewaldt and others, 1985)
  A. Geologic setting
    1. Regional setting (Hunter and Reid, 1987)
      a. Emplaced into the Transvaal Sequence (Hatton and von Gruenewaldt, 1987)
      b. Division of the Bushveld Complex into 3 units (SACS, 1980)
      c. Exposures of layered mafic rocks - the Rustenberg Layered Suite (von Gruenewaldt, 1979)
    2. Age - Proterozoic (Rustenburg Layered Suite is approximately 2050 m.y. old; Vermaak and von Gruenewaldt, 1986; Hunter and Reid, 1987)
    3. Thickness and areal extent
      a. Total area 66,000 square km (Hatton and von Gruenewaldt, 1987)
      b. Total thickness 4.2 to 8.6 km (Walraven, 1986, SACS, 1980)
    4. Geophysical studies
      a. Mafic rocks do not extend into center of complex (Molyneux and Klinkert, 1978)
      b. Shows subsurface extensions of complex beneath younger cover (von Gruenewaldt, 1979)
  B. Stratigraphic relations
      1. Formal subdivisions recommended by SACS (1980) (see Walraven, 1986)
    2. Informal subdivision into five zones: marginal, lower, critical, main, and upper (Vermaack and von Gruenewaldt, 1986)
    3. Variation of mineral compositions with stratigraphic height
      a. Lower zone (Cameron, 1978; Hulbert and von Gruenewaldt, 1982)
      b. Lower Critical zone (Cameron, 1980)
      c. Upper critical zone (Cameron, 1982; Naldrett and others, 1986)
      d. Main and Upper zones (von Gruenewaldt, 1973; Vermaack and von Gruenewaldt, 1981)
    4. Lateral variations in stratigraphy
      a. Lower zone - very poor correlation between the major areas of the complex (Vermaack and von Gruenewaldt, 1981; Hulbert and von Gruenewaldt, 1982)
      b. Critical zone (Hatton and von Gruenewaldt, 1987; Naldrett and others, 1987)
    5. Transgressive relations
      a. With floor of complex (Naldrett and others, 1987)
      b. Main and Upper zones transgressing Lower and Critical zones (van der Merwe, 1976)
      c. Main zone transgressing Critical zones (Leeb-du Toit, 1986; Coertze, 1974)
  C. Parental magmas (Sharpe, 1981)
  D. Isotope geochemistry
    1. Discontinuities in initial Sr^{87}/Sr^{86} (Kruger and Marsh, 1982; Sharpe, 1985)
  E. PGE-Ni-Cu Mineralization
    1. Merensky Reef (Naldrett and others, 1987; Wyllie, 1987; Viljoen and Hieber, 1986; Viljoen and others, 1986a,b; Kinloch, 1982))
    2. Platreef (Gain and Mostert, 1982; Vermaack and von Gruenewaldt, 1981; Buchanan and others, 1981; Cawthorn and others, 1985; Barton and others, 1986; Buchanan 1987)
    3. UG-2 (Gain, 1985; Wyllie, 1987; Buchanan, 1987; McLaren and DeVilliers, 1982; Kinloch, 1982)

4. Volspirit pyroxenite - Lower zone mineralization (Hulbert and von Gruenewaldt, 1982)
5. Vlakfontein Ni pipes (Vermaak, 1976)
6. Hortonolite pipes (Wagner, 1929; Cameron and Desborough, 1964; Willemse, 1969; Stumpfl and Rucklidge, 1982; Schiffries, 1982)
7. Other PGE information
   a. Marginal rocks and sills (Sharpe, 1982; Davies and Tredoux, 1985)
   b. Lower and Lower Critical zones (Lee and Tredoux, 1986)
   c. Associated with chromitites (von Gruenewaldt and others, 1986)
   d. Main and Upper zones (Page and others, 1982)

III. Stillwater Complex, Montana, USA (Czamanske and Zientek, 1985)
   A. Geologic setting
      1. Regional setting (Page and Zientek, 1985)
      2. Age - Archean (approximately 2700 m.y.; Lambert and others, 1985)
      3. Thickness and areal extent
         a. 5.5 km of layered cumulates
         b. outcrop area approx. 40 by 6 km
      4. Geophysical studies
         a. Magnetics (Blakely and Zientek, 1985) shows units in complex
         b. Gravity (Kleinkopf, 1985) shows subsurface extent of the intrusion
   B. Stratigraphic relations (Zientek and others, 1985)
      1. Subdivision into 5 series - Basal, Ultramafic, Lower Banded, Middle Banded series, and Upper Banded
      2. Stratigraphic variation in mineral chemistry
         a. Basal series (Page and others, 1985a)
         b. Ultramafic series (Page and others, 1985; Raedeke and McCallum, 1985)
         c. Lower Banded series (Page and others, 1985)
         d. Banded series (Raedeke and others, 1985)
         e. An I and An II (Czamanske and Scheidle, 1985)
         f. Picket Pin section (Boudreau and McCallum, 1987)
   C. Parental magmas (Helz, 1985; Zientek and others, 1986)
   D. Isotope geochemistry (Lambert and others, 1985; Lambert and others, 1989)
   E. PGE-Ni-Cu mineralization (Page and others, 1985b)
      1. J-M Reef (Todd and others, 1982; Barnes and Naldrett, 1985; Zientek and others, 1990)
      2. Basal series (Page, 1979; Zientek and others, 1986)
      3. Picket Pin (Boudreau and McCallum, 1986)
      4. A chromitite (Talkington and Lipin, 1985)
      5. Sulfur isotopes (Zientek and Ripley, 1990)

DAY 6: Ophiolites and the PGE association

I. Overview: The purpose is to be able to identify permissive tracts for particular deposit types in ophiolites and define rules to draw the tracts on geologic maps.

II. Definition of an ophiolite

III. General structural, genetic, and emplacement observations and comments

IV. Ophiolite stratigraphy as viewed by igneous petrology (Coleman, 1977)
  A. Peridotites with tectonite fabric (Mercier and Nicolas, 1975)
    1. Mineralogy and petrography: xenoblastic granular harzburgite and dunite
    2. Chemistry: restricted range in compositions
  B. Cumulate complexes: sequences derived by fractional crystallization
    1. Structure - tabular shape, ultramafic cumulate section, transition zone, gabbroic part
    2. Mineralogy and petrography: adcumulate, poiklitic textures, variation in Fo and En contents with FeO enrichment
    3. Chemistry - variable due to number of rock types
  C. Dike complexes swarms, sheeted complexes of diabasic dikes
    1. Structure: asymmetric chilled margins, multiple subparallel dikes
    2. Mineralogy and petrography-fine-grained, ophitic textures, typically altered to albite, chlorite, epidotes, sphene, carbonate
    3. Chemistry: generally tholeiitic
  D. Extrusives: Normally submarine pillow lavas interlayed with pelagic sediments
  E. Leucocratic associated rocks: plagiogranite

V. Trace Element geochemistry (Coleman, 1977)

VI. Metamorphism (Coleman, 1977)
  A. Types of metamorphic changes: internal and external
  B. Hydrothermal alteration
  C. Metamorphic aureoles

VII. Associated ore deposits: pre- and post-accretion
  A. Pre-accretion deposit types
    1. Podiform chromite
      a. Synonym: Alpine type chromite
      b. Description: examples; John-Day, OR; Marais-Kiki mine, Gr2H, Anna-Madeline, New Caledonia (Leblanc, 1987; Cassard and others, 1981)
      c. Mineralogy
        i. Chromite (Dick and Bullen, 1984)
        ii. PGM (Auge, 1986, 1985, 1988; Burgath, 1988; Burgath and Mohr, 1986; Cabri, 1981; Constantinides and others, 1980; Legendre and Auge, 1988; Orberger and others, 1988; Stockman and Hiava, 1984; Ahmed, 1981; Talkington and Watkinson, 1986; Moring and others, 1987)
        iii. Laurite dominates
        iv. Others
      d. Chondrite normalized PGE patterns
        i. Oman (Page and others, 1982)
        ii. New Caledonia (Page and others, 1982)
        iii. Polar Urals (Page and others, 1983)
        iv. Newfoundland (Page and Talkington, 1984)
        v. India
        vi. Turkey (Page and others, 1984)

            - vii. North Fork of Smith, Ca-Or, USA
        - e. Tonnage-grade models
            - i. Minor podiform chromite (Singer and Page, 1986)
            - ii. Major podiform chromite (Singer and others, 1986)
        - f. Reconnaissance PGE evaluation of podiform chromite in California and Oregon (Page and others, 1986)
        - g. Origin of podiform chromite
        - h. PGE recovery problems
    - 2. Unst chromitite-PGE type deposits
        - a. Geologic maps
        - b. PGE mineralogy-most chromitite deposits same as others in the world but are 2 known exceptions (Prichard, 1987)
        - c. Rock analytical data and chondrite normalized patterns (Gunn and others, 1985)
    - 3. Acoje Ni-Cu-PGE (Orberger and others, 1988)
        - a. Description: disseminated to matrix magmatic sulfides in cumulus peridotites near contact with peridotite tectonite
        - b. Ore minerals
        - c. Tonnage/Grade characteristics
        - d. other possible examples
    - 4. Cyprus type massive sulfides (Oshin and Crocket, 1986)
    - 5. Volcanogenic manganese (Mosier and Page, 1988)
- B. Post- to syn-accretion deposits
    - 1. Limassol Forest Co-Ni and Bou Azer (Fisher and others, 1988; Leblanc, 1987; Leblanc and Lbouabi, 1988; Leblanc and Billaud, 1982; Panayiotou, 1980)
    - 2. Others

DAY 7: Archean greenstone belts and other rift-related environments

I. Introduction

II. Archean greenstone belts
  A. Komatiite-hosted nickel deposits (Lesher, in press)
    1. Nomenclature and classification
    2. Age and distribution
    3. Tectonic setting
    4. Stratigraphic setting
    5. Host units
    6. Mineralization
    7. Physical volcanology of host komatiites
    8. Ore genesis
    9. Exploration guides
    10. Examples
      a. Volcanic peridotite hosted deposits
        i. Kambalda, Yilgarn block, Australia (Cowden and others, 1986)
        ii. Abitibi belt, Canada (Arndt and Naldrett, 1987; Crocket and MacRae, 1986)
        iii. Tonnage/Grade curves (Cox and Singer, 1986)
      b. Dunite-hosted deposits
        i. Agnew, Yilgarn block, Australia (Barnes and others, 1988a,b; Hill and others, 1987)
        ii. Tonnage/Grade curves (Cox and Singer, 1986)
  B. Mineralization in layered intrusions in greenstone belts
    1. Bird River sill, Manitoba (Hurlbut and others, 1988; Scoates and others, 1987; Scoates and others, 1986)
      a. Geologic setting
      b. Stratigraphy
        i. Ultramafic series
        ii. Transition series (5 m)
        iii. Mafic series
      c. PGE Mineralization
        i. Lower group platinum-bearing unit
    2. Kanechee, Ontario (James and Hawke, 1984)
      a. Introduction and geologic setting
      b. Stratigraphy and modal variation
        i. Five igneous cycles
      c. Compositions of the parent magmas
      d. PGE Mineralization
        i. Geology of the ore zone
        ii. Mineralogy and distribution of the ore
        iii. PGE geochemistry (Naldrett, 1981)

III. Intracratonic rifts
  A. Aulacogens
    1. Permo-Triassic rift of the Noril'sk area (Genkin and others, 1982; Hulbert and others, 1988)
      a. Geologic setting
      b. Types of sulfide-bearing intrusions and the stratigraphic sequence in each
        i. Fully differentiated intrusions with horizons of basic and ultrabasic rocks
        ii. Differentiated leucocratic intrusions composed predominantly of basic rock, lacking well developed horizons of ultramafic rocks
        iii. Differentiated melanocratic intrusions composed largely of ultrabasic rocks

- c. Cu-Ni-PGE Mineralization
    - i. Introduction
    - ii. Distribution, types and mineral varieties of ores
    - iii. Sulfur isotopes (Grinenko, 1985)
    - iv. Zoning of the ore bodies
    - v. PGE geochemistry and minerals

2. Insizwa - Karoo rift (Lightfoot and Naldrett, 1984; Lightfoot and others, 1984; Maske and Cawthorn, 1986)
    - a. Geologic setting
        - b. Parental magma - low Mg parent (Lightfoot and others, 1984)
    - c. Stratigraphy
        - i. Basal zone
        - ii. Central zone
        - iii. Roof zone
        - iv. Variation in mineral compositions
    - d. Cu-Ni-PGE Mineralization
        - i. Introduction
        - ii. Types and distribution of ore
        - iii. Sulfur isotope data
        - iv. Ni contents of olivine
        - v. Ni-Cu mineralization
        - vi. PGE geochemistry
3. Crystal Lake gabbro - Keewanawan and mid-continent rift (Hulbert and others, 1988; Geul, 1970; Cogulu, 1985)
    - a. Introduction and geologic setting
    - b. Stratigraphy
        - i. Basal contact zone
        - ii. Lower unlayered zone
        - iii. Cyclic zone
        - iv. Upper zone
    - c. PGE Mineralization
        - i. Introduction
        - ii. Disseminated Cu-Ni-PGE sulfides in the Lower unlayered and contact zones
        - iii. PGE mineralization associated with Cr-spinel rich layers in the Cyclic zone
        - iv. S isotopes and S/Se
        - v. PGE geochemistry
4. Duluth Complex - Keewanawan and mid-continent rift (Weiblen and Morey, 1980; Naldrett, 1989)
    - a. Geologic setting
    - b. Stratigraphy
        - i. Nathan's layered series
        - ii. Anorthositic series
        - iii. Troctolitic series
        - iv. Felsic series
        - v. Minor units
    - c. Cu-Ni-PGE Mineralization (Listerud and Meineke, 1977)
        - ii. Disseminated to massive sulfide mineralization near the lower contact of Troctolite series intrusions (Bonnichsen, 1972; Bonnichsen and others, 1982; Dahlberg, 1987; Foose and Weiblen, 1986; Ripley, 1981, 1986; Ripley and Alawi, 1986; Mainwaring and Naldrett, 1977)
        - iii. Oxide-PGE anomaly in the South Kawishiwi intrusion (Sabelin and others, 1986)

- B. Rifted continental margins
  - 1. Mesozoic basins of the eastern United States
    - a. Geologic setting (Manspeizer and Consminer, 1988; Sutter, 1988)
    - b. Diabase types (de Boer and others, 1988)
      - i. Quartz normative (Froelich and Gottfried, 1988)
      - ii. Olivine normative
    - c. PGE anomaly
      - i. Postcumulus fractionation (Shirley, 1988)
      - ii. PGE geochemistry (Gottfried and Froelich, 1988; Gottfried and others, 1989)
  - 2. British-Greenland Tertiary province
    - a. Skaergaard Au-PGE anomaly
    - b. Rhum (Emeleus, 1987)
- C. Dike-like mafic complexes and mafic dike swarms
  - 1. Great Dyke, Zimbabwe (Worst, 1960; Wilson, 1982; Wilson and Prendergast, 1987)
    - a. Geologic setting (Podmore and Wilson, 1987; Wilson and Prendergast, 1989)
    - b. Longitudinal subdivision of the complex (Wilson and Prendergast, 1987)
    - c. Vertical subdivision of stratigraphy
      - i. Ultramafic Sequence (Prendergast, 1987)
      - ii. Mafic Sequence (Wilson and Wilson, 1981)
      - iii. Thicknesses
      - iv. Mineral fractionation patterns (Wilson, 1982; Podmore and Wilson, 1987)
    - d. Parental magmas
      - i. East Dike chill phase - approximately 15% MgO (Wilson, 1982)
    - e. PGE Mineralization - MSZ in P1 (Prendergast, 1988; Wilson and Prendergast, 1987)
  - 2. Muskox (T.N. Irvine in Hulbert and others, 1988)
    - a. Geologic setting (Irvine, 1980)
    - b. Stratigraphy
      - i. Keel dike
      - ii. Marginal zones
      - iii. Layered series (1800 m)
      - iv. Roof zone
      - v. Fractionation patterns and infiltration metasomatism
    - c. PGE Mineralization
      - i. Footwall contacts
      - ii. Chromite-rich layers

DAY 8: Synorogenic intrusions, zoned complexes, and others

I. Introduction

II. Synorogenic intrusions
  A. Southeast Alaska (Brew, 1988; Brew and Morrel, 1983)
    1. La Perouse Layered Gabbro (Loney and Himmelberg, 1983; Himmelberg and Loney, 1981; Czamanske, and others, 1981)
      a. Geologic setting
      b. Stratigraphy
        i. Cumulate rock types and crystallization orders
      c. Ni-Cu-(PGE) Mineralization (Himmelberg and Loney, 1981; Czamanske and others, 1981)
  B. Caledonides in Norway and New England
    1. Moxie pluton (Thompson and Naldrett, 1984)
      a. Geologic setting
      b. Geology
        i. Broad differentiation from dunitic rocks in the southwest to gabbros and diorites in the northeast
        ii. Marked lack of layering features within the intrusion; cryptic variation is irregular. Post-crystallization deformation and alteration affects account for part of this.
      c. Ni-Cu-(PGE) Mineralization
        i. Three sulfide showings
        ii. Sulfur isotopes
        iii. Olivine compositions
    2. Rana (Boyd and Mathiesen, 1979; Boyd and Nixon, 1985; Boyd and others, 1987; Barnes, in press)
      a. Geologic setting
      b. Stratigraphy
        i. Concentric arrangement (Boyd and Mathiesen, 1979)
        ii. Stratigraphic zones (Barnes, 1987)
        iii. Bruvann area (Boyd and Nixon (1985)
        iv. Tverrfjell portion of the intrusion (Barnes, 1989) - only area of the intrusion with regular layering
      c. Ni-Cu-PGE Mineralization

III. Zoned Alaska-type complexes
  A. Tulameen Complex (Findlay, 1969)
      a. Geologic setting
      b. Distribution of rock types
        i. Model composition of Tulameen ultramafic rocks
        ii. Clinopyroxene compositions
        iii. Model for the configuration of units
      c. PGE Mineralization
        i. Associated placer deposits (Raicevic and Cabri, 1976; Mertie, 1969)
        ii. PGE geochemistry and minerals (St. Louis and others, 1986)
  B. Nizhnetagil or Ural-type intrusions (Razin, 1976, Smirnov, 1977)
      a. Geologic setting
      b. Distribution of lithologies
        i. Shoot-like segregations of Pt-bearing chromite
      c. PGE Mineralization
        i. Ores and PGE minerals
        ii. PGE geochemistry and grades (Mertie, 1969)

IV. Others
- A. Lac des Iles mafic-ultramafic complex (MacDonald, 1988)
  - a. Geologic setting
  - b. Geology
    - i. Ultramafic complex
    - ii. Mafic complex
  - c. PGE Mineralization
    - i. Ultramafic complex
    - ii. Mafic complex - Roby zone

DAY 9: Alkaline intrusions, carbonatites, and associated PGE mineralization

I. Introduction
  A. Definitions - alkaline rocks, carbonatites, high K_2O rocks
  B. Classification of alkaline rocks (Sorensen, 1974)
  C. Types of intrusions
  D. Associations

II. Shonkin Sag, Montana (Hurlburt and Griggs, 1939)
  A. Geological Framework - Highwood Mountains
  B. Structure, shape, form, age
  C. Stratigraphy - chilled margin, shonkinite, syenite, sodasyenite
  D. Evidence for mineralization

III. Coryell Intrusions, British Columbia
  A. Geologic Setting (Hulbert and others, 1988)
  B. Rock types and sequence - granite, syenite, monzonite, including shonkinite
  C. Mineralization
  D. Maple Leaf property
  E. Sappho property

IV. Coldwell Complex, Ontario
  A. Synonyms - Marathon, Duck Lake
  B. General geology (Currie, 1980)
  C. Two Duck Lake prospect (Hulbert and others, 1988)
  D. Mac Rae prospect

V. Allard Stock, La Plata District, Colorado (Eckel and others, 1949)
  A. General geology
  B. Igneous rocks - petrography
  C. Geologic observations near Copper Hill Glory Hole
  D. Emplacement history (Werle and others, 1984)
  E. Copper Hill Glory Hole
  F. Other potential areas
  G. Associated depths

VI. Pala Bora Igneous Complex, South Africa
  A. Location and general geology (PBMCLGMS, 1976)
  B. Petrography - pyroxenite, syenite, foskorite, banded and transgressive carbonatite
  C. Ore deposits - vermiculite, phosphate, copper

DAY 10: Hydrothermal Deposits

I. Definition
  A. Hot aqueous fluids of unspecified origin
  B. Most ore fluids are saline aqueous solutions (3 to >40% dissolved salts)

II. Types of hydrothermal fluids (fluid types vs deposit types)
  A. Magmatic
  B. Metamorphic
  C. Connate and deep groundwater
  D. Surface water (meteoric)
  E. Sea water
  F. Mixture of at least any two of the above

III. Classification of hydrothermal fluids
  A. Lindgren's pressure and temperature categories
    1. hypothermal--high P, high T
    2. mesothermal--high P, moderate T
    3. epithermal--low P, moderate T
    4. xenothermal (added by Buddington)--moderate P, low to high T
  B. Epigenetic versus syngenetic types

IV. Tectonic environments of PGE-bearing hydrothermal deposits
  A. Island arc-Andean-type arc
    1. Porphyry Cu--rift-phase of Andean and island arc
    2. Volcanic-hosted Cu-As-Sb--rift-phase of Andean and island arc
  B. Back-arc rift
    1. Homestake Au--extensional zones with plutons nearby producing greenschist metamorphism
  C. Marginal cratonic basin
    1. Au skarn
    2. Porphyry Cu
  D. Collisional suture zones
    1. New Rambler Cu-Au

V. Porphyry Cu
  A. Description
    1. Large system hydrothermal (mesothermal) disseminations and stockwork veinlets of chalcopyrite and other sulfides in altered monzonitic porphyry stock and adjacent country rock in orogenic belts.
  B. Depositional environment
  C. Textures
  D. Rock types (alkali-silica variation diagram).
  E. Age
  F. Structural classification
  G. Dimensions of stock (dimensions of different porphyry stocks)
  H. Associated rocks
  I. Mineralogy (cross-section of ore deposit showing mineral distribution patter and zoning)
  J. PGE
  K. Alteration
  L. Ore texture (fracture and veinlet-microveinlet control of mineralization)
  M. Ore control
  N. Tonnage and grades

- O. Example
  - 1. Bingham, Utah
    - a. Generalized geologic map
    - b. Geologic cross-section
    - c. Cross-section of mineral zones
    - d. Cross-section of pyrite distribution
- P. Genetic models
- Q. Suggested reading
  - 1. Titley and Bean (1981)

VI. Volcanic-hosted Cu-As-Sb

- A. Definition
  - 1. Hydrothermal (mesothermal) stratabound to pipelike massive copper sulfosalt deposits in volcanic flows, breccias, tuffs near porphyry copper systems
- B. Rock Types (generalized geologic map of Bor, Yugoslavia)
- C. Age
- D. Mineralogy
- E. Ore texture
- F. Ore control (cross-section of Bor orebody)
- G. Alteration
- H. Tonnage and grades
- I. PGE
- J. Genetic model
- K. Examples
  - 1. Bor, Yugoslavia
    - a. Generalized geologic map and ore deposits at Bor
    - b. Geologic cross-section of the Bor Deposits
- L. Suggested reading
  - 1. Sillitoe (1983)
  - 2. Jankovic and others (1980)
  - 3. Jankovic (1982)

VII. Homestake Au

- A. Definition
  - 1. Stratabound to stratiform gold deposits in iron-rich chemical sediments and associated volcanic rocks in Precambrian metavolcanic terrane
- B. Rock Types
- C. Age
- D. Depositional environment
- E. Mineralogy
- F. PGE
- G. Ore texture
  - 1. Narrow thinly laminated beds
  - 2. Veins
- H. Ore control
- I. Tonnage and grades
- J. Genetic models
- K. Examples
  - 1. Homestake, South Dakota
    - a. Generalized cross-section of the Homestake mine
  - 2. Dome, Ortario, Canada
    - a. Plan of geology at Dome mine
    - b. Geologic cross-section at Dome mine

- L. Suggested reading
  - 1. Fryer and others (1979)
  - 2. Rye and Rye (1974)

VIII. Gold-bearing skarns

- A. Definition
  - 1. Hydrothermal (mesothermal) irregular or tabular deposits of gold and base-metal sulfides in calc-silicate contact metasomatic rocks
- B. Depositional environment
- C. Rock types
- D. Age
- E. Mineralogy (mineral zoning away from stock)
- F. Alteration (alteration zoning away from stock)
- G. PGE (Cameron and Gamoe, 1987)
- H. Tonnage and grades (Orris and others, 1987)
- I. Examples
  - 1. Carr Fork, Utah
    - a. Geologic map of the 1200-m level and cross-sections of deposit at Carr Fork
- J. Genetic models
- K. Suggested reading
  - 1. Einaudi, M.T., Meinert, L.D., and Newberry, R.S. (1981)
  - 2. Atkinson, W.W., and Einaudi, M.T. (1978)

IX. New Rambler Cu

- A. Definition
  - 1. Hydrothermal (mesothermal) copper-gold-jasperoid replacement veins in shear zones that cut layered mafic igneous rocks
- B. Depositional environment
- C. Rock types
- D. Metamorphism
- E. Ore control
- F. Ore texture
- G. Age
- H. Alteration
- I. Mineralogy
- J. PGE occurrence
- K. Tonnage and grades
- L. Example
- M. Genetic models
- N. Suggested reading
  - 1. McCallum and Orback (1968)
  - 2. McCallum and others (1976)

DAY 11: PGE In Sediment-hosted Deposits

I. Introduction (Cox and Singer, 1986)
  A. Deposit types
    1. Placers, well known source of PGE
    2. Ancient placers
    3. Sediment-hosted (redbed) coppers
    4. Laterites
    5. Unconformity uranium deposits
    7. Coal
  B. Similarities
    1. No direct igneous relation
    2. Most unmetamorphosed to greenschist facies
    3. Organic compounds
  C. Differences
    1. Some syn/diagenetic, other epigenetic
    2. Wide age range
    3. Diverse tectonic and sedimentary settings
    4. PGE major product, byproduct, geochemical anomaly, or speculated
    5. PGE source mafic and ultramafic rocks to unknown

II. Placer deposits (Mertie, 1969; Wells, undated; Orris and Bliss, 1986; Singer and Page, 1986)
  A. Many types; stream and bench gravels most productive
  B. Tectonic settings
    1. Accreted terranes
    2. Conglomerates along fault zones
    3. Areas of multicycle sedimentation
    4. Terraces caused by regional uplift
  C. Deposited where rivers enter low-energy regime
  D. Hosted in gravels or conglomerate
  E. Tertiary and Holocene
  F. Deposits flat, tabular, may include several commodities, vary in size, have flakes to dust sized ore, have wide range in grades and tonnages
  G. PGE
    1. Derived from ophiolite, zoned intrusions, may be subordinate to Au
    2. Generally alloys with other PGE or Fe
    3. Examples
      a. Klamath Mountains, USA, derived from opohiolite
      b. Ural Mountains, USA, derived from zoned intrusions
      c. Sierra Nevada, USA, where Au is dominant
  H. Placer evaluation
    1. Reconnaissance to determine general characteristics
    2. Determine best sampling method, many available
    3. Decide on sample density, size, to minimize risks
    4. Problems: boulders, erratic high values, uncased drill holes, salting
    5. Ore recovery by riffle system
    6. Records of evaluation very important

III. Ancient placer deposits (Feather, 1976; Feather and Koen, 1975; Houston and Karlstrom, 1979; Minter, 1976; Pretorius, 1976; Pretorius, 1981; Smith and Minter, 1980; Tankard and others, 1982)
  A. Similar to placer deposits: Lithification and low-grade metamorphic overprint
  B. Mostly late Archean, early proterozoic
  C. Quartz-pebble conglomerate host rocks

- D. More Ore minerals than in modern placers
  - 1. Several PGE and detrital uranium minerals
  - 2. Minerals altered during diagenesis and metamorphism, some secondary
- E. Examples
  - 1. Witwatersrand, South Africa (to be described)
  - 2. Jacobina, Brazil
  - 3. Tarkwa, Ghana

IV. Sandstone-hosted copper (redbed) (Banas, 1980; Gustafson and Williams, 1981; Hayes, 1985; Jung and Gerhard, 1976; Jowett, 1986; Jowett and others, 1987; Kucha, 1982, 1983)

- A. Failed rift or passively subsiding basin
- B. Basins deep, large, contain near-shore sediments
- C. Bimodal or basaltic volcanics
- D. Continental redbeds overlain by marine transgression
- E. Basement granitoid or metamorphic rocks
- F. Proterozoic to recent
- G. Local setting of deposits
  - 1. In first major marine transgression; algal dolomite, sandstone, shale
  - 2. Near basement highs or basin margins
- H. Deposit description
  - 1. Very thin but laterally extensive
  - 2. Chalcocite dominant economic sulfide
  - 3. U and Co important in some deposits
  - 4. Galena, sphalerite, PGE, and organic compounds with many deposits
  - 5. Zoned relative to direction of fluid flow
  - 6. Ore mostly disseminated
  - 7. Alteration reflects diagenesis
  - 8. Some minor faults
- I. Genesis
  - 1. Diagenetic
  - 2. Fluids likely low temperature, high salinity, chlorinity, intermediate oxygen fugacity
  - 3. Deposited at redox boundary, organics important
  - 4. Ore-bearing fluids convected or passed through sabkha system
  - 5. Metals from volcanics, sediments, or basement rocks
- J. PGE
  - 1. Byproduct of some Kupferschiefer and Zaire-Zambian deposits
  - 2. In reduced layers
  - 3. Clay mineralogy, organic chemistry important
  - 4. Mineralogy: organic matter, sulfides, PGE minerals
  - 5. PGE correlates with phosphate, illite, bituminous shale
  - 6. PGE as catalysts of oxidation and desulfurization
  - 7. Concentrations vary, data for Kupferschiefer
    - a. Pt, 1-370 ppm
    - b. Pd, 1-120 ppm
    - c. Ir present but no quantitative data
- K. Examples
  - 1. Kupferscheifer, Germany and Poland (to be described)
  - 2. Zaire-Zambia (to be described)
  - 3. Udokan, USSR
  - 4. Spar Lake, USA
  - 5. Creta, USA

V. Laterites (Bowles, 1986, 1988)

- A. Tectonic setting at convergent margins

- B. Warm, humid climate
- C. Underlying ultramafic rocks
- D. Precambrian to Tertiary
- E. Minerals: garnierite, hydrous silicates, quartz, goethite
- F. Host red-brown pisolitic soils
- G. Zoned
- H. Deposits products of chemical weathering
- I. Enriched in Ni, Co, Cr; depleted in MgO
- J. PGE
  - 1. Acid, high Eh conditions
  - 2. Laurite-erlichmanite, Os-Ir and Pt-Fe alloys
  - 3. Grown in situ
- K. Examples
  - 1. Nickel Mountain, Oregon
  - 2. Freetown, Sierra Leone

VI. Unconformity uranium deposits (Hoeve and Sibbald, 1978;Hulbert and others, 1988; Nash and others, 1981)

- A. Intracratonic basins flanking Archean domes
- B. Host rocks deposited in shelf environment
- C. Regional metamorphic foliation and brecciation
- D. Ore Minerals
  - 1. Pitchblende, uraninite, coffinite
  - 2. Less common pyrite, chalcopyrite, galena, sphalerite, arsenopyrite, niccolite, gold or silver, tellurides
  - 3. Gangue mostly chlorite, also quartz, calcite, dolomite, hematite, siderite, sericite
- E. Ore as breccia filling, veins, disseminated
- F. Multistage chloritization dominant, other local alteration
- G. Geochemical signatures
  - 1. U, Mg, P
  - 2. Local increases in Ni, Cu, Pb, Zn, Co, AS
  - 3. Local decreases in SiO_2
- H. Genesis poorly understood; likely several stages of concentration and enrichment
- I. PGE, at Beaverlodge, Canada, 17.3 ppm Pd, 13.8 ppm Pt, 0.4 ppm Rh
- J. Examples
  - 1. Rabbit Lake, Canada
  - 2. Cluff Lake, Canada (to be described briefly
  - 3. Ranger deposits, Australia
  - 4. Jabiluka deposits, Australia

VII. Coal (Block and Dams, 1975; Chyi, 1982; Finkelman and Aruscavage, 1981; Van der Flier-Keller and Fyfe, 1987; Van der Flier-Keller and Goodarzi, 1988)

- A. Favorability for PGE (Finkelman and Tewalt, 1989, written commun.)
  - 1. Contain abundant sulfides
  - 2. Chalcophile elements abundant
  - 3. Organic matter easily complexes with PGE
  - 4. Natural filtering action of peat
  - 5. Interaction with carbonaceous matter
- B. Reported PGE values in coals (various sources)
  - 1. Pt, 6-800 ppb
  - 2. Pd, 3-47 ppb
  - 3. Ir, 0.1-9 ppb
  - 4. Rh 1 ppb

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DAY 12: Analytical techniques for the platinum-group elements

I. The platinum-group metals - a brief history of their discovery and early chemistry

II. General obstacles to successful platinum-group analysis

III. An overview of analysis for PGE (platinum-group elements)
   A. Extraction of PGE
      1. Inorganic leach
      2. Organic leach
      3. Volatization
      4. Fusion
   B. Detection systems
      1. Gravimetric
      2. Colarimetric
      3. Atomic absorption
         a. Flame
         b. Flameless
      4. Emission spectrographic
      5. Neutron activation
      6. X-ray
      7. Ion chromatography
      8. Inductively coupled plasma
         a. Emission spectrography
         b. Mass spectroscopy

IV. Analytical techniques
   A. Inorganic leach methods for:
      a. Colorimetric determination
      b. Atomic absorption determination
      3. Neutron activation
   B. Organic leach methods
   C. Ion chromatography techniques
   D. Emission spectrography
   E. Fire-assay preconcentration methods
      1. Classical Pb assay
         a. Gravimetric determination by acid parting
         b. Acid digestion to:
            i. Flame atomic absorption determination
            ii. Graphite furnace (flameless atomic absorption determination
            iii. ICP-mass spectroscopy determination
      2. Nis assay, acid digestion to:
         a. Atomic absorption determination
         b. Neutron activation determination
         c. ICP-mass spectroscopy determination

V. Other methods
   A. Scanning electron microscope studies
   B. Electron microprobe studies
   C. Os-Re isotope geochemistry

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DAY 13: Geochemistry and geophysics in PGE exploration

I. Introduction to Exploration Geochemistry

II. Considerations in design of geochemical program
  A. Pilot studies
  B. Parameters in a survey that need decisions
  C. Necessary information for a survey

III. Prospecting by panning

IV. New Rambler studies (Theobald and Thompson, 1968)
  A. Mine waste
  B. Concentration
  C. Soil sampling
  D. Stream sediment chemistry

V. Soil sample studies in Stillwater Complex (Fuchs, 1972; Fuchs and Rose, 1974)
  A. Soils downhill from showing with 3.1 ppm Pt and 3.125 ppm Pd
  B. Component Analysis

VI. Overall exploration program in Stillwater (Conn, 1979)
  A. Exploration history
  B. Pt and Pd anomalies

VII. Geochemical exploration in Unst for PGE (Gunn and others, 1985)
  A. General map
  B. Stream sediment panned concentrates
  C. Overburden Sampling Cliff

VIII. Biogeochemistry applied to Pt and Pd (Dunn, 1986)
  A. Rottenstone or Hall deposit
  B. Biochemistry-species tested
  C. Results for twigs of black spruce

IX. Other studies (Thayer and others, 1977; Rosenblum and others, 1986)

X. Design of soil surveys (Fletcher and others, 1986)

XI. Introduction to geophysical exploration

XII. Information that can be provided
  A. Geologic framework of an area
  B. Location of fault contacts and structural boundaries
  C. Shape and extent of mafic and ultramafic bodies
  D. Location of areas where there has been the alteration or concentration of magnetite
  E. Continuity of units in an intrusion
  F. Location of sulfide deposits

XII. Pro and cons of methods
  A. Gravity method
  B. Magnetic method
  C. Induced polarization method
  D. General electromagnetic method

XIII. Examples
   A. Bouguer and isotatic residual gravity map of the conterminous U.S.
   B. Isostatic residual gravity map of the North America
   C. Stillwater Complex - magnetics and gravity
   D. Shadow magnetic anomaly map of the Abitibi greenstone belt

DAY 14: Synthesis into a genetic/descriptive framework

DAY 15: Application of models and assessment techniques to Indonesia

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APPENDIX B: A METHOD FOR SEMIQUANTITATIVE SPECTROGRAPHIC ANALYSIS OF FIRE ASSAY DORE´BEADS FOR THE PLATINUM-GROUP ELEMENTS AND GOLD

B.M. Adrian and R.R. Carlson
U.S. Geological Survey

Abstract

Platinum, palladium, rhodium, ruthenium, iridium, osmium, and gold are determined by direct spectrographic analysis of a silver fire-assay dore´ bead. Fire-assay methods and standards preparation are described. The fire-assay bead is placed into a graphite electrode containing 2.5 mg of silver oxide and arced at 4, 8, and 13A DC in an argon-oxygen atmosphere. For a 15 g sample, the method provides determination limits of: Pt - 10 ppb, Pd - 1 ppb, Rh - 10 ppb, Ru - 100 ppb, Ir - 10 ppb, Os - 200 ppb, and Au - 1 ppb.

Introduction

The 1976 analytical method used by the Branch of Exploration Research, U.S. Geological Survey, for determination of the platinum-group elements and gold in geologic materials was published in Applied Spectroscopy (Cooley and others, 1976). That fire-assay / emission spectrographic method has been considerably modified in the detection (emission spectrographic) system, and has also had the determination of osmium added to the previous group of determined elements.

This paper describes the method used through 1988 by the Branch (now Branch of Geochemistry) for the routine semiquantitative analysis of geological and biological samples for platinum, palladium, rhodium, ruthenium, iridium, osmium, and gold.

I. Experimental

A. Apparatus and Reagents.

Tables I and II list the fire-assay and spectrographic equipment used.

Table I. Fire-assay equipment and reagents

Furnace:	Denver Fire Clay Company Type 2F1 electric assay furnace
Crucibles:	30 g, clay, DFC Ceramics, Inc.
Cupels:	1 3/4 in., processed natural tricalcium phosphate, DFC Ceramics, Inc.
Litharge:	c.p., Pueblo brand, American Smelting and Refining Company, Inc. (ASARCO)
Silica:	140 mesh and finer, Fisher Scientific Company
Sodium carbonate:	Calcined, purified, Fisher Scientific Company
Sodium tetraborate:	Fused-ground, borax glass, Fisher Scientific Company
Graphite:	Grade No. 38, Fisher Scientific Company
Silver oxide:	Ag_2O powder, Specpure, Johnson Matthey Chemicals, Ltd.

Table II. Spectrographic equipment, chemicals and operating conditions.

Spectrograph:	Jarrell-Ash 1.5 m Wadsworth-mounted having a dispersion of 5.45 Å/mm over a spectral range from 2100 Å to 4800 Å in the second order
Power source:	Jarrell-Ash utility DC-arc
Electrodes	
Anode:	1/4-in. diameter thin-walled graphite electrode (Ultra Carbon No. C001489-00 U-2 grade)
Cathode:	1/8-in. x 2 in. graphite rod (Ultra Carbon No. 001686-00 U-2 grade)
Analytical gap:	4 mm held constant
Exposure time:	120 seconds
Slit width:	20 µm
Film:	35 mm Kodak spectrum analysis No. 1, processed with D-19 developer for 3 minutes at 20°C, stopped in cold running water (30 seconds), fixed for 3 minutes, rinsed in cold water, and air-dried
Comparator:	Jarrell-Ash console microphotometer (model 23-120)
Pt group compounds:	Specpure, Johnson Matthey Chemicals, Ltd. (see Table III for compounds used)
Buffer:	Silver oxide (Ag_2O), powder, Specpure, Johnson Matthey Chemicals, Ltd.
Gas:	70 percent argon / 30percent oxygen. Custom Grade Mixture

B. Procedure

1. Preparation of powder standards.

The matrix of the standards is SiO_2 which is obtained from natural quartz crystals. The quartz is crushed, pulverized to minus 0.15 mm with ceramic plates, and washed free of impurities using the following procedure:

(1) Soak in hot 6 N HCL for 1 day, decant, and repeat.
(2) Rinse with deionized water, alternately washing, and decanting six times.
(3) Check for impurities -- repeat complete procedure again if necessary.

Two sets of standards are used in this method: PGE-1 and PGE-2. The first set of standards (PGE-1) contain Ir, Os, and Ru; the second set (PGE-2) contain Au, Pd, Pt, and Rh. Table III lists the weights of the platinum-group compounds and SiO_2 used in preparing the PGE-standard 1. The weighed compounds are placed into a 1 oz. glass jar with three 3/8" methacrylate beads, and are pulverized and homogenized by 15 min. of vigorous shaking in a Spex Industries No. 8000 mixer well.

Table III. Platinum group and gold in quartz matrix, standard 1

Element	Compound used	Quantity added	Concentration of element (μg/mg)
	PGE-1 standard		
Os	$(NH_4)_2OsCl_6$	0.06924	30
Ir	$(NH_4)_2IrCl_6$	0.06883	30
Ru	$(NH_4)_2Ru(H_2O)Cl_5$	0.9867	30
	SiO_2 (Arkansas quartz)	0.76326	
Total		1.00000	
	PGE-2 standard		
Pt	$(NH_4)_2PtCl_5$	0.06826	30
Pd	$(NH_4)_2PdCl_4$	0.08016	30
Rh	$(NH_4)_3RhCl_6•H_2O$	0.11304	30
Au	NH_4AuCl_4	0.05435	30
	SiO_2 (Arkansas quartz)	0.68419	
Total		1.00000	

Starting with this standard material, each successive PGE-1 standard was prepared as a dilution of the previous one (see Table IV). Each standard was thoroughly mixed as before.

Table II also lists the weights of the platinum group and gold compounds and SiO_2 used in preparing the PGE-2 standard. The procedure is the same as in the preparation of the PGE-1 standard.

Table IV. Platinum group and gold standards in quartz: Preparation of standards.

Standard No.	Amount added (g) Previous Standard	Amount added (g) Matrix (SiO_2)	Concentration of element (µg/mg)	1 mg of standard in ppb[a]
1			30	2000
2	0.5	0.5	15	1000
3	0.5	0.6	7.5	500
4	0.4	0.6	3	200
5	0.5	0.5	1.5	100
6	0.5	0.5	0.75	50
7	0.4	0.6	0.3	20
8	0.5	0.5	0.15	10
9	0.5	0.5	0.075	5
10	0.4	0.6	0.03	2
11	0.5	0.5	0.015	1

[a] The ppb value is relative to a 15-g geologic sample used in the fire-assay procedure. For values higher than 2000 ppb, the appropriate weight of standard 1 is used.

2. Fire assay.

The PGE-1 and PGE-2 standards are mixed with the fire-assay flux (Table V) and 5 mg of Ag_2O in 30-g crucibles.

Table V. Fire-assay flux for standards

Material	Quantity (g)
Standard	.001
PbO	80
SiO_2	15
Na_2CO_3	30
Borax glass	2
C (graphite powder)	1.75

The charged crucibles are then fused eight at a time arranged laterally in two rows of four at the rear of the furnace. A third row of crucibles filled with crushed used carbon electrodes is set in front of the charged crucibles.

The crucibles are quickly loaded into the furnace at 1060°C. The crucibles absorb heat, cooling the furnace down to 870°C. The furnace remains at 870°C for 30 minutes while the samples are fusing. The furnace temperature is then increased to 1060°C (a 30-40 minute procedure with electric furnaces). The fused samples are then removed from the oven and poured into cast iron molds that have been painted with a thin film of Fe_2O_3 solution. The poured samples are covered with inverted 10-g crucibles or metal plates to protect against flying glass shards from the cooling slag. When the slag has cooled, any cohesive slags are cracked with a pick-type hammer or sharpened bolt applied through a hole in a shield. Any slag remaining on the lead buttons is removed by gently tapping the glass.

For the cupellation step, new cupels are loaded into the furnace at 650°C. They are arranged into three rows of 5, 6, and 5 cupels in honeycomb fashion. Surrounding and interlocking with the new cupels are empty, previously used cupels referred to as deadmen. The furnace temperature is raised to 980°C. Once this temperature is reached, two rows of 3-inch scorification dishes filled with crushed, used carbon electrodes are set between the cupels and the front of the furnace. The lead buttons are loaded into the new cupels and allowed to melt. Upon melting they acquire an incandescent appearance, at this point the furnace is opened halfway, the furnace vent fan turned on, and the temperature controller lowered to 800°C. When the furnace reaches 800°C, the vent fan is turned off and the door is left half open. Once the last bit of incandescent lead is absorbed into each cupel, the cupel is removed from the furnace and set onto the door's table ledge for cooling. The resulting Ag dore´ beads are then analyzed spectrographically.

3. Spectrography.

The dore´ bead is transferred into the cavity of a preformed electrode (Ultra Carbon No. C001489-00 or equivalent) containing 2.5 mg of Johnson Matthey Specpure silver oxide. The beads are arced using the equipment and conditions described in Table II at 4A for 5 seconds, 8A for 5 seconds, and 13A for 110 seconds in an atmosphere of 70% argon and 30% oxygen delivered by a modified Helz gas jet (Curry and Cooley, 1971).

The film is processed as described in Table II. The analytical lines used and the sensitivities obtained are given in Table VI.

Table VI. Spectral lines used and their ranges

Element	Spectral line (A)	Detection range (ppb)[a]
Pt	3064.71	2-500
	2659.45	5-200
	3139.37	200-5000
	2747.61	1000-5000
Pd	3404.58	1-200
	3251.64	1-200
	3242.70	2-500
	3142.81	1000-5000
Rh	3434.89	5-200
	3478.91	200-5000
	2652.66	500-5000
Au	2675.95	1-200
	3122.50	10-1000
	2748.26	20-2000
	3033.18	200-5000
Ir	3133.31	20-2000
	3220.78	50-2000
	3219.51	200-5000
Ru	3436.74	100-5000
	2678.76	500-5000
Os	3058.66	5-5000
	2909.06	100-5000

[a] For a 15 g sample.

II. Precision

In addition to the precision tests reported for the 1976 method on multiple analyses of artificial, quartz standards material (Cooley and others, 1976), precision tests for the current method were made on natural geological materials. Relative standard deviations for the 1976 quartz standards were: Pt - 7.8%, Pd - 11.0%, Rh - 11.4%, Ru - 9.8%, Ir - 13.7%, and Au - 4.5%. Table VII shows the results of precision tests of nine analyses of each geological sample.

Table VII. Relative standard deviations of PGE and Au in three geologic standards.

Sample	Description	Pt	Pd	Rh	Ru	Ir	Os	Au
STC-1	Anorthosite/Peridotite mix (elevated Cr and Ni)	20%	9%	19%	--	--	--	24%
Pt Std. #2	Mafic rock with elevated Cu and Ni sulfides	--	--	20%	19%	0%	0%	20%
NB-1	Chromite ore	42%	38%	--	--	--	--	32%

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APPENDIX C: ANALYTICAL TECHNIQUES FOR THE PLATINUM-GROUP ELEMENTS

R.R. Carlson
U.S. Geological Survey

I. The platinum-group metals: a brief history of their discovery and early chemistry.

Egyptians used alloys of the platinum-group metals artistically and in hieroglyphics over 2,800 years ago, and the Indians of South America (in what is now Columbia and Ecuador) prized platinum as a rare metal, useful in jewelry and art, 1000 years ago. However, Europeans had no knowledge of platinum until 1748, when it was referred to by Don Antonio de Ulloa as a new metal occuring in South America. In 1751 William Watson wrote several papers on this metal called Platina di Pinto ("little white gold") that occurred in a gold mine on the island of Santo Domingo in the Spanish West Indies (Caribbean Sea North and South America). Fifty more years passed before the first reference to palladium was made in 1803, by Richard Chenivix. He thought at first that it was only a "pretended new metal" and that it was possibly composed of platinum and mercury. Also in 1803, A.F. Fourcroy and L.N. Vaugeulin reported on a reaction in platinum chemistry that showed an impurity (the description of the reaction indicates that the "impurity" was probably iridium). In 1804, S. Tennant reported finding two metals in black powder remaining after dissolution of "platina". He described their separation and properties and named them iridium and osmium. Rhodium was independently discovered in 1804 by A.F. Fourcroy (referring to it as "new metal in platinum") and by W.H. Wollaston, who researched its properties. Up to this time, platinum had only been used for jewelry, works of arts, and coinage, but in 1817, Sir Humphry Davy noted that platinum was involved in some unusual chemical reactions. He did not understand that he was observing the catalytic nature of platinum. Johann Wolfgang, in 1823, experimented with platinum catalysis. He noted that when hydrogen and oxygen gas were introduced to a chamber containing platinum powder on a filter paper, the volume of gases decreased and water was formed. Here, the platinum was acting as a chemical catalyst - promoting the reaction, but not being changed in the process. He also noted that so much heat was produced by the catalytic reaction that the filter paper was charred. In 1830, Michael Faraday found that platinum was ideal for making glass, because it didn't contaminate the final product. This, together with the catalytic nature of platinum, began a shift in the use of platinum from the ornamental to the industrial. The catalytic power of platinum became very useful in manufacturing chemicals (such as sulfuric acid and fuming nitric acid) and in refining petroleum (it is capable of combining short hydrocarbon chains into the longer hydrocarbon chains we use as fuel). Ruthenium was the last of the platinum-group elements (or "platinoids" - platinum-like elements) to be recognized. C. Claus discovered it in 1844, in the Ural Mountain platinoids of the Soviet Union.

I.A. An overview of the platinum-group elements, chemistry and physical properties.

In the Periodic Chart of the Elements, the PGE (platinum-group elements) are in Group VIII B, the Transition Elements. They are arranged with iron, cobalt, nickel, and their neighbors in Group I B as shown below:

VIII B					I B
	Fe	Co	Ni		Cu
Atomic No.	26	27	28		29
Density	7.9	8.9	8.9		9.0
	Ru	Rh	Pd		Ag
Atomic No.	44	45	46		47
Density	12.4	12.4	12.0		
	Os	Ir	Pt		Au
Atomic No.	76	77	78		79
Density	22.7	22.6	21.5		19.3

All of the Group VIII B metals are grayish-white in color, all have high melting and boiling points, all absorb hydrogen, all have good catalytic power, and all have a strong affinity for sulfur.

In solution, they all form complexes readily, with platinum doing so extremely readily. Fe, Ru, and Os have a strong affinity for oxygen, but that affinity declines significantly, left to right, across the periodic table for group VIII B. As a group, Ir, Ru, and Os are insoluble in acids, although Os is somewhat soluble in HNO_3 if the osmium is a finely-divided powder. Osmium is also soluble in strong alkaline oxidizing reagents. However, as the Os dissolves in either HNO_3 or alkaline oxidizers, osmium tetroxide forms (Os_5O_4), which is very volatile (and toxic) at moderately high temperatures. Pd is somewhat soluble in HNO_3, and its neighbor in the Periodic Chart, silver, is of course very soluble in HNO_3. Pt, Pd, Rh, Au, and Ag are all soluble, to various extents, in aqua regia (1 part HNO_3, 3 parts HCl) and HBr + Br_2.

II. General obstacles to successful platinum-group analysis

The platinum-group elements are much more difficult to detect and separate than the other noble elements, gold and silver. Literally thousands of chemists have investigated and researched their chemistry, but no single proposed analytical method is entirely satisfactory. The platinoid elements are considered to present the most difficult analysis in the field of inorganic chemistry. The major catogories of problems are as follows:

1. Other than a few enriched environments (such as placer deposits, hydrothermal deposits, and sulfide melts), the platinoids normally occur at such low concentrations (in the part - per - trillion range) that they are not detectable by "easy", simple techniques.
2. They normally occur together and are difficult to separate chemically.
3. They tend to resist attack by wet chemical methods and, even to some extent, by high temperature fusion methods.
4. They can be hard to separate effectively from such base metals as copper, lead, zinc, nickel, and chromium.
5. They occur in such diverse matrices of interest to the exploration geologist and geochemist as sulfides, arsenides, tellurides, selenides, chromites, mafic to silicic silicates, natural metal alloys with Fe, Cu, and Ni, natural solutions, biological samples, and a host of man-made matrices including concentrates, mattes and slags, alloys, and solutions - all of which require specific analytical techniques.
6. They show a lack of homogeneity, in dispersed occurrences, with small grain sizes, and with diverse grain composition.

To overcome these obstacles, most analytical techniques aimed at geochemical exploration for the platinum-group elements try to:

1. Use a large sample size to minimize the lack of homogeneity in a sample.
2. Concentrate the PGE to obtain detection limits in line with their low crustal abundances.
3. Simplify the sample matrix to eliminate detection interferences

III. An overview of Analysis for PGE.

A.1. Extraction of PGE - Inorganic leach

Inorganic leaches are generally ineffective on the analysis of PGE as a whole. However, individual elements in the group show more suspectibility to inorganic attack than others. Platinum and palladium can be dissolved in aqua regia, and, if alloyed with excessive gold or silver, can also be dissolved with nitric acid alone (the recovery is only partial and must be repeated several times following realloying with silver). Hot sulfuric acid will partially dissolve palladium and, to a lesser extent, rhodium, platinum, iridium, and osmium. Hydrobromic acid enriched with bromine will dissolve platinum and palladium. Osmium is dissolved by strong alkaline oxidizing agents and by hot HNO_3 if the osmium is finely divided. High temperature inorganic leaches are more effective - "all" the PGE are soluble in molten bases such as lead, antimony, arsenic, sodium, phosphorous, and silicon.

A.2. Extraction of PGE - Organic leach

Sodium cyanide has been used as a leach for Pt, Pd, Au, and Ag. This can be done at room temperature on a finely-ground sample. The collection of Pt and Pd can be increased if a sodium peroxide sinter (medium temperature fusion) is performed to dissolve chromite ores and granites before cyanide extraction. Most other uses of organic chemicals in PGE determinations are not as primary leaches but as a follow-up to an inorganic acid leach, and they (the organic reagents) act as:

1. complexing agents to provide a new chemical signature to the individual platinoids, to allow for their separation.
2. immiscible media into which the platinoids are extracted prior to introduction to a detector (such as MIBK extracting the bromine complexes of Pt, Pd, and Au from hydrobromic acid, prior to introduction to the flame of an atomic absorption spectrophotometer).

A.3. Extraction of PGE - Volatization

Methods of direct volatization of the sample are presently limited to very small sample sizes. Laser ablation techniques are limited to a very small two dimensional sample (the surface of polished rocks and minerals). Only emission spectroscopy is applicable to exploration techniques, and its usefulness for PGE analysis is limited by a sample size of only 5 - 10 mg and detection limits in the part-per-million range (Pt - 10 ppm, Pd - 2 ppm, Rh - 20 ppm, Ru - 200 ppm, Ir - 20 ppm, Os - 400 ppm).

A.4. Extraction of PGE - Fusion

Fusion techniques for platinoid extraction from samples are by far the most useful and therefore the most popular. Fusion techniques are simply high temperature liquid chemistry that began with room temperature mixing of solid reagents. "Room temperature" wet chemistry is, in general, concerned with reactions of Bronsted acid and bases (that is, proton donors and acceptors). High temperature "wet" chemistry (fusion melts) is, in general, concerned with reactions of Lewis acid and bases (that is, electron acceptors and donors). A major advantage of fusion techniques is that they almost always involve total digestion of the sample, as opposed to the partial digestions of the leach methods. Thus, PGE are not lost due to being locked up inside small grains of rock or minerals. The three most popular methods of fusion of samples for purposes of collecting the PGE contained in them are:

1. The classical lead fusion, in which SiO_2, CO_3^{2-}'s, and $B_4O_7^{2-}$'s are used to dissolve the sample, while molten lead collects the metallic form of the PGE plus Au and Ag. Long used for Au and Ag analysis of ore materials, the method has been modified slightly to enhance PGE collection.
2. The nickel sulfide fusion, which is currently popular in attempts at producing detection limits in the part-per-trillion range for all six PGE. The same SiO_2, CO_3^{2-}'s, and $B_4O_7^{2-}$'s are used to dissolve the sample at high temperature, but molten NiS is used to collect the sulfide form of the PGE. This fusion method is equal to the lead fusion method in collecting Pt, Pd, Rh, and Ir, is two to three times better at collecting Ru and Os, and is two to three times worse at collecting Au.
3. The tin fusion, which is least favored, also dissolves the sample with SiO_2, CO_3^{2-}'s, and $B_4O_7^{2-}$'s, and then collects the PGE in metallic tin. The detection system for this method involves an extremely complex isolation scheme of ion exchange, distillation, and solvent extraction processes. Consequently, the method will not be discussed further in this review.

B.1. Gravimetric Detection System

The oldest detection system for quantification of a known material, weighing an analytical result, is generally only useful for ore grade or highly concentrated sample material. With early separation schemes for the noble metals, Ag was counted as Ag and any PGE present were counted as Au. The next step in development of separation schemes for the noble metals included Pd with Ag and the other five PGE with Au. These separation schemes are called "acid parting" and were accomplished with HNO_3 or H_2SO_4. They are very difficult to perform on alloys of Au, Ag, and PGM because the degree of dissolution of the target metal depends on the ratios between pairs of elements in the alloy; therefore, it is almost necessary to know the contents of the alloy before analyzing to determine the contents of the alloy.

B.2. Colorimetric Detection System

Colorimeters are designed to take advantage of the fact that many chemical compounds, in solution, absorb light at specific wavelength. The light source may be adjusted with filters to produce specific wavelengths in the milli-micron range. Alternatively, a broad spectrum of light may be adjusted with filters to a specific wavelength after the light has passed through the sample liquid but prior to entering the detector. The absorbance of the chemical compounds in the unknown solution is compared to standard solutions to determine the amount of the target element present.

B.3. Atomic Absorption Spectrometer

In this instrument, energy from a light source emitting spectral wavelengths particular to an element, is passed through a volume of those atoms in an excited atomic state. The excited atoms absorb some of the light energy, and resultant loss of light is measured by a detector. By comparison to the same energy loss to standards, the quantity of the element present in the sample is determined. Two methods of exciting the atoms are used - flame and flameless systems. In a flame atomic absorption instrument, the atoms to be measured are introduced in liquid form to a flame between the light source and the detector. The heat of the flame puts the atom into the excited state. Most elements detectable by flame AA, including Au and Ag, can be read in the heat of an air - acetylene flame. The PGE, however, require the use of the hotter nitrous oxide flame to eliminate the interferences present at lower temperatures. With flameless atomic absorption, the liquid or dry sample medium to be analyzed is placed into a carbon rod atomizer or graphite boat, and is electrothermally atomized to introduce the energy-absorbing excited atoms between the light source and the detector.

B.4. Emission Spectrograph

In the emission spectrograph, light emitted by thermally excited atoms is passed through a diffraction grating (which acts like a prism) and is dispersed onto film, where individual spectral lines corresponding to specific elements can be detected. The density of the individual lines directly relates to the quantity of atoms emitting light at that particular wavelength. The two most popular ways of exciting the atoms are: 1. introducing the sample in dry form to an electric arc created between two carbon electrodes, the sample being in a cup formed in the lower electrode and 2. introducing the sample in liquid form to a high temperature ion plasma jet.

B.5. Neutron Activation System

Here, the samples to be analyzed are bombarded by a neutron source, making them radioactive. The amount of induced radioactivity for a particular element is compared to the amount of radioactivity induced in a standard of known element concentration. The element of interest may undergo wet chemical separation from other activated elements after the irradiation - in which case the method is called radiochemical neutron activation analysis, or RNAA. If no chemical separation of the activated element from the rest of the activated sample is performed, the method is called instrumental neutron activation analysis, or INAA. In either method, the elements to be determined may also be concentrated before irradiation, for instance, by NiS fire-assay fusion.

B.6. X - ray System

As yet, there are no good methods to detect the PGE in large samples by X-ray diffraction or florescence. When done on small samples, the detection limits are in the high part-per-million (ppm) range. Thus, this detection system is not a good geochemical exploration tool for the PGE, but it is useful in studying the composition of individual grains and small amounts of powder.

B.7. Ion Chromatography

Here, the PGE, in solution as various molecular complexes (such as cyanide complexes), are passed through a column filled with an ion - charged resin. The different PGE complexes, carried by a variety of solvents, travel through the resin column at different speeds - separating the Pt, Pd, Au, and Ag. As each of these noble element complexes emerges from the column, the quantity is detected by its electrical conductivity. An ultraviolet light detector is an alternative to the conductivity detector.

B.8. Inductively - Coupled Plasma (ICP)

In both of the following ICP detection systems, the PGE, in solution, are introduced into a high temperature plasma of argon gas. In the case of ICP - emission spectroscopy, the light energy emitted by each excited element species is detected by individual, tuned light detectors (adjusted for each element). In the case of ICP - mass spectroscopy, the individual isotopes of the PGE (such as Pt 194, 195, and 198) are separated within the instrument and "counts" of individual isotopes are performed by a series of detectors adjusted to the isotope masses of interest.

IV. Analytical Techniques

A. Inorganic Leach Methods

Because of the resistance to acid attack of Ir, Ru, Os, most inorganic leach methods have been directed at Pt, Pd, Au, and Ag.

A.1. Colorimetric determination

Colorimetric methods for the PGE require extensive wet chemical pretreatment (see Faye, 1969) to separate the noble elements. Each element, in a variety of acid solutions and usually as a chloro - or - bromo - complexes, is then complexed with various organic reagents (such as tri-n-butyl phosphate for Pt, p-nitroso-dimethylanaline for Pd and Ru, pyrogallol for Os, or just as the bromo-complex for Rh and Ir. These individual solutions for each element, in each sample, are then read in a colorimeter (with wavelengths for the afore-mentioned complexes ranging from 350 µm for Pt up to 600 µm for Ru). Detection limits for the PGE by this method are 0.1 ppm and higher.

A.2. Atomic absorption determination

A 10 g sample may be leached with a concentrated HBr + Br_2 solution, producing Pt, Pd, and Au bromo-complexes. Methylisobutilketone (MIBK) is added and the solutions shaken to extract the Pt, Pd, Au bromo-complexes into the immiscible organic layer. This MIBK is then aspirated into the flame of an atomic absorption instrument and the amounts of Pt, Pd, and Au determined one at a time with suitable light source lamps. The detection limits are about 0.05 ppm under best circumstances (for instance, with no interference from Fe).

A.3. Neutron activation determination

Here, the wet chemistry is performed after irradiation of a 100 - 500 mg sample to isolate the PGE from the many other irradiated species in the sample. The radioactivity of the PGE are then measured and compared to known standards. The wet chemical separations vary with the rock type. Commonly used reagents are HF for digestion of silicates, Na_2O_2 and NaOH for alkali fusions, and Se and Te for co-precipitation of the precious metals. Disadvantages of this method of analyzing for PGE directly in the sample are: 1) the small sample size (remember, we want to make the sample size large to minimize the sampling error prevalent in PGE analysis), 2) the fact that Rh^{104} has a short half-life and cannot be determined unless a high energy neutron source is used, and 3) chromites, two separate determinations must be done to retain Os and Ru in the method. Detection limits range from 0.5 ppb for Ir to 20 ppb for Ru.

B. Organic leach method to atomic absorption finish

A sodium cyanide leach of Pt, Pd, Au, and Ag is followed by conversion to the bromo-complexes with HBr + Br_2. The complexes are then extracted into MIBK and determined by an atomic absorption spectrometer. Detection limits for this method range from 0.1 - 10 ppm for Au, Pt, Pd, and Ag.

C. Organic leach/Ion chromatography

This method for Pt, Pd, Au, and Ag involves a hot NaCN leach of the sample, to produce cyanide complexes of the precious metals. Alternatively, the sample could be leached by aqua regia, or HBr + Br_2, or sintered with Na_2O_2; then, the solutions from these digestions would be evaporated to dryness and the resulting precious metal salts dissolved in NaCN to produce the same cyanide complexes as in the NaCN leach. In cyanide form, the precious metals are injected into an ion chromatograph and detected at the 1 - 2 ppb level (for Pt, Pd, Au, and Ag, only).

D. Emission spectroscopy

Here, 5 - 10 mg of sample are arced in the graphite electrode. Although the sample digestion is total, the detection system of the spectrograph has poor sensitivity (due mainly to the dependence on a photographic emulsion as the detector, and the detection limits are 2 ppm for Pd and Au, 10 ppm for Pt, 20 ppm for Ir and Rh, 200 ppm for Rh, and 400 ppm for Os). The small sample size and high detection limits make this an inappropriate technique for geochemical exploration for the PGE.

E. Fire - assay preconcentration methods

E.1. Classical lead assay

Probably the most ancient chemical method known, lead fire-assay was well established 1,000 years ago, and had its roots in the age of the Egyptian Pharoahs. Although the chemicals may vary slightly from assayer to assayer, the usual method involves mixing powdered sample with the following powdered chemicals: litharge (PbO), silica (SiO_2) , sodium carbonate (Na_2CO_3), sodium tetraborate ($Na_2B_4O_7$, and a reducing agent, which could be baking flour, graphite powder, coke, or potassium bitartrate (Argol). This mixture (flux) will melt and digest the sample at high temperatures (about 1000 C). Part of the PbO is reduced to Pb, which collects the PGE, Au, and Ag. The lead button is removed from the rest of the mixture (which consists of silicates, oxides, and other non-metallics) when cool. The lead is then placed in a bone-ash cup (cupel) and oxidized at 800° C. The lead oxide soaks into the cupel, leaving behind the metallic silver, gold, and PGE. Silver (about 5 mg) may be added to the flux or to the lead button so that the precious metals are in a silver matrix after the oxidation of the lead in the cupel (cupellation). The silver bead, with the precious metals, is then processed in one of the following metal determination schemes.

E.1.a. Pb assay/gravimetric determination by acid parting

The Ag bead is weighed and digested in hot HNO_3; the acid will dissolve the Ag and some Pd. The undigested residue contains Au and the PGM if they are present in the sample. The weight of the residue is counted as gold, and the difference between it and the original bead weight is counted as Ag. If silver was added to collect the precious metals, its weight must be subtracted to achieve the silver value of the sample. Detection limits are 0.25 ppm for Au and Ag, with a 15 g sample.

E.1.b. Pb assay/acid digestion to atomic absorption determiation

1. Flame atomic absorption determination

The silver bead is digested in hot HNO_3 and the silver content is determined by flame-AA on the nitric acid. The residue is digested in aqua regia and taken to dryness.
HBr + Br_2 is added to create the bromo-complexes, which are then extracted into MIBK. The MIBK is aspirated into the flame of the atomic absorption spectrometer to determine Au, Pt, and Pd at a detection limit of 0.05 ppm for a 15 g sample.

2. Graphite furnace (flameless) atomic absorption determination

In this method, gold, instead of silver, is added to the fire-assay flux or lead button. The gold fire-assay bead is digested in aqua regia and this solution is atomized in the graphite furnace of the atomic absorption spectrometer. Detection limits are 1 ppb for Pd, 2 ppb for Rh, and 5 ppb for Pt, with a 15 g sample.

3. ICP - mass spectroscopy determination

A gold fire assay bead is dissolved in aqua regia and the solution (diluted) is atomized into the plasma jet of an inductively coupled plasma-mass spectrograph. Detection limits for a 15 g sample are Pt - 1 ppb, Pd - 0.1 ppb, Rh - 0.001 ppb. Pt and Pd are blank limited ; that is, detection limits are restricted by Pt and Pd contaminants in the chemical reagents.

E.1.c. Pb assay/emission spectroscopy determination

A fire assay silver bead is inserted into the graphite electrode of an emission spectrograph and arced to produce a diffracted spectrum on photographic emulsion (see Adrian and Carlson, 1989, appendix x). Detection limits for a 15 g sample are Pt - 3ppb, Pd - 0.7ppb, Rh - 7ppb, Ru - 70ppb, Ir - 7ppb, Os - 150ppb, and Au - 0.7ppb.

E.2. Nickel - sulfide assay/acid digestion

The NiS fusion currently used by Meier and otheres (1989) consists of a 10 g sample being fused at 1050° C by a flux mixture of Ni powder, silica (SiO_2), sodium carbonate (Na_2CO_3), sodium tetraborate ($Na_2B_4O_7$), and powdered sulfur. The resulting NiS button, containing the precious metals, is dissolved in hot HCl. The PGE sulfide residue is then dissolved in aqua regia, except for determination by neutron activation where analysis is performed directly on the filtered sulfide residue. The determination techniques follow:

E.2.a. NiS assay/Atomic Absorption determination

Here, the diluted aqua regia is atomized in either a flame, or flameless (graphite furnace) atomic absorption spectrometer. Detection limits for a 15 g sample are blank limited in the low ppb range for Pt, Pd, and Rh because of contaminated $NiCO_3$ in the flux mixture. Use of Ni powder purified by a carbonyl process should eliminate the blank problem.

E.2.b. NiS assay/neutron activation determination INAA

In this method, the NiS fusion/acid digestion is performed as preconcentration, prior to irradiation, of the PGE. The sulfide residue left from the HCl digestion is the irradiated medium. This instrument neutron activation analysis method produces detection limits of Pt - 5ppb, Pd - 5ppb, Rh - 1ppb, Ru - 3ppb, Ir - 0.1ppb, and Os - 2ppb for a 50 g sample.

E.2.c. NiS assay/ICP - MS determination

The digested sulfide residue, in dilute agua regia, is pumped into the hot argon plasma of the inductively coupled plasma - mass spectrometer. Masses measured are Pt^{194}, Pt^{195}, Pd^{105}, Rh^{103}, Ru^{99}, Ir^{191}, Ir^{193}, and Os^{189}. Detection limits for a 10 g sample are: Pt - 0.3 ppb, Pd - 0.4 ppb, Rh - 0.1 ppb, Ru - 0.9 ppb, Ir - 0.4 ppb, and Os - 0.3 ppb.

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5/14/91

APPENDIX D: DESCRIPTIVE MODEL FOR PGE (AU) PLACER DEPOSITS

Michael L. Zientek
U.S. Geological Survey

SUMMARY

Environment:

Deposits of gravel, sand, silt, and clay, and their consolidated equivalents, that contains grains and nuggets of platinum-group element minerals and Au.

Principal commodities: PGE

By-products: Au, occasionally diamonds

Examples of typical occurrences:

Urals Mountains placers, USSR; Choco district, Columbia; Goodnews Bay, Alaska, U.S.A.; Tulameen placers, British Columbia, Canada.

General References: Mertie (1969, 1976); Raicevic and Cabri (1976); Smirnov (1977).

Regional Geologic Attributes

Tectonostratigraphic setting:

Usually found in accretionary complexes formed along convergent plate margins.

Regional setting :

Dominantly alluvial deposits representing a mix of depositional environments and energy levels. Highest PGE and Au values near contact with bedrock; PGM may be concentrated in bedrock "traps" (natural riffles, fractured bedrock, dikes, bedding planes). Streams or rivers with PGM concentrations usually head in regions of ultramafic rock (Alaskan-type ultramafic complexes).

Age Range:

Quaternary; some deposits may be late Tertiary.

Local Geologic Attributes

Host rocks :

Productive strata generally are deposits of sand and gravel of fluvial or glacio-fluvial origin that directly overlie bedrock. Alluvial PGM may occur a meter into underlying fractured or shattered bedrock; increased recovery was achieved by stripping a meter of bedrock in both the Urals and Goodnews Bay deposits.

Size and shape of deposits :

Productive strata range from few centimeters to 10's of meters in thickness. Length of paystreaks vary considerably. One deposit in the Urals (Iss and Tura Rivers) extended for 160 km from bedrock source (Weressowy-Onwal dunite); Au and PGM placers extend for 120 km downstream from the Tulameen complex. Paystreaks extending over 60 km are found in the Choco district in Columbia. Widths of paystreaks range from 10's of meters to almost 5 kilometers; widths of 300 to 600 m are common.

Au/PGM ratios :

In the upstream reaches of some deposits, close to the PGM source, little or no Au may be present. Further downstream Au/PGM varies: 4/1 (Tulameen); 1/5 (Urals); 1/3 to 22/1 (Choco district, Columbia); 1/50 (Goodnews Bay, Alaska). Au/Pt may vary from drainage to drainage in a district but generally increases away from the bedrock source for PGM. By comparison, gold placers in California derived predominantly from low sulfide-Au quartz veins have Au/PGM ranging from 500/1 to 1000/1. This may suggest that Au and PGM in these deposits originate from different sources.

Mineralogy and Textures:

The principal mineral is Pt-Fe alloy, typically with inclusions of Os-Ir alloy. Minor and rare minerals include: a variety of Os-Ir-Ru alloys, tulameenite, platiniridium, laurite, geversite, irasite, erlichmanite, sperrylite, cooperite, mertieite, hollingsworthite, cuproplatinum, braggite, and a variety of unnamed phases. Generally, the minor and rare phases are found as inclusions in or intergrowths with Pt-Fe alloy although discrete grains of these phases can also be found.

Magnetic concentrates from Goodnews Bay in Alaska contain magnetite grains with amoeboid inclusions of Pt-Fe alloy and lathes of Ir-Fe alloy intergrown with magnetite. Other PGM occurred with the Pt-Fe and Ir-Fe alloy (sperrylite, hollingworthite, and 3 unnamed phases) (Rosenblum and others, 1986).

Inclusions of chromite commonly are found in the PGM. Magnetite and olivine inclusions have also been described. Nixon and others (1988) investigated the composition of olivine and chromite inclusions in PGM from Tulameen placers and determined they closely match the composition of these phases in chromitite schlieren in the Tulameen intrusion.

Mertie (1976) described the following inclusions found as insoluble residue from the dissolution of 8 Pt-Fe alloy granules that were uniform with smooth surface, devoid of cracks, cavities, or external signs of adhering intergrowths: Os-Ir alloy, enstatite, chromite, rutile, tremolite, epidote, spinel, sphene, diamond, tourmaline, topaz, and corundum.

Minerals found in concentrates vary depending on rock types present and distance from source. The principle mineral is magnetite; chromite and ilmenite are common. Other phases reported include : hematite, olivine, pyroxenes, amphiboles, pyrite, arsenopyrite, galena, chalcopyrite, pentlandite, cinnabar, zircon, rutile, corundum, sphene, garnet, apatite, tourmaline, epidote, chlorite, dolomite, serpentine, quartz, feldspars, and clay.

Size of particles:

There is not much detailed information on the size of particles but available information suggests the grain size of the particles decreases away from the bedrock source. The largest nuggets were found in the Urals placers; one was reported to weigh over 11 kg. The largest nugget reported from Goodnews Bay was 62.2 g. Large nuggets generally are found close to the bedrock source. The PGM in the Urals placers are said to range in size from 0.5 to 18 mm in diameter (Hulbert and others, 1988). In Columbia, the particles ranged from < 0.075 mm to 0.85 mm. Sizes varied between different valleys; screened samples from 4 different areas in Columbia showed the following results: (1) 29 % of grains with mean diameter of 0.21 mm; (2) 33 % of grains with mean diameter of 0.21 mm; (3) 50 % of grains with diameters between 0.1 and 0.15 mm, and (4) 50% of grains with diameters between 0.21 and 0.30 mm. Detailed sieve analyses from Goodnews Bay showed the greatest volume of Pt-Fe alloy had a mean diameter of 0.42 mm; the greatest volume of Os-Ir alloy had a mean diameter of 0.3 mm. Sieve records for the paystreak on the valley floor of the Salmon River, clearly document the decrease in grain size downstream away from the source.

	Percentage of grains		
Claim	**mean diameter >0.83 mm**	**mean diameter >0.42 to <0.83**	**mean diameter <0.42 mm**
2B	26.57	42.35	31.08
15B	2.41	10.39	87.20

Claim 2B is immediately downstream from the mouth of the last tributary carrying PGM to the Salmon River. Claim 15B is approximately 5 km downstream from 2B.

Morphology of particles

Limited descriptions suggest particles are rounded and flattened during transport. Granules showing little wear are described as angular to subangular, with sharp, irregular protrusions, and rough pitted surfaces. With wear, the grains become rounded, resembling fine shot. With continued transport, the grains may be flattened.

PGE tenors:

Singer and Page (1986) present tonnage and grade curves based on 83 deposits from the Urals. 90 percent of the deposits have a grade of 0.33 ppm or higher; 50 percent have a grade of 2.5 ppm or higher; 10 percent have grades of 6.5 ppm or higher. Highest grades reported were close to 200 ppm (Mertie, 1969). Tributaries near the ultramafic source in the Goodnews Bay placers were reported to have average grades of 0.4 to 0.6 ppm; highest grades were close to 2 ppm (Mertie, 1976). A bulk sample collected at Tulameen contained 6.1 ppb Au and 0.7 ppb Pt (Raicevic and Cabri, 1976).

PGE Geochemistry:

The proportions of the PGE in these placer deposits is quite unique and is virtually identical to the PGE proportions in chromitite schlieren found in Alaskan-type ultramafic intrusions typically found in the source regions for these deposits. On chondrite-normalized PGE diagrams, a "M"-shaped pattern is evident, the proportions of Pt and Ir being highest, the proportions of Pd and Ru being lowest, with Os having intermediate values (Figures 44 and 45). This reflects the mineralogy of these ores, Pt-Fe alloy and Os-Ir alloys with little else. This contrasts with sulfide-dominant systems, where Os-Ir are typically low and Pt and Pd are high and with podiform chromites, dominated by the mineral laurite, which typically have high Os, Ir, and Ru, and low Pt and Pd.

The compositions of these deposits can be modeled as a mixture of Pt-Fe alloy and Os-Ir alloy. This is further illustrated in Figure 46, a plot of the proportion of Pt versus the proportion of Os+Ir. The data for these placers essentially forms a linear trend, showing increasing Os+Ir with decreasing Pt; however compositions are Pt dominant and lie near the range of reported lode compositions from Alaska-type ultramafic intrusions in the Urals. The composition of PGM from gold placers from California is also shown in Figure 13; their compositions span a wider range; some quite rich in Os+Ir. PGM from the Au deposits in the Witswatersrand deposits are dominated by Os-Ir alloys. The composition of vein deposits of Os-Ir alloy in sheared serpentinite from the Adamsfield district in Tasmania is also shown.

The proportions of the PGE can vary in a deposit. Mertie (1976) showed different tributaries derived from the same ultramafic intrusion have distinctly different PGE proportions. In addition, the proportion of Os, Ir, and Rh increase, and Pt decreases going downstream (Figure 47). The differences between tributaries is thought to reflect variations in the PGE in the lode source, whereas changes in PGE proportions downstream are thought to reflect the difference in mean size between Pt-Fe alloy and Os-Ir alloy. Os-Ir alloy is finer-grained and is more quickly dispersed down the alluvial channel that the heavier, larger particles of Pt-Fe alloy.

Sources:

Alaskan-type ultramafic intrusions. PGM are enriched in chromitite schleiren and Fe-Ti-V lens and layers in these deposits but may also occur disseminated in the ultramafic rock.

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Figure 44. Chondrite normalized PGE diagrams for analyses of placer platinum-minerals, Goodnews Bay, Alaska (Table 4, analyses A and B; Mertie, 1976) and Choco district, Columbia (Table 37, analysis D; Mertie, 1969). Platinum metals computed free of Au and impurities.

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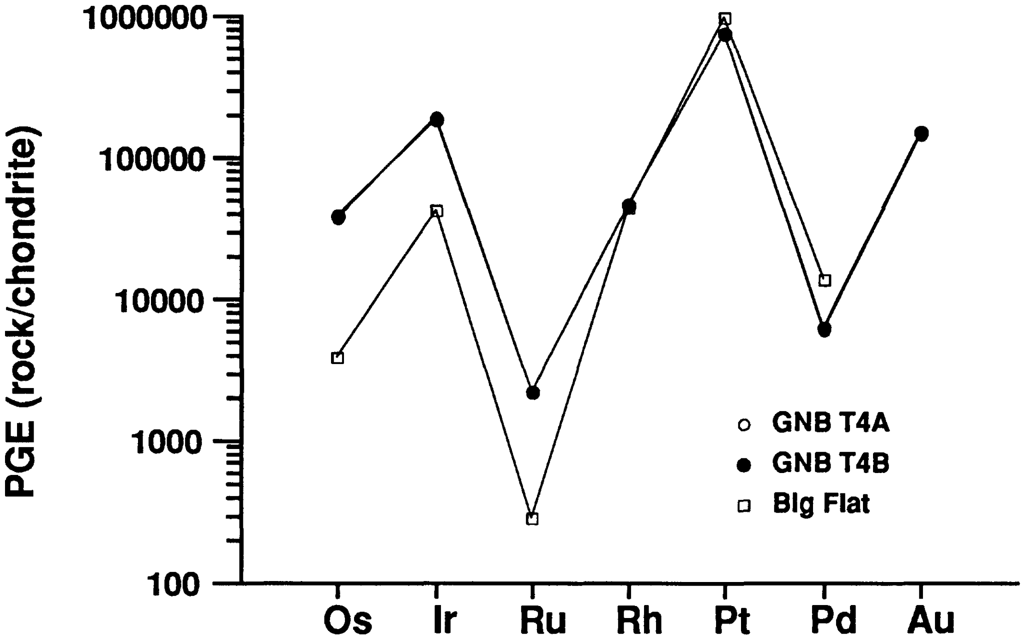
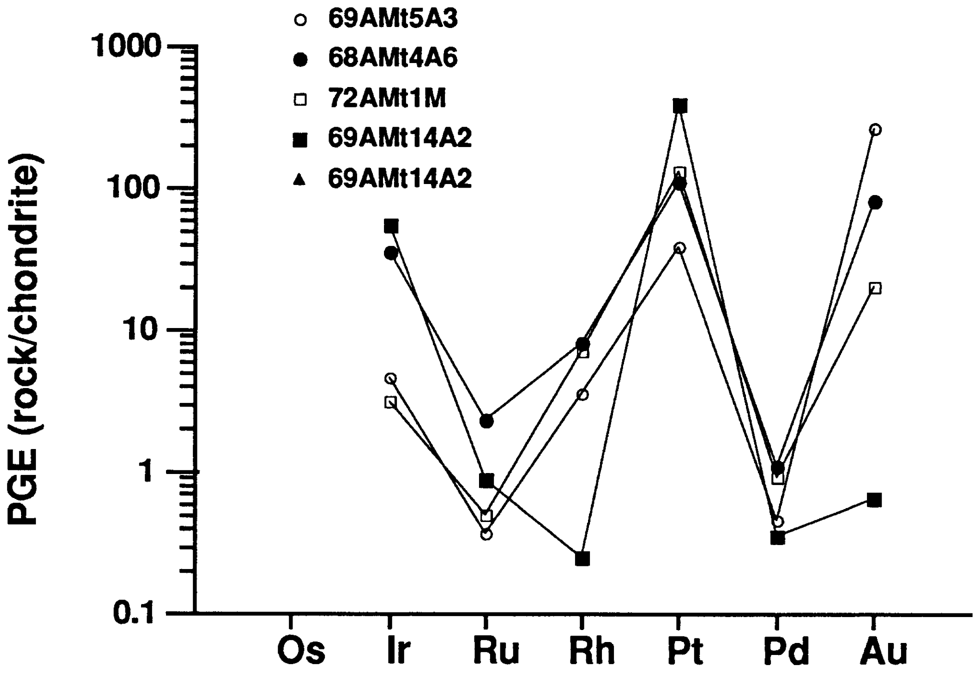

PGE (rock/chondrite)
1000000
100000
10000
1000
100
Os
Ir
Ru
Rh
Pt
Pd
Au
○ GNB T4A
● GNB T4B
□ Big Flat

Figure 45. Chondrite normalized PGE diagram for analyses of magnetic (68AMt 5A3, 69 AMt14a2, and 68AMt4A6) and non-magnetic (72AMt 1M) concentrates, Goodnews Bay, Alaska. Data from Rosenblum and others (1986).


○ 69AMt5A3
● 68AMt4A6
□ 72AMt1M
■ 69AMt14A2
▲ 69AMt14A2
PGE (rock/chondrite)
1000
100
10
1
0.1
Os
Ir
Ru
Rh
Pt
Pd
Au

……

Figure 46. Variation in the proportion of Pt to Os + Ir for PGE- placer and lode deposits. PGE analyses were recomputed to 100 percent, free of Au and impurities. Data from Mertie (1969).

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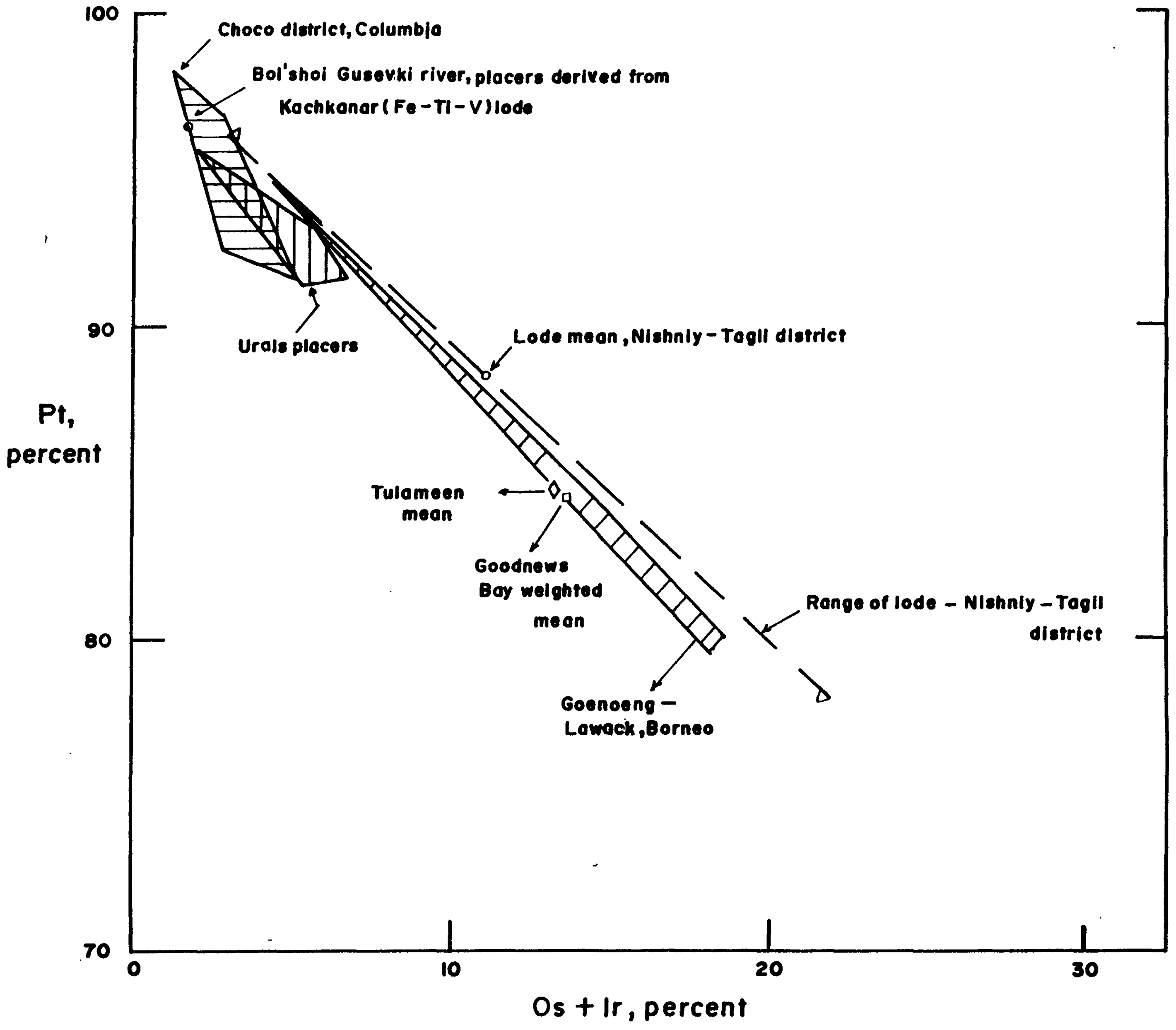
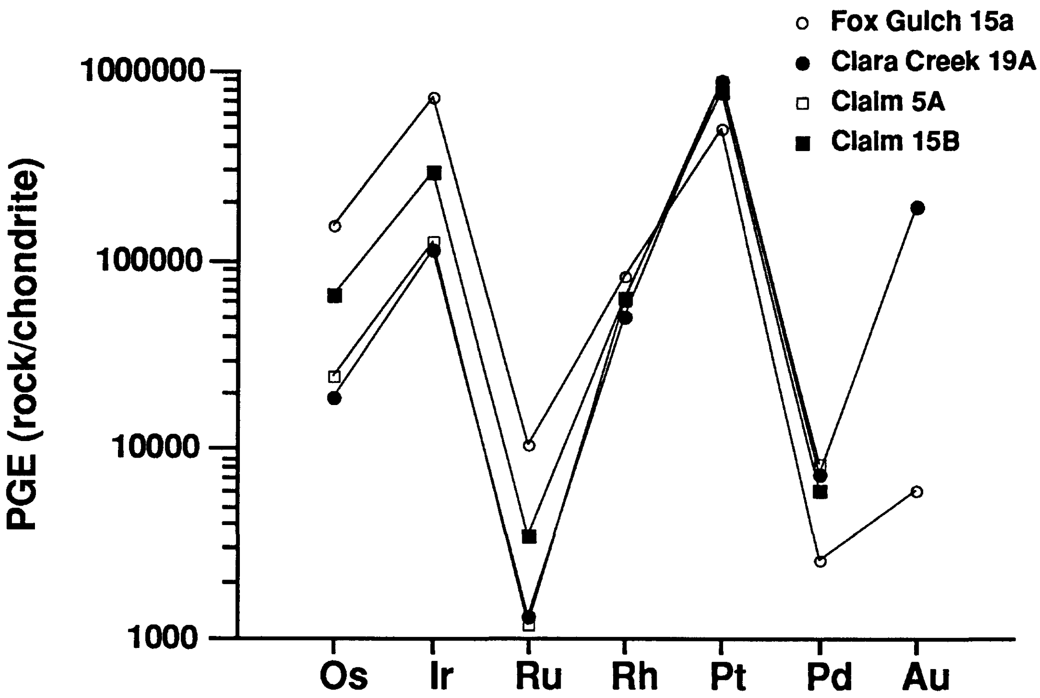

Choco district, Columbia
Bol'shoi Gusevki river, placers derived from Kachkanar (Fe-Ti-V) lode
Urals placers
Lode mean, Nishniy-Tagil district
Tulameen mean
Goodnews Bay weighted mean
Range of lode - Nishniy-Tagil district
Goenoeng - Lawack, Borneo
100
90
80
70
Pt, percent
0
10
20
30
Os + Ir, percent

Figure 47. Chondrite normalized PGE diagrams for analyses of platinum minerals from placer deposits, Goodnews Bay, Alaska. Mean of analyses, Clara Creek (circle); and Fox Gulch and the valley of Platinum Creek above the mouth of Squirrel Creek (dot). Mean analyses for claim SA (square) and 15 B (triangle) for valley floor pay streak on Salmon River. Claim 15 B is downstream of 5 A. Analyses of platinum metals computed free of gold and impurities (Mertie, 1976).


○ Fox Gulch 15a
● Clara Creek 19A
□ Claim 5A
■ Claim 15B
PGE (rock/chondrite)
1000000
100000
10000
1000
Os
Ir
Ru
Rh
Pt
Pd
Au

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5/14/91

APPENDIX E: DESCRIPTIVE MODEL FOR PGE ASSOCIATED WITH ALASKAN-TYPE ULTRAMAFIC COMPLEXES

Michael L. Zientek
U.S. Geological Survey

SUMMARY

Environment:
Small, shallow-level ultramafic plutons in subduction-related orogenic belts.

Principal commodities produced/anticipated: PGE

Byproducts: Cu, Ni, Co

Examples of typical occurrences:
Tulameen Complex, British Columbia, Canada; Duke Island Ultramafic Complex, southeastern Alaska, U.S.A.; Guseva Gora-Kachkanar and Nizhnii Tagil intrusions in the Ural Mountains, U.S.S.R.; Inagli intrusion in the Aldan shield, U.S.S.R.

General references: Irvine (1974); Findlay (1969); Smirnov (1977); Mertie (1969).

REGIONAL GEOLOGIC ATTRIBUTES

Tectonostratigraphic setting:

Ultramafic intrusions found in subduction-related fold belts or mobile belts near plate suture zones or margins. Some investigators believed compression was still occurring at the time of crystallization of the intrusions (Irvine, 1974); in other cases, the intrusions may be post-orogenic (Gray and others, 1986).

Regional setting:

In some regions, the plutons intrude and are closely associated with arc volcanic rocks or derived sedimentary rocks. In other settings, the intrusions are emplaced into obducted ophiolite assemblages. There are well developed contact aureoles when lithologic contacts have not been disturbed by later deformation. Plutons commonly form linear belts associated with gabbroic intrusions that parallel the trend of the subduction complex. On a local scale, the ultramafic complexes commonly intrude spatially associated igneous units. Depth of emplacement is shallow; Razin (1976) estimated 1 to 3 km for intrusions in the Ural Mountains.

Age range:

The intrusions in the Ural Mountains are Paleozoic; the intrusions in British Columbia (Tulameen, Polaris, Hickman, Gnats Lake, Menard Creek) are thought to be Late Triassic although some may be as young as Middle Jurassic (Nixon and Rublee, 1988); the intrusion in the Klamath Mountains are Jurassic (Gray and others, 1986); the intrusions in the Klukwan-Duke mafic/ultramafic belt (Duke Island and others) are Early Cretaceous (Brew, 1988).

LOCAL GEOLOGIC ATTRIBUTES:

HOST ROCKS:

Size and morphology of intrusions

Intrusions are small stocks or plugs roughly circular or elliptical in plan. Composite plutons are common. Areal extent of the intrusions rarely exceeds 60 km^2; the diameter of an intrusion is typically only a few kilometers. Thickness of layered cumulates may exceed 3 km in some intrusions.

Igneous stratigraphy (rock types, crystallization relation, modal and compositional variation)

The principal ultramafic rocks are cumulates. The characteristic mineral association is olivine, diopsidic clinopyroxene, magnetite, and hornblende. Plagioclase and orthopyroxene are exceedingly rare in the ultramafic rocks.

The intrusions are generally composed of varying proportions of dunite, wehrlitic peridotite, olivine clinopyroxenite, clinopyroxenite, magnetite-hornblende clinopyroxenite, and hornblendite. The lithologies may show a concentric zonal arrangement (typically dunite core surrounded by zones of clinopyroxenite and hornblendite). Cumulus layering, defined by varying proportions of cumulus olivine, diopsidic clinopyroxene, and magnetite, may also be developed. Fragmental layers and large blocks and fragments are common. Depositional structures are well developed in some intrusions. Concentrations of chromite are present in the olivine-rich ultramafic rocks (olivine cumulates or dunites) and high concentrations of titanomagnetite are found in some clinopyroxenites and hornblendites.

Replacement dunites and peridotites are present in some intrusions. Their bodies have sharp boundaries, irregular shapes, and contain remnants of original rocks. They transgress layering but rarely displace or distort it. Veins of clinopyroxene or clinopyroxene and olivine are common near the replacement bodies. Recrystallization results in coarse-grained olivine and pyroxene in dunite and olivine clinopyroxenite.

Penetrative fabrics are developed in some intrusions. Undulatory extinction of olivine, wavy or patchy extinction in pyroxene, deformed and bent pyroxenes, and incipient recrystallization can be observed.

Zoned plutons that grade from ultramafic rocks through gabbros and diorites into tonalites and granodiorites are probably not Alaskan type intrusions. These intrusion may contain orthopyroxene in the ultramafic rocks.

Composition of the parent magma:

Irvine (1974) proposed that these types of ultramafic complexes are derived from liquids that are critically undersaturated with silica, such as a mafic alkaline suite composed mainly of ankaramite, alkalic augite basalt or trachybasalt, and hornblende trachybasalt.

Associated rocks:

The ultramafic intrusions are generally associated with gabbroic rocks of variable composition: syenogabbro and syenodiorite (Tulameen Complex, Findlay, 1969); shonkinites, melanocratic alkaline syenites, and dioritic porphyries (Inagly massif, Razin, 1977); and olivine gabbro, norite, olivine ferronorite, and hypersthene gabbro (Duke Island, Irvine, 1974). The ultramafic rocks commonly intrude the gabbroic rocks. Granitoid plutons do not appear to be spatially or temporally associated with the ultramafic intrusions.

MINERALIZATION:

Permissive geologic setting for PGE deposits:

1. Chromitite schlieren in dunite,
2. Concentration of iron-titanium oxide minerals,
3. Concentrations of copper sulfide minerals (Salt Chuck, Alaska).

Chromitite schlieren in dunite:

Platinum-group elements in Alaskan-type ultramafic complexes are most commonly associated in small pods, lenses, veins, and schlieren of chromitite scattered through dunite. Most production of PGE is not from the chromitites themselves but from eluvial and alluvial placers derived from them. Examples of intrusions with PGE-enriched chromitites include the Nishniy-Tagil (Nizhne Tagil) and Inagly massifs in the Soviet Union (Mertie, 1969; Smirnov, 1977; Hurlbut and others, 1988) and the Tulameen Complex in British Columbia (St. Louis and others, 1986; Nixon and others, 1988; Nixon and Rublee, 1988; Talkington and Watkinson, 1986).

Size and shape of deposit

The chromitites are generally small and discontinuous. At the Inagly massif, chromitite segregations form nests, schlieren, lenses, and veins whose dimensions vary from a few centimeters to a few meters. Segregations were noted to be concentrated in the central portions of dunite exposures. Approximately, 600 masses of chromite-rich segregations were found in the Nishniy-Tagil intrusion. The segregations varied from small pockets several centimeters in diameter to shoot-or vein-like bodies extending for tens of meters along strike, are 6-7 meters thick, and extended to depths of 150 m. Only about 40 percent of the chromitites were enriched in PGE. At Tulameen, chromitite concentrations occur in pods, lens, veins, or schlieren. These schlieren are generally 0.5 to 2 cm wide and 5 to 25 cm in length. The schlieren are oriented parallel to a weak to strong penetrative foliation in the dunite; boudinaged chromitite layers, tight to isoclinal minor folds, and domical folds have been observed. These penetrative fabrics can be equated with regional foliation developed in the country rocks.

PGE tenors

Inagly, U.S.S.R. - 1 to 40 ppm PGE

Tulameen, British Columbia, Canada - Pt (60 to 13,830 ppb, average 3,410 ppb); Ir (13 to 236 ppb, average 100 ppb); Au (1.2 to 44 ppb, average 8.2 ppb); Os (10 to 80 ppb, average 40 ppb); Pd (not detected). Selected assays to 17 ppm. Pt:Pd ranges from 75 to 500.

Nishniy-Tagil, U.S.S.R. - 10's to 100's ppm PGE. A mass of high-grade chromite-platinum ore at the top of one ore body (Krutoylog) extended in one adit for a distance of 2 meters. From this deposit, 965 ounces of native platinum metals were recovered, of which the largest mass weighed 13 3/4 troy ounces (Mertie, 1969).

Goodnews Bay, Alaska, U.S.A. - chromitite pebbles recovered in dredging operations contained 1.8 ppm platinum metals.

MINERALOGY

Location	Principal Minerals	Minor and rare phases
Nishniy-Tagil	Pt-Fe alloy, platin-iridium	Os-Ir alloys (Osmiridium, iridosmine), tulameenite, irasite, cooperite, laurite.
Inagly	Pt-Fe alloy	Os-Ir alloys, cooperite
Tulameen	Pt-Fe alloys, sperrylite	tulameenite, stumpflite, geversite, genkinite, sperrylite, enlichmanite, laurite, rhodium, and iridium, sulfarsenides (hollingsworthhite/ irasite); Pt in solid solution in copper.

Other minerals at Tulameen include nickel sulfides (pentlandite, violarite, bravoite), nickel antomonides, nickel antimonide, nickel arsenides, Ni-Co-Fe sulfide, native Cu and Ag, copper oxide, nickel oxide.

Textures and sizes

Inagly - polymineralic; intergrowths and monomineralic grains and crystallites, 0.5 mm.

Nishniy-Tagil - generally molded upon chromite. Occur as: 1) isolated grains, 2) small, "nest-like" concentrations, 3) concentrations along the center of a chromitite segregation, 4) concentrations along contact between chromitite and surrounding rock.

Tulameen - Two modes of occurrence: 1) euhedral to subhedral inclusions in chromite, <2 μm to 30 x 35 μm, and 2) anhedral grains interstitial to chromite, typically <30 μm in diameter.

Compositional data

Tulameen - Talkington and Watkinson (1986) and St. Louis and others (1986) for PGE analyses of chromitites and other rocks, chromitite data plotted in Figure 48.

Nishniy-Tagil - see table 23 in Mertie (1969) for partial analyses of platinum metals.

Compare with Pt, Pd, and Rh analyses from Alaskan-type ultramafic complexes, California and Oregon (Gray and others, 1986). Generally, there are very few modern, complete analyses of the chromitites. Information shows enrichment in Pt and Ir and is generally compatible with composition of placer deposits derived from there intrusions.

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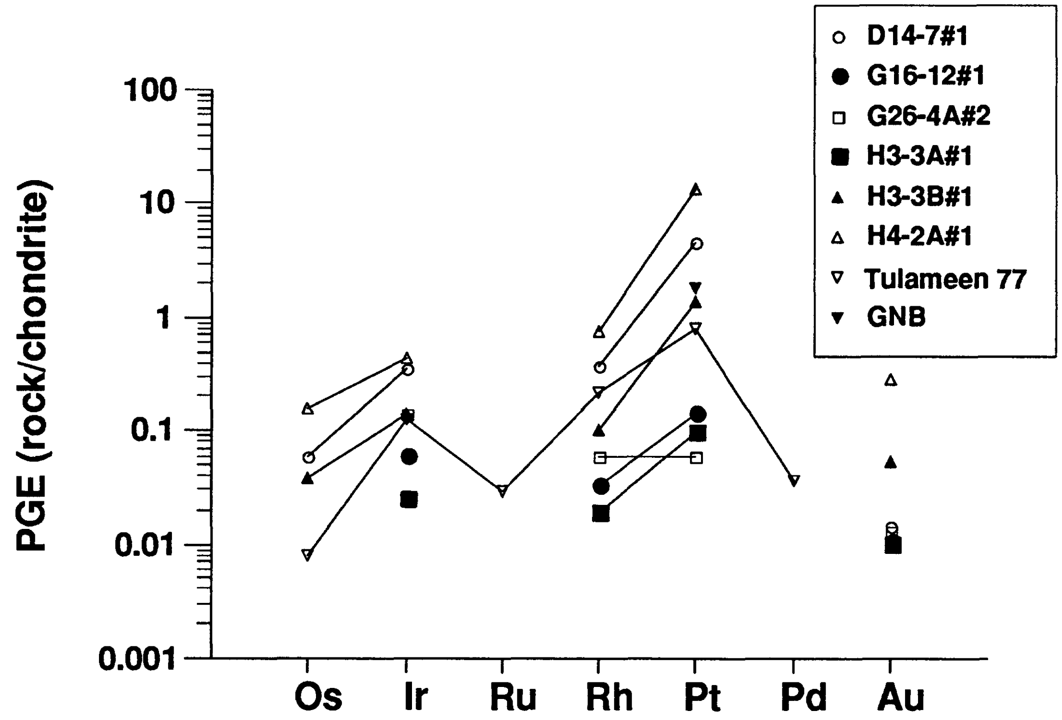

Figure 48. Chondrite normalized PGE diagram for analyses of chromitite from the Tulameen Complex, British Columbia and Goodnews Bay, Alaska. Tulameen data from St. Louis and others (1986) and Talkington and Watkinson (1986). Goodnews Bay data from Mertie (1976).

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Concentrations of iron-titanium-vanadium oxide minerals

Concentrations of iron-titanium-vanadium oxide minerals, either as lenses or layers in clinopyroxenites, also contain elevated concentrations of PGE. In the Russian literature, these deposits are referred to as the Rachkanar-type, an example of which is the Gusevogorsk deposit. In this deposit, Pt-Fe alloy is the predominant mineral; iridosmine, platin-iridium, cooperite, and osmium have also been noted. The dimensions of the particles were large, averaging 0.2 mm. Mertie (1969) notes that in five localities in the Urals, placers are derived from pyroxenite intrusions without dunite. Massive magnetite lens in hornblende clinopyroxenite from the Tulameen Complex contained 0.12 to 0.47 ppm Pt.

Vanadium-iron-copper deposits (Volkovo-type) occur in gabbros of a pseudo-stratiform clinopyroxenite-gabbro complex, the Barancha massif in the Soviet Union. Pd concentrations are found in chalcopyrite and bornite.

Concentration of copper-sulfide minerals

Concentrations of bornite, with some native Cu, gold, and chalcopyrite in the Salt Chuck intrusion in Alaska are enriched in palladium. Sulfide-rich rocks from the Tulameen Complex contain 120 ppb Pd on average.

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APPENDIX F. PGM, AU, AND CINNABAR OBSERVED IN THE FIELD IN PAN CONCENTRATE SAMPLES FROM THE RIAM PINANG AREA, TANAH LAUT SUBPROVINCE, SOUTH KALIMANTAN

DMR Platinum Exploration Team

Appendix F. PGM, Au, and cinnabar observed in the field in pan concentrate samples from the Riam Pinang area, Tanah Laut subprovince, South Kalimantan.

Sample Number	PGM					Au					cinnabar					Au : PGM	explanation
					total					total					total		
	vvf	vf	v	m	f	vvf	vf	f	m	f	vvf	vf	f	m	f		
RMP.89001.P	-	-	-	-	-	-	12	-	-	6	-	2	-	-	1		Au: subrounded; flake
RMP.89002.P	-	-	-	-	-	-	3	-	-	1.5	-	-	-	-	-		Au: subrounded, massive
RMP.89003.P	-	-	-	-	-	-	10	-	-	5	-	-	-	-	-		Au: subangular-subrounded, needle flake
RMP.89004.P	-	-	-	-	-	1	-	-	-	.25	-	-	-	-	-		
RMP.89006.P	-	-	-	-	-	-	2	-	-	1	-	-	-	-	-		Au: subrounded
RMP 89013.P	-	-	-	-	-	-	1	-	-	0.5	-	-	-	-	-		Au: subrounded, massive
RMP.89014.P	-	-	-	-	-	-	15	-	-	7.5	-	-	-	-	-		Au: subrounded, massive
RMP.89015.P	-	-	-	-	-	-	4	-	-	2	-	-	-	-	-		Au: subrounded, massive
RMP 89017.P	-	-	-	-	-	-	10	-	-	5	-	-	-	-	-		Au: subrounded, massive
RMP.89018.P	-	-	-	-	-	-	10	-	-	5	-	-	-	-	-		Au: subrounded, massive
RMP.89019.P	-	-	-	-	-	-	6	-	-	3	-	-	-	-	-		Au: subangular - subrounded, massive flake
RMP.89020.P	-	-	-	-	-	-	1	1	-	1.5	-	-	-	-	-		Au: subangular-subrounded, massive
RMP.89022.P	-	-	-	-	-	-	4	-	-	2	-	-	-	-	-		Au: subrounded, massive
RMP.89024.P	-	-	-	-	-	-	10	-	-	5	-	1	-	-	0.5		Au: subangular-subrounded, massive
RMP.89025.P	-	-	-	-	-	-	10	-	-	5	-	-	-	-	-		Au: subangular-subrounded; needle, massive
RMP.89026.P	-	-	-	-	-	-	7	-	-	3.5	-	-	-	-	-		Au: subrounded, massive
RMP.89027.P	-	-	-	-	-	-	7	-	-	3.5	-	-	-	-	-		Au: subangular-subround
RMP.89028.P	-	-	-	-	-	-	4	-	-	2	-	-	-	-	-		Au: subrounded, massive
RMP.89029.P	-	-	-	-	-	-	2	3	-	4	-	-	-	-	-		Au: subangular, massive
RMP.89030.P	-	-	-	-	-	-	4	-	-	2	-	-	-	-	-		Au: subrounded, massive
RMP.89034.P	-	-	-	-	-	-	2	-	-	1	-	-	-	-	-		Au: subrounded
RMP.89035.P	-	-	-	-	-	-	1	-	-	0.5	-	-	-	-	-		Au: subrounded
RMP.89037.P	-	-	-	-	-	-	1	-	-	0.5	-	-	-	-	-		Au: subrounded

Appendix F. PGM, Au, and cinnabar observed in the field in pan concentrate samples from the Riam Pinang area, Tanah Laut subprovince, South Kalimantan (continued).

Sample Number	PGM					Au					cinnabar					Au : PGM	explanation
					total					total					total		
	vvf	vf	v	m	f	vvf	vf	f	m	f	vvf	vf	f	m	f		
RMP.89038.P	-	-	-	-	-	-	1	-	-	0.5	-	-	-	-	-		Au: subrounded
RMP.89040.P	-	-	-	-	-	-	20	4	-	14	-	-	-	-	-		
RMP.89041.P	-	3	3	-	4.5	-	4	1	-	3	-	-	-	-	-	0.7:1	Au: subangular, PGM: angular-subangular, massive
RMP.89042.P	-	-	-	-	-	5	-	2	-	3.25	-	-	-	-	-		
RMP.89043.P	1	-	-	-	0.25	-	-	8	-	8	-	2	-	-	1	32:1	Au: subangular
RMP.89044.P	-	4	-	-	2	-	5	1	-	3.5	-	1	-	-	0.5	1.75:1	Au: subrounded, massive, PGM: angular-subangular, massive
RMP.89045.P	-	-	-	-	-	4	-	-	-	1	-	4	-	-	2		Au: subrounded, massive
RMP.89046.P	-	-	2	-	2	-	4	-	-	2	-	1	-	-	0.5	1:1	Au and PGM: subangular-subrounded, massive
RMP.89048.P	-	3	2	-	3.5	-	2	1	-	2	-	-	-	-	-	0.6:1	Au: rounded, PGM: subrounded
RMP.89051 P	-	-	-	-	-	-	-	4	2	8	-	-	-	-	-		Au: rounded-subrounded
RMP.89052.P	-	-	-	-	-	-	-	1	1	3	-	-	-	-	-		Au: rounded
RMP.89057.P	-	-	-	-	-	-	-	3	4	11	-	-	-	-	-		Au: subrounded
RMP.89058.P	-	-	-	-	-	-	5	1	-	3.5	-	-	-	-	-		Au: subangular
RMP.89059.P	-	-	1	-	1	-	8	6	1	12	-	-	-	-	-	12:1	Au, PGM: subangular
RMP.89060.P	-	-	-	-	-	-	2	3	2	8	-	-	-	-	-		+ 1 cc, 2 mc.
RMP.89062.P	-	-	-	-	-	-	2	3	-	4	-	-	-	-	-		Au: subrounded
RMP.89063.P	-	-	-	-	-	-	2	-	-	1	-	-	-	-	-		Au: rounded
RMP.89064.P	-	-	-	-	-	-	32	-	-	16	-	-	-	-	-		Au: rounded
RMP.89065.P	-	1	2	-	2.5	-	6	1	-	4	-	6	3	-	6	1.6:1	PGM: angular
RMP.89066.P	-	2	1	-	2	-	1	2	-	2.5	-	2	1	-	2	1.25:1	PGM: subangular
RMP.89067.P	-	-	-	-	-	-	3	-	-	1.5	-	-	1	-	1		Au: rounded
RMP.89068.P	-	1	-	-	0.5	-	6	1	-	4	-	-	1	-	1	8:1	PGM: rounded
RMP.89069.P	-	-	-	-	-	-	47	1	-	24.5	-	-	-	-	-		Au: subangular

Appendix F. PGM, Au, and cinnabar observed in the field in pan concentrate samples from the Riam Pinang area, Tanah Laut subprovince, South Kalimantan (continued).

Sample Number	PGM					Au					cinnabar					Au : PGM	explanation
					total					total					total		
	vvf	vf	v	m	f	vvf	vf	f	m	f	vvf	vf	f	m	f		
RMP.89070.P	-	-	-	-	-	-	47	-	-	23.5	-	-	-	-	-		Au: subangular
RMP.89071.P	-	-	-	-	-	-	15	-	-	7.5	-	2	-	-	1		cinnabar: rounded
RMP.89072.P	-	-	-	-	-	-	11	19	2	28.5	-	-	-	-	-		
RMP.89074.P	-	-	-	-	-	1	18	-	-	9.25	-	12	-	-	6		Au: subrounded
RMP.89075.P	-	-	-	-	-	-	-	1	-	1	-	-	-	-	-		Au: rounded
RMP.89076.P	-	-	1	-	1	-	4	17	13	45	-	1	-	-	0.5	45:1	Au: angular-subrounded
RMP.89077.P	-	-	-	-	-	-	5	3	-	5.5	-	-	-	-	-		Au: rounded
RMP.89078.P	-	-	-	-	-	-	3	-	-	1.5	-	-	-	-	-		Au: rounded
RMP.89079.P	-	-	-	-	-	-	5	2	-	4.5	-	-	1	-	1		Au: rounded
RMP.89086.P	-	-	-	-	-	3	-	-	-	0.75	-	-	-	-	-		Au: rounded
RMP.89088.P	-	-	-	-	-	-	33	6	1	24.5	-	3	6	-	7.5		Au: subangular, cinnabar.: angular
RMP.89089.P	-	-	-	-	-	2	-	-	-	0.5	-	-	-	-	-		Au: rounded
RMP.89090.P	-	-	-	-	-	-	-	-	-	-	-	-	2	-	2		cinnabar: rounded
RMP.89091.P	-	2	-	-	1	-	-	1	-	1	-	-	-	-	-	1:1	Au, PGM: rounded
RMP.89092.P	1	1	-	-	0.75	-	-	2	-	2	-	-	-	-	-	2.7:1	Au, PGM: rounded
RMP.89093.P	2	8	-	-	4.5	-	-	2	-	2	-	-	-	-	-	0.4:1	Au, PGM: subrounded
RMP.89095.P	-	6	2	-	5	-	6	2	-	5	-	-	-	-	-	1:1	PGM: angular
RMP.89096.P	-	2	2	-	3	-	6	2	-	5	-	-	3	-	3	1.7:1	Au, PGM: subrounded
RMP.89097.P	-	-	-	-	-	-	1	-	-	0.5	-	-	-	-	-		Au: rounded
RMP.89098.P	1	-	-	-	0.25	2	-	-	-	0.5	-	-	-	-	-	2:1	Au, PGM: rounded
RMP.89099.P	11	4	5	-	9.75	-	2	-	-	1	-	1	-	1	2.5	0.1:1	PGM: angular
RMP.89100.P	2	-	-	-	0.5	-	2	-	-	1	-	-	-	-	-	2:1	PGM: rounded
RMP.89101.P	-	-	-	-	-	-	1	-	1	2.5	-	-	-	-	-		Au: subangular, needle, massive
RMP.89102.P	-	-	-	-	-	-	2	2	-	3	-	1	-	-	0.5		Au: subrounded, massive
RMP.89103.P	-	3	-	-	1.5	-	-	6	1	8	-	-	-	-	-	5.3:1	Au: subrounded, massive

Appendix F. PGM, Au, and cinnabar observed in the field in pan concentrate samples from the Riam Pinang area, Tanah Laut subprovince, South Kalimantan (continued).

Sample Number	PGM					Au					cinnabar					Au : PGM	explanation
	vvf	vf	v	m	total f	vvf	vf	f	m	total f	vvf	vf	f	m	total f		
RMP.89104.P	-	-	-	-	-	-	20	1	-	11	-	-	-	-	-		Au: subround-subangular, massive
RMP.89105.P	-	-	-	-	-	-	5	-	-	2.5	-	-	-	-	-		Au: angular-subrounded, massive
RMP.89106.P	-	-	-	-	-	-	-	10	-	10	-	-	4	-	4		Au: subround-subangular, massive
RMP.89107.P	-	-	-	-	-	33	7	-	-	12.25	-	-	-	-	-		Au: rounded
RMP.89108.P	-	-	-	-	-	-	1	1	-	1.5	4	-	1	1	4		Au: rounded
RMP.89109.P	-	-	-	-	-	20	20	5	-	20	-	-	-	-	-		
RMP.89110.P	-	-	-	-	-	5	-	-	-	1.25	-	-	-	-	-		Au: subrounded
RMP.89111.P	-	-	-	-	-	2	-	-	-	0.5	-	-	-	-	-		Au: subrounded
RMP.89112.P	1	-	-	-	0.25	-	1	-	-	0.5	-	2	-	-	1	2:1	Au, PGM: rounded
RMP.89113.P	14	6	-	-	6.5	2	2	-	2	5.5	-	-	-	-	-	0.8:1	Au, PGM: angular-subrounded
RMP.89114.P	1	1	2	-	2.75		3	4	-	5.5	-	-	-	-	-	2:1	PGM: subrounded
RMP.89115.P	-	-	-	-	-	2	-	-	-	0.5	-	-	-	-	-		Au: rounded
RMP.89116.P	-	3	-	-	1.5	-	6	-	-	3	-	1	-	-	0.5	2:1	Au, PGM: subangular, massive
RMP.89117.P	-	2	-	-	1	1	5	-	-	2.75	5	-	-	-	1.25	2.75:1	
RMP.89119.P	-	1	-	-	0.5	-	1	1	-	1.5	-	-	-	-	-	3:1	Au, PGM: subangular, massive
RMP.89121.P	-	-	-	-	-	1	-	-	-	0.25	-	-	-	-	-		Au: rounded
RMP.89127.P	-	-	-	-	-	2	2	2	-	3.5	11	2			3.75		Au, cinnabar: rounded
RMP.89128.P	-	-	-	-	-	-	3	-	-	1.5	-	7	12	-	15.5		Au, cinnabar: rounded-subrounded
RMP.89129.P	-	3	-	-	1.5	5	-	7	-	8.25	-	1	-	1	2.5		Au, cinnabar: rounded
RMP.89131.P	-	-	-	-	-	2	-	-	-	0.5	-	-	-	-	-		Au: rounded
RMP.89133.P	-	-	-	-	-	2	-	-	-	0.5	-	-	-	-	-		Au: rounded
RMP.89134.P	-	-	-	-	-	-	2	-	-	1	-	-	-	-	-		

Appendix F. PGM, Au, and cinnabar observed in the field in pan concentrate samples from the Riam Pinang area, Tanah Laut subprovince, South Kalimantan (continued).

Sample Number	PGM PGM					Au					cinnabar					Au : PGM	explanation
					total					total					total		
	vvf	vf	v	m	f	vvf	vf	f	m	f	vvf	vf	f	m	f		
RMP.89137.P	-	-	-	-	-	1	-	-	-	0.25	-	-	-	-	-		Au: rounded
RMP.89138.P	-	-	-	-	-	1	1	-	-	0.75	-	-	-	-	-		Au: rounded
RMP.89139.P	-	-	-	-	-	-	2	-	-	1	-	-	-	-	-		Au: rounded
RMP.89142.P	5	3	-	-	2.75	-	2	-	-	1	-	-	-	-	-	0.4:1	PGM: subangular - subrounded
RMP.89146.P	-	-	-	-	-	11	3	2	2	10.25	-	-	-	-	-		Au: angular
RMP.89146TP	-	-	-	-	-	2	6	4	3	14.5	-	-	-	-	-		Au: angular - subangular
RMP.89147.P	-	-	-	-	-	7	8	-	4	13.75	-	-	-	-	-		Au: subangular - angular
RMP.89147TP	-	-	-	-	-	1	2	-	-	1.5	-	-	-	-	-		Au: subrounded
RMP.89148.P	-	1	-	-	0.5	50	12	-	-	18.5	-	-	-	-	-		Au: angular - subangular
RMP.89149.P	-	-	-	-	-	8	10	5	-	12	-	-	-	-	-		Au: subrounded
RMP.89150.P	-	-	-	-	-	4	4	1	-	4	-	-	-	-	-		Au: subrounded
RMP.89151.P	-	-	-	-	-	-	3	-	-	1.5	-	-	-	-	-		Au: rounded
RMP.89152.P	-	-	-	-	-	-	1	1	-	1.5	-	-	-	-	-		Au: subangular
RMP.89154.P	-	-	-	-	-	-	2	-	-	1	-	-	-	-	-		Au: subrounded
RMP.89155.P	-	-	-	-	-	-	-	1	-	1	-	-	-	-	-		Au: rounded
RMP.89156.P	-	-	-	-	-	1	-	-	-	0.25	-	-	-	-	-		Au: rounded
RMP.89157.P	-	1	-	-	0.5	-	6	6	-	9	-	-	-	-	-	18:1	Au, PGM: subrounded
RMP.89158.P	-	-	-	-	-	-	3	-	-	1.5	-	-	-	-	-		Au: rounded
RMP.89159.P	-	-	-	-	-	-	2	-	-	1	-	-	-	-	-		Au: rounded
RMP.89161.P	-	-	-	-	-	95	2	9	-	33.75	-	-	-	-	-		Au: rounded
RMP.89162.P	-	-	-	-	-	34	3	-	-	10	-	-	-	-	-		Au: subrounded
RMP.89164.P	-	3	-	-	1.5	59	6	-	-	17.75	-	-	-	-		11.8:1	PGM: rounded, Au: subrounded
RMP.89165.P	-	-	-	-	-	27	6	-	-	8.25	-	-	-	-	-		Au: subrounded

Appendix F. PGM, Au, and cinnabar observed in the field in pan concentrate samples from the Riam Pinang area, Tanah Laut subprovince, South Kalimantan (continued).

Sample Number	PGM					Au					cinnabar					Au : PGM	explanation
					total					total					total		
	vvf	vf	v	m	f	vvf	vf	f	m	f	vvf	vf	f	m	f		
RMP.89166.P	1	-	-	-	0.25	5	2	-	-	2.25	-	-	-	-	-	9:1	PGM: rounded, Au: subrounded
RMP.89167.P	-	-	-	-	-	6	-	3	-	4.5	-	-	-	-	-		Au: rounded
RMP.89168.P	-	-	-	-	-	-	-	1	-	1	-	1	-	-	0.5		Au, cinnabar: rounded
RMP.89169.P	-	-	-	-	-	-	-	1	-	1	-	2	-	-	1		Au, cinnabar: rounded
RMP.89170.P	-	-	-	-	-	-	1	-	-	0.5	-	-	1	-	1		Au, cinnabar: rounded
RMP.89171.P	-	-	-	-	-	-	5	-	-	2.5	-	1	-	-	0.5		Au: rounded
RMP.89172.P	-	-	-	-	-	5	-	-	-	1.25	-	-	4	-	4		Au, cinnabar: rounded
RMP.89173.P	-	-	-	-	-	-	-	1	-	1	-	-	-	-	-		Au: rounded
RMP.89174.P	-	-	-	-	-	-	4	1	-	3	-	5	1	-	3.5		Au: rounded, cinnabar: angular
RMP.89175.P	-	-	-	-	-	8	5	6	-	10.5	-	-	-	-	-		Au: angular-subangular
RMP.89176.P	-	-	-	-	-	7	2	-	-	2.75	-	-	-	-	-		Au: subrounded
RMP.89177.P	-	-	-	-	-	2	1	-	-	1	-	-	-	-	-		Au: rounded
RMP.89178.P	-	-	-	-	-	19	8	3	3	17.75	-	-	-	-	-		Au: angular, 1cc = 2 mc
RMP.89179.P	-	-	-	-	-	4	1	-	-	1.5	-	-	-	-	-		Au: rounded
RMP.89180.P	-	-	-	-	-	9	1	-	-	2.75	-	-	-	-	-		Au: rounded
RMP.89181.P	-	-	-	-	-	8	4	2	-	6	-	-	-	-	-		Au: subrounded
RMP.89182.P	-	-	-	-	-	14	9	2	-	10	-	-	-	-	-		Au: subrounded
RMP.89183.P	-	-	-	-	-	-	5	2	-	4.5	-	-	-	-	-		Au: subrounded
Asam Janar.PC	-	-	-	-	-	-	7	-	-	3.5	-	-	-	-	-		Au: angular - subangular
Rinaat (PC)	-	-	-	-	-	-	1	-	-	0.5	-	-	-	-	-		Au: subrounded
Trini (PC)	-	-	-	-	-	8	-	-	2	6	-	-	-	-	-		Au: subangular
S. Burung, PC	-	-	-	-	-	1	3	-	-	1.75	-	-	-	-	-		Au: subrounded

Appendix F. PGM, Au, and cinnabar observed in the field in pan concentrate samples from the Riam Pinang area, Tanah Laut subprovince, South Kalimantan (continued).

Sample Number	PGM					Au					cinnabar					Au : PGM	explanation
	vvf	vf	v	m	total f	vvf	vf	f	m	total f	vvf	vf	f	m	total f		
RMP.89054Rf: PC	-	-	-	-	-	3	-	1	-	1.75	-	-	-	-	-		Au: angular - subangular
RMP.89090R: PC	21	6	2	-	10.25	-	-	-	1	2	-	-	-	-	-	0.2:1	PGM: angular - subangular
RMP.89137R: PC																	PGM: angular - subangular
RMP.89148R: PC	1	-	-	-	0.25	4	-	-	-	1	-	-	-	-	-	4:1	Au, PGM: subangular
RMP.89173R: PC	-	-	-	-	-	18	3	-	-	6	-	-	-	-			
RMP.89174R1: PC	2	-	-	-	0.5	1	-	-	-	0.25	-	-	-	-	-	0.5:1	PGM: subangular
RMP.89174R2: PC	-	-	-	-	-	5	-	-	-	1.25	-	-	-	-	-		Au: angular - subangular
RMP.89208R: PC	-	-	-	-	-	11	1	-	-	3.25	-	-	-	-	-		

f = vvf (0.25) + vf (0.5) + v + m (2)

APPENDIX G: DETAILED DESCRIPTION OF ROCK SAMPLES, RIAM PINANG AREA, SOUTH KALIMANTAN

Michael L. Zientek

U.S. Geological Survey

RMP 89001 R At least two rock types present: 1. very altered porphyritic andesite- 15 percent hornblende phenocrysts to 3 mm in aphanitic green-gray groundmass; 2. dunite - olivine cumulate - sheared, only 1 of 3 pieces could see rock texture; olivine appears to be relatively fresh; 1-2 percent disseminated chromite; only weakly magnetic

RMP 89002 R Dunite - olivine adcumulate? - two 3-5 mm crystals of pyroxene in two samples looked at; both appeared to be deformed

RMP 89003 R Fine-grained aphanitic basalt? - weakly magnetic

RMP 89004 R Two lithologies: 1. hornblende-plagioclase andesite porphyry; 15 percent hornblende phenocrysts to 3 mm; 5 percent plagioclase phenocrysts to 2 mm; one calcite filled vesicle; second sample has 25 percent plagioclase and 5 percent hornblende phenocrysts; in one sample, hornblende phenocrysts strongly aligned; 2. dunite - olivine cumulate - trace chromite and phlogopite?; cut by 1 cm dikelet of mafic material (pale green, aphanitic), weakly magnetic

RMP 89005 R Two lithologies: 1. aphanitic fine-grained basalt/basaltic andesite; 2. augite-plagioclase andesite porphyry - 30 percent augite phenocrysts to 5 mm and 5-10 percent plagioclase microphenocrysts to 1-2 mm in aphanitic groundmass; 1-3 percent calcite-filled amygdules

RMP 89006 F Medium-grained gabbroic rock - 60-65 percent plagioclase; 35-40 percent pyroxene; cut by thin calcite veinlets

RMP 89007 R Fine-grained aphanitic basalt/basaltic andesite? - two pieces are pale grey and contain 20 percent disseminated pyrite

RMP 89008 R Vesicular plagioclase - ferromagnesian mineral (olivine) phyric basalt - plagioclase phenocrysts to 2 mm; ferromagnesian mineral phenocrysts to 3 mm- dark green with conchoidal fracture and no cleavage, prismatic habit, possibly olivine?; 30 percent plus vesicles filled with calcite, epidote and occasionally pyrite

RMP 89009 R Two lithologies: 1. Altered mafic volcanic rock - note ovoid calcite filled amygdules; 2. argillically altered dacite porphyry - 10 percent plagioclase phenocrysts and 5-10 percent quartz phenocrysts in aphanitic, altered groundmass; ferromagnesian minerals 1-2 percent and altered

RMP 89010 R Plagioclase-hornblende andesite porphyry - 15-20 percent plagioclase phenocrysts to 3 mm and 10-15 percent elongate hornblende phenocrysts to 7 mm in fine-grained aphanitic pale gray groundmass

RMP 89011 R Layered websterite - olivine-augite cumulate - fine scale layering of olivine cumulate with disseminated (trace-1 percent) chromite and augite cumulate; augite cumulate layers 2-5 mm wide; olivine cumulate layers 7-15 mm wide; very little if any modal gradations between layers, appear to have sharp contacts between contrasting lithologies

RMP 89012 R Dunite - olivine cumulate - trace-2 percent disseminated chromite; dense black serpentinite cut by subparallel lens where serpentinized olivine are pale green; the rock is generally slightly magnetic both in dark serpentinite and in the bleached areas; trace pyroxene and phlogopite

RMP 89013 F Medium-grained clinopyroxenite - augite adcumulate

RMP 89014 R Medium-grained websterite - layered olivine-augite cumulate - dominantly olivine cumulate with 1-3 percent disseminated chromite with 2-3 augite cumulate layers 3 to 5 mm wide; very sharp contacts; no modal gradations

RMP 89015 R Fine-grained to fine-medium-grained diorite? - described in field as microdiorite; approximately 10-15 percent biotite; possibly some quartz in matrix; could be fine-grained diorite, quartz diorite, or tonalite

RMP 89016 R Medium-grained biotite diorite - 20-25 percent biotite

RMP 89017 R Fine-medium-grained diorite - hornblende crystals 3-5 percent of rock forming needles to 4 mm; trace disseminated pyrite; didn't see quartz in groundmass

RMP 89018 R Massive magnetite - local ovoid lens or pits where altered to yellow-brown limonite; no included silicates

RMP 89019 R fine-medium-grained monzonite/diorite? - 10 percent mafic minerals; all appear to be altered to fine-grained biotite?; 3-5 percent disseminated pyrite; feldspars glassy-fresh; 2 feldspars present-one lath-like and one equant; saw very little or no quartz

RMP 89020 R (ridge) Layered olivine clinopyroxenite - augite-olivine cumulate - two layers-one augite cumulate with trace disseminated oxide and olivine in sharp contact with oa$_{5\text{-}10}$c with trace disseminated chromite

RMP 89020 R Suite of samples: 1. serpentinized jade-green dunite with 1- 2 percent disseminated chromite and trace phlogopite; 2. two samples that have discontinuous lens/veinlets? of dark brown mineral that forms radiating spherules (looks similar to idocrase but have no idea what it is); host rock appears to be altered dunite that is pale red-brown, almost cherty looking but with chromite and phlogopite crystals as with sample 1

RMP 89021 F Vein quartz together with sample of dense aphanitic hornfels-mottled pale green (diopside? or chlorite) and pink (garnet) with 3-5 percent disseminated pyrite

RMP 89021 F2 Jasparoid - consists of fine-grained sucrose quartz - occasional vugs filled with euhedral quartz; irregular patches of fine-grained chlorite; disseminated pyrite approximately 5-10 percent; pyrite up to 8 mm

RMP 89021 R Fine-grained dense siliceous rock - metaquartzite with < 5 percent fine-grained biotite and trace-2 percent pyrite

RMP 89022 R Faintly layered calc-silicate hornfels - no fabric; dense; with garnet and epidote; open cavities with quartz and epidote

RMP 89023 R Fine-grained chlorite-quartz hornfels - almost no fabric-weak foliation; no garnet

RMP 89024 F Vein quartz - with muscovite

RMP 89024 R Crest of fold in quartz-chlorite schist - quartz grains form elongate ribbons separated by thin chlorite-rich folia

RMP 89025 R Fine-grained greenstone - aphanitic; massive; 1-3 percent garnet to 2-3 mm

RMP 89026 R Two lithologies: 1. fine-grained-fine-medium-grained biotite diorite/tonalite?; 2. dense aphanitic amphibolite/andesite?

RMP 89026 R2 Fine-medium-grained biotite diorite/tonalite? - 10-15 percent biotite books in sucrose equigranular matrix; difficult to tell if quartz is present

RMP 89027 F Dense gray aphanitic hornfels with clots of pyrite and calc-silicates

RMP 89027 R Andesite porphyry - 20-25 percent augite to 7-8 mm in aphanitic felted groundmass

RMP 89028 R Altered andesite porphyry - 15 percent 2-3 mm plagioclase phenocrysts in aphanitic, pale gray groundmass; trace-2 percent fine-grained disseminated oxide in groundmass

RMP 89029 R Deformed websterite - olivine-augite cumulate - approximately 5-10 percent deformed pyroxene and trace-1 percent disseminated chromite; minor asbestoes veins

RMP 89030 R Medium-grained hornblende diorite - 35 percent hornblende crystals up to 1 cm; 2-3 percent disseminated pyrite

RMP 89031 R Very altered volcanic porphyry? - 3-5 percent hornblende? crystals (dark, prismatic) to 3 mm in altered gray aphanitic groundmass

RMP 89032 Add Medium-grained mafic gneiss - 55 percent hornblende with rest of rock feldspar

RMP 89032 R Two lithologies: 1. medium-grained quartz-chlorite gneiss with 1-3 percent disseminated pyrite; 2. calc-silicate hornfels-mottled gray and pink matrix-pink areas (20 percent) may be garnet; gray areas are aphanitic; 1-3 percent very fine-grained , disseminated oxide

RMP 89033 R Very altered mafic schist - largely chlorite (45-55 percent) with fine-medium-grained feldspar and quartz

RMP 89035 R Very altered plagioclase-andesite porphyry - 15-20 percent plagioclase phenocrysts to 4 mm in gray-green aphanitic groundmass-plagioclase replace by mixtures of clay/epidote/chlorite? so that they appear very pale green and punky

RMP 89036 R Two lithologies: 1. medium-grained quartz muscovite gneiss; 2. fine-grained amphibolite

RMP 89037 R Medium-grained quartz-chlorite gneiss - fine-medium-grained quartz-hornblende-chlorite gneiss

RMP 89038 R Massive vein quartz and fine-medium-grained quartz-chlorite gneiss

RMP 89039 R Medium-grained-coarse-grained quartz-chlorite gneiss - 1-3 percent opaque oxide; trace disseminated pyrite

RMP 89040 R Medium-grained feldspar-quartz-chlorite gneiss - chlorite to 25 percent-metatonalite gneiss

RMP 89042 R Fine-medium-grained hornblende andesite - hornblende micro-phenocrysts in fine grained matrix; single 1 cm hornblende phenocryst; no quartz, plagioclase in groundmass greenish. Disseminated pyrite

RMP 89043 R Two lithologies: 1. fine-medium-grained andesite with microphenocrysts of plagioclase, biotite, and hornblende in aphanitic matrix; vugs filled with epidote; 2. dunite - olivine adcumulate - no pyroxene

RMP 89044 R Dunite - olivine adcumulate - no pyroxene; trace-1 percent disseminated chromite

RMP 89045 R Medium-grained dunite-olivine cumulate - no pyroxene; accessory chromite approximately 1 percent; cut by 3-4 mm silicic dikelet

RMP 89046 R Variety of lithologies ranging from fine-grained aphanitic greenstone through fine-grained andesite with aphanitic groundmass and microphenocrysts of hornblende to fine-medium-grained hornblende-plagioclase andesite with hornblende and plagioclase microphenocrysts and phaneritic matrix consisting largely of feldspar; fractures coated with red to yellow-brown limonite; trace disseminated pyrite; epidote is common alteration phase

RMP 89047 R Mineralized, altered hornblende andesite - green aphanitic matrix with 5 percent hornblende phenocrysts to 5 mm. 5-10 percent disseminated pyrite in matrix; hornblende still fresh; plagioclase altered to clays/sericite

RMP 89048 R Medium-grained clinopyroxenite - augite adcumulate - trace-1 percent cumulus oxide

RMP 89049 R Fine-grained-fine-medium-grained diorite/andesite as with 76 R; 79 R; 59 R - pervasively altered; cut by calcite veinlets; all ferromagnesium minerals altered to chlorite

RMP 89050 R Deformed websterite-olivine-augite cumulate - 15- 20 percent pyroxene (2-3 mm) showing suggestion of layering; all pyroxene slightly deformed (bent cleavage); cut by 1-2 mm pyrrhotite veinlets

RMP 89050 R2 Silicified (?) volcanic rock - aphanitic matrix; faint suggestions of relict phenocrysts; 1-3 percent disseminated sulfide in what may have been phenocrysts sites; cut by thin (< 0.5 mm) dark veinlets (sulfides?)

RMP 89051 = 89101 R Medium-grained clinopyroxenite - augite adcumulate - trace-0.5 percent interstitial magmatic sulfide minerals

RMP 89051 R Altered fine-medium-grained hornblende diorite - 15 percent hornblende (replaced by fine-grained ferrromagnesian minerals, sulfides, and some epidote); feldspars affected by argillic alteration; 3 percent pyrite; could be hornblende-plagioclase andesite porphyry

RMP 89052 = 89102 R Adcumulate olivine cumulate - dunite - no pyroxene; trace chromite; one sample has 7 mm augite cumulate layer; no cumulus augite outside layer

RMP 89052 R1 Fine-medium-grained augite cumulate - clinopyroxenite - sheared or recrystallized; difficult to see through joint coating, slightly magnetic

RMP 89052 R2 Very altered hornblende andesite porphyry - 10-15 percent pseudomorphs of hornblende in aphanitic matrix

RMP 89053 R Hornblende-plagioclase dacite? porphyry - 10-15 percent hornblende to 6 mm; plagioclase to 5-10 percent, 2-3 mm, indistinct from groundmass; fine-grained pale gray aphanitic groundmass

RMP 89053 Ra Hornblende-plagioclase dacite porphyry - hornblende and plagioclase phenocrysts approximately 10 percent each; fine grained gray aphanitic matrix-looks like quartz present but difficult to positively identify

RMP 89054 R Dark hornflesed carbonate-rich rock - consists of carbonate with ovoid, 1 by 1.5 cm clots of calc-silicate minerals; pale green-brown garnet occurs at the outer edge of the clots against carbonate; a white mineral (H < 5) and a granular phase (H < 5) occur in the interior of the clots; calc-silicate clots may have been siliceous areas (silt-filled worm tracks?) in carbonate; reacted forming small exoskarn near contact with igneous rock

RMP 89054 Ra Hornblende dacite/andesite? porphyry - hornblende and groundmass unaltered; unidentified pink "spots" in groundmass

RMP 89054 Rb Very similar to Rc - vesicles fewer and smaller

RMP 89054 Rc Intermediate composition volcanic rock - dacite - fine-grained, aphanitic matrix that contain up to 15 percent altered mafic microphenocrysts; calcite filled vesicles approximately 10 percent of rock; matrix gray; sucrous-felted

RMP 89054 Rd Contact between altered microdiorite and limestone - igneous rock as with Ri - has 10 percent disseminated pyrite; in contact with dark compact or structureless carbonate; probably recrytstallized; < 1 mm microveinlets cut carbonate; can't tell mineralogy

RMP 89054 Re Hydrothermally altered hornblende andesite/dacite porphyry - up to 15 percent hornblende replaced by fine-grained secondary ferromagnesian mineral; groundmass altered

RMP 89054 Rf Hornfels-dense dark rock - small pockets with garnet and chlorite prophyroblasts after garnet; lens of graphite; trace-2 percent fine-grained disseminated pyrite; open minikarst with dissolution voids or pits

RMP 89054 Rf Fe oxides concretions from soil zone over hornfels - Au here was found by panning; no silicates; with root hairs, reddish soil

RMP 89054 Rg Very dark fine-grained limestone - micrite with approximately 3-5 percent sparry grains (fossils?) to 3-4 mm

RMP 89054 Rh As with Rc - matrix largely altered; plagioclase with hornblende microphenocrysts; rare altered biotite microphenocrysts; trace disseminated sulfide; grey-green color due to alteration of plagioclase; rock better called microdiorite; saw little or no quartz in matrix

RMP 89054 Ri Completely altered rock as with Rc and Rh - matrix now smooth pale gray; no visible grains/granules; moderately hard to scratch; clay/sericite +?; ferromagnesian minerals altered to chlorite; no sulfide minerals; alteration pervasive; not vein controlled

RMP 89055 R Fine-grained aphanitic andesite/basalt?

RMP 89056 Ra Vein quartz and fine-medium-grained tonalite with 5-10 percent disseminated sulfide

RMP 89056 Rb Dunite - olivine cumulate - trace phlogopite; no pyroxene

RMP 89056 Rc Two specimens; larger of two appears to be coarse-grained hornblendite with 3 x 1 cm augen of calcite; calcite doesn't appear to be vein or tectonic tension gash; hornblende identification based on very dark colors and vitreous luster of crystals; second specimen is altered and sheared; may be hornblendite, possibly in contact with another lithology-need to cut to be sure; sulfide minerals on slickenslided surfaces

RMP 89056 Rd More than one lithology - sample of medium-grained clinopyroxenite - augite adcumulate; augite-olivine cumulate in contact with dunite - olivine cumulate; sheared pieces of dunite; one sample has sulfide minerals on shear surface

RMP 89057 R Two lithologies: 1. layered olivine-augite cumulate; actually layers of olivine-augite cumulate and augite cumulate; pyroxene slightly deformed in olivine-augite cumulate; trace-2 percent chromite in olivine-augite cumulate; 2. very altered plagioclase-hornblende andesite porphyry-both hornblende and plagioclase altered; 10-15 percent hornblende; 5-10 percent plagioclase

RMP 89059 R Altered (argillized) fine-medium-grained tonalite - > 20 percent quartz; < 5 percent ferromagnesian mineral sites; too altered to identify ferromagnesian minerals; couldn't see any strong fabric in rock

RMP 89059 R Two lithologies: 1. altered fine-medium-grained hornblende-biotite diorite-no quartz; all feldspar is plagioclase; hornblende altered to tremolite?; biotite altered to chlorite; sub-mm quartz veinlets; plagioclase altered to mixtures of clay and chlorite; no phenocrysts; 2. deformed websterite - olivine-augite cumulate - 5-10 percent deformed pyroxene up to 3 mm; pyroxene pseudolayered (cumulate layering?); micro-veinlets of pyrrhotite up to 2 cm long, en echelon through sample; accessory chromite

RMP 89060 Ra Medium-grained tonalitic (feldspar-quartz-chlorite) gneiss

RMP 89060 Rb Fine-grained chloritic schist - 3 percent porphyroblasts of pale colored phase with good cleavage; trace disseminated pyrite

RMP 89060 Rc Very weathered medium-grained tonalitic gneiss? - all ferromagnesian minerals leached out

RMP 89060 Rd Massive vein quartz

RMP 89060 Re Fine-grained hornblende andesite porphyry dike? in medium-grained tonalitic gneiss - includes sample of contact; aphanitic, non-porphyritic phase (with stretched vesicles); porphyritic phase (hornblende crystals to 15 percent-up to 5-7 mm); vesicles filled with chalcedony; aphanitic groundmass

RMP 89061 R Fine-medium-grained quartz-chlorite gneiss - 1-3 percent disseminated pyrite

RMP 89062 R Dacite? - volcanic rock with hornblende microphenocrysts in pale gray fine-grained matrix; sugary; some feldspar; quartz probably present

RMP 89063 R Two lithologies: 1. moderately foliated chlorite-quartz garnet schist - 30 percent garnet ; 2. medium-grained tonalite gneiss - 10-15 percent hornblende crystals to 3 mm

RMP 89064 F1 Medium-grained altered clinopyroxenite - augite cumulate - suspect may contain 3-5 percent interstitial hornblende; can see two phases; greenish stout crystals with cleavage that appear to be augite (no twinning, etc) and dark brown phase (hornblende)

RMP 89064 R2 Flattered fragments of foliated friable serpentinite - up to 1 mm fines on surface

RMP 89065 R Tonalitic gneiss-quartz-feldspar-hornblende gneiss - foliated and lineated; 15 percent plus hornblende; feldspar > quartz

RMP 89066 R Medium-grained melanocratic quartz-hornblende (- chlorite) gneiss - cut by 1 cm quartz vein subparallel to foliation; mafics up to 35 percent of rock; blocky habit suggests they are hornblende

RMP 89066 Rb Medium-grained quartz-chlorite gneiss

RMP 89067 R Medium-grained quartz-muscovite-chlorite gneiss

RMP 89068 R Medium-grained quartz-chlorite (after biotite) gneiss with metaquartzite segregations - 1-5 percent disseminated pyrite in gneiss

RMP 89069 R1 Quartz-chlorite schist-quartz - grains show extreme flattening/attenuation

RMP 89069 R2 Massive quartz - probably from metamorphic vein segregation in gneiss

RMP 89070 R Fine-medium-grained quartz-chlorite gneiss with 5-10 percent disseminated pyrite

RMP 89071 R Weakly foliated fine-medium-grained quartz-chlorite schist and quartz-chlorite-garnet schist - up to 30 percent disseminated chalcopyrite and pyrite in lens; 2-3 percent disseminated pyrite on foliation planes

RMP 89072 R Fine-grained to fine-medium-grained quartz-biotite/chlorite-garnet schist - metamorphic layering defined by variation in proportion of minerals and grain size

RMP 89073 F Quartz vein - sucrose with open vugs with euhedral quartz; pyrite crystals to 2 mm in vugs

RMP 89073 R Medium-grained quartz-feldspar-chlorite gneiss - deformed silicic igneous rock?

RMP 89074 R Deformed websterite - olivine-augite cumulate - 3 pieces; one of clinopyroxenite which shows deformed pyroxene crystals; other two samples olivine-rich websterite or dunite; estimate 3-5 percent pyroxene at most; pyroxenes are deformed; accessory chromite 1-3 percent

RMP 89075 B Serpentinized dunite - 1 undeformed pyroxene crystal approximately 5 cm long; accessory chromite 1 to 3 percent

RMP 89075 C Fine-medium-grained clinopyroxenite layer, 1 cm wide, in sharp contact with serpentinized dunite with 1 percent augite (saw single 1-2 mm crystal that appeared to be bent); accessary chromite 1-3 percent

RMP 89075 F Medium-grained clinopyroxenite layer, 2 cm wide, in sharp contact with serpentinized dunite (no pyroxene)

RMP 89075 F2 Medium-grained clinopyroxenite - augite cumulate - appears undeformed; no oxide minerals

RMP 89075 R Medium-grained dunite - olivine cumulate with thin < 1 cm clinopyroxenite layer; accessory chromite to 2-3 percent

RMP 89075 Rb Medium-grained dunite - olivine-augite cumulate - rare 5-7 mm augite crystals (undeformed) perhaps in thin layers; accessory chromite to 2-3 percent

RMP 89076 R Fine-grained porphyritic hornblende microdiorite/andesite - matrix of fine-grained plagioclase, no quartz, hornblende needles; phenocryst < 5 percent total; plagioclase and hornblende up to 3 mm

RMP 89077 R Serpentinized dunite - trace disseminated chromite; no pyroxene crystals observed

RMP 89078 R Deformed websterite - olivine-augite cumulate - < 5 percent deformed pyroxene; accessory chromite 2-3 percent

RMP 89079 R Two lithologies: 1. fine-medium-grained hornblende-chlorite (after biotite) diorite - no quartz; no phenocrysts; needle-like hornblende and altered biotite in matrix of plagioclase; 2. deformed websterite - olivine-augite cumulate - < 5 percent deformed pyroxene crystals usually < 3 mm; 1 undeformed crystal approximately 5-7 mm long

RMP 89080 R Deformed websterite - olivine-augite cumulate with 0.5-1 cm pyroxenite layers - pyroxenes in websterite and pyroxenite layers are deformed; 1-2 percent pyroxene in websterite deformed, < 3 mm long; accessory chromite 2-3 percent

RMP 89081 R Medium-grained websterite - olivine-augite cumulate - 15-20 percent pyroxene 3-7 mm long; largest pyroxene crystals are deformed (bent cleavage); either tectonized websterite or deformed olivine-augite cumulate

RMP 89082 R1 Fine-medium-grained dark, granular dunite - olivine cumulate - 1 to 2 percent pyroxene; cleavages deformed; trace-1 percent chromite

RMP 89082 R2 Deformed websterite - olivine-augite cumulate - 3-5 percent deformed pyroxene; trace-1 percent chromite

RMP 89082 R3 Plagioclase-hornblende dacite (andesite?) porphyry - 15 percent plagioclase phenocrysts to 3 mm and 10 percent needle-like hornblende phenocrysts to 5 mm in aphanitic gray groundmass

RMP 89082 R4 Dunite - samples are irregularly shaped; all surface coated with serpentine; chip away to find dunite (olivine cumulate) with trace-2 percent disseminated chromite; trace phlogophite; one questionable pyroxene grain; approximately 2 mm long; undeformed

RMP 89083 R1 Dunite - olivine adcumulate - no pyroxene; trace-1 percent disseminated chromite; trace phlogophite

RMP 89083 R2 Two lithologies: 1. dunite - olivine cumulate - trace-1 percent disseminated chromite; 2. fine-medium-grained dacite porphyry - plagioclase phenocrysts to 2 mm; 10 percent; hornblende phenocrysts; needle-like up to 4 mm; 10 percent; groundmass includes needle like hornblende; otherwise sucrose to aphanitic; pale gray color

RMP 89083 R3 Two lithologies: 1. fine-grained leucocratic dike rock - 20 percent altered ferromagnesian mineral microphenocrysts in altered, gray aphanitic matrix 2. pale green serpentinized dunite - olivine grains are serpentinized

RMP 89084 Fine-medium-grained clinopyroxenite - augite cumulate - tremolitic alteration along grain boundaries and cleavages

RMP 89084 R Fine-medium-grained tonalitic/granitic? gneiss - 3-5 percent chlorite after biotite; trace-2 percent disseminated pyrite; moderately developed fabric; quartz elongated along foliation planes

RMP 89084 R2 3 samples of fine-medium-grained clinopyroxenite - augite cumulate - trace disseminated sulfide; veinlets filled with chloritic/tremolitic material; some pyroxenes deformed adjacent to veinlets; 1 piece of aphanitic basalt/basaltic andesite

RMP 89084 R2 Two rock types: 1. fine-grained aphanitic basalt ; 2. fine-medium-grained andesite porphyry - 1-2 percent 3-5 mm pyroxene phenocrysts; matrix dark; ferromagnesian minerals altered to sheet silicates

RMP 89085 R Fine-medium-grained tonalitic/granitic gneiss - trace-3 percent disseminated pyrite; chlorite < 3 percent; mixture of quartz and feldspar-quartz > 25 percent

RMP 89086 RA Two lithologies: 1. hornblende andesite porphyry - 25 percent hornblende phenocrysts to 5 mm in green-gray aphanitic groundmass; 2. very altered hornblende clinopyroxenite or gabbro - matrix appears to be medium-grained; ferromagnesian minerals to 30 percent look like hornblende; green medium-grained phase may either be very altered pyroxene or very altered plagioclase; need to see thin section or rock slab

RMP 89086 RB Hornblende andesite porphyry - 10-15 percent hornblende phenocrysts up to 5 mm in aphanitic medium gray groundmass

RMP 89087 F Fine-grained aphanitic mafic rock - extremely small, weathered pieces of rock

RMP 89087 F Massive magnetite - with hematite after magnetite

RMP 89087 R Crushed sheared ultramafic rock - altered friable/slightly competent serpentinite cut by magnetite veinlets - angular-slightly flattered rock fragments coated with brown clay-rich soil; serpentine coated surfaces not striated; moderately friable; weakly magnetic; mostly rock chips thinly coated with red-brown clay

RMP 89088 F Two pieces of nearly massive iron oxides - up to 70 percent magnetite with yellow geothite in pits between magnetite grains; coated with red hematitic powder

RMP 89088 R Massive vein quartz - coated locally with Mn-Fe oxides; muscovite on one surface; no sulfide minerals or pseudomorphs

RMP 89089 R Fine-medium-grained tonalitic gneiss - 3-5 percent chlorite after biotite; trace - 2 percent disseminated pyrite; moderate fabric quartz elongated along foliation planes

RMP 89090 F Two lithologies: 1. fine-grained hornblende-plagioclase gneiss - 60 percent hornblende and 40 percent plagioclase; planar fabric; medium-grained; 2. hornblende-plagioclase gneiss - hornblende/plagioclase ratios vary between 60: 40 to 30: 70;

RMP 89090 F2 Two lithologies: 1. fine-grained amphibolitic schist; 2. medium-grained altered pyroxenite

RMP 89090 R Crushed, sheared ultramafic rock - suspect olivine-rich lithology; abundant magnetite veinlets; most surfaces coated with black limonite or serpentine; competent to friable fragments up to 3 cm; only minor amount of fines; serpentine not slickenslided; matrix visible in some chips; almost all show pale green granular silicate cut by subparallel magnetite veinlets; one chip was of relatively unaltered pyroxenite

RMP 89091 R Fine-medium-grained clinopyroxenite - augite adcumulate - augite 3-5 mm

RMP 89092 F Fractured quartzite/vein quartz with lens of pyrite; coated with hematite wash

RMP 89092 R Fine-grained tonalite - 20 percent plus quartz with feldspar in granular matrix; 10 percent biotite (locally replaced by chlorite); weakly foliated

RMP 89093 R Fine-medium-grained tonalite - contains 10-30 percent quartz; altered feldspars, altered ferromagnesian minerals (10 percent); quartz in matrix as well as phenocrysts; no strong fabric

RMP 89094 R Altered medium-grained clinopyroxenite - augite adcumulate - pervasive tremolitic alteration and bleaching; gray green

RMP 89095 R Very altered medium-grained clinopyroxenite - augite adcumulate - sample leached; joint and fracture surfaces coated with gray green alteration minerals including a fibrous phase (asbestoes?) and calcite (no acid to test); some alteration extends along grain boundaries and cleavages; pyroxene cleavages still very apparent

RMP 89096 F Schist - chlorite (after biotite?) up to 60 percent of rock; altered feldspar makes up rest of rock; no quartz observed

RMP 89097 F Weakly foliated chlorite-quartz schist - chlorite easily > 50 percent of rock; other silicates very fine-grained

RMP 89099 F Cobble of vein quartz - two pieces of spongy textured, crudely layered quartz vein material

RMP 89099 R Two lithologies: 1. altered greenstone - probably altered mafic volcanic; ovoid calcite-filled amygdules 2. argillically altered dacite porphyry - 10 percent plagioclase phenocrysts; 5-10 percent quartz phenocrysts in aphanitic altered groundmass; ferromagnesian minerals 1-2 percent of rock and all altered; pale blue gray color

RMP 89100 R Variably altered augite andesite porphyry? - up to 20 percent blocky, stubby phenocrysts in aphanitic gray matrix; where altered (in lens shaped lighter colored areas), matrix is pale gray; ferromagnesian minerals commonly partially replaced by sulfide minerals; epidote on joint surfaces; 5-10 percent sulfide minerals

RMP 89103 R Fine-grained aphanitic basaltic andesite/basalt - zones of vesicles (ovoid area); some vesicles filled with sub-mm euhedral vitreous brown phase; 2-3 mafic phenocrysts 3-5 mm noted

RMP 89104 R Intensely altered rock (tonalite?) - consists of mixture of fine-medium-grained quartz and clay pseudomorphs after feldspar; no ferromagnesian minerals left; coated with black limonite and thin red-brown-pink limonite wash

RMP 89105 R Fine-medium-grained hornblende diorite? - didn't see quartz; 3-5 percent euhedral hornblende

RMP 89106 R Serpentinized dunite - olivine cumulate - olivines pale green (serpentinized) magnetite/serpentine in network around grains and interconnected into veinlets; interconnected magnetite/serpentine network give fabric (foliation) to rock; largest magnetite veinlets cut the foliation at high angle; parts of sample appear to have interstitial biotite now altered to chlorite

RMP 89107 R Medium-grained gabbroic rock? - uncertain on identification ; pale green phase > 50 percent of rock; probably altered plagioclase; some altered pyroxene; felted cleavages (-altered) couldn't estimate proportion; small poikilitic crystals of hornblende up to 5-10 percent in rock ; would need thin section or sawn surface to make better identification

RMP 89108 F Two rock types: 1. metamorphic rock-hornfels? - quartz, chlorite, garnet, with porphyroblasts of uncolored phase with curved cleavages; difficult to see any fabric in rock (therefore didn't call schist/gneiss); trace-1 percent disseminated sulfide minerals; 2. weathered rock, matrix pale green granular; cut by quartz veinlets and microveinlets; not sure what it was; skarn?; pale green doesn't look like epidote; could be vesuvianite or pale garnet; just don't know; could also be silicified rock with small amount of fine-grained green phase such as chlorite or epidote

RMP 89109 R Fine-medium-grained quartz diorite/tonalite - quartz > 10 percent; maybe up to 15; ferromagnesian minerals < 10 percent; leached from rock; weathered, coated with yellow brown limonite

RMP 89110 R Fine-medium-grained altered gabbro or diorite - no visible quartz; perhaps 30 percent mafics; looks like they have been replaced or altered; one ferromagnesian mineral seen as reaction rind on another; plagioclase greenish; need thin section for good identification

RMP 89112 R Fine-grained amphibolitic schist - approximately 100 percent ferromagnesian minerals; most probably hornblende; chlorite could be present

RMP 89113 F Gossan - porous limonite/goethite

RMP 89114 R Fine-medium-grained diorite - 30 percent ferromagnesian minerals now mostly chlorite; one piece of white argillaceous tuff?

RMP 89115 R Schist - largely pale green chlorite and feldspar; didn't see any quartz; micaceous minerals up to 40 percent

RMP 89116 F Fine-grained quartz-chlorite-garnet schist - trace disseminated pyrite

RMP 89117 R Fine-medium-grained diorite? - 25 percent ferromagnesian mineral; largely chlorite and biotite; if hornblende was present now altered; weak foliation; no quartz observed

RMP 89118 F Medium-grained dioritic gneiss - no quartz; all light colored minerals appears to be feldspar; approximately 15 percent ferromagnesian mineral that are flattered along foliation; augen of feldspar; ferromagnesian minerals probably are chlorite

RMP 89120 R (250-251 M) Fine-grained to fine-medium-grained tonalite - 5 percent ferromagnesian minerals- hornblende approximately 1 mm; quartz and feldspar in granular matrix; trace disseminated pyrite

RMP 89121 R Fine-medium-grained quartz-chlorite-garnet schist with 5-10 percent disseminated pyrite

RMP 89122 F Metaquartzite? - 3-5 percent disseminated pyrite; 2-5 percent chlorite define vangue foliation in rock

RMP 89123 F Fine-grained gneiss - quartz-amphibole gneiss with 2-5 mm distinct interlayers of garnet and quartz

RMP 89123 R Medium-grained quartz-chlorite-garnet schist with 10 percent plus disseminated pyrite

RMP 89124 F Chlorite (-biotite)-quartz-garnet schist

RMP 89125 R Weakly foliated medium-grained quartz-chlorite gneiss - 3-5 percent disseminated pyrite

RMP 89126 R Medium-grained quartz-chlorite gneiss

RMP 89127 R Extremely weathered tonalite/tonalitic gneiss - < 20 percent quartz; 30 percent mafic minerals (now all chlorite); feldspar altered to clay minerals

RMP 89129 R Extremely weathered chlorite-feldspar-quartz? schist

RMP 89130 R Biotite-quartz schist with augen of garnet (pale pink, fine-grained, granular)

RMP 89131 R Hornblende-plagioclase-garnet schist (garnet amphibolite)

RMP 89132 R Highly weathered rock - now granules of fine-medium-grained quartz, pyrite (20 percent), and trace chlorite; feldspar completely leached leaving vugs-little clay; was this mineralized quartz-chlorite gneiss?

RMP 89133 R Clinopyroxenite - samples deformed; structural foliation caused by shearing; pyroxene are kink banded and deformed near folia; trace disseminated sulfide minerals

RMP 89134 R Augite cumulate

RMP 89135 F Fine-grained to fine-medium-grained plagioclase-hornblende andesite porphyry - 15-20 percent plagioclase micrphenocrysts; 10-15 percent hornblende phenocrysts; aphanitic dark-gray matrix

RMP 89135 Ra Altered medium-grained clinopyroxenite - augite adcumulate

RMP 89135 Rb Altered (argillic) felsite - no phenocrysts; mixture of quartz and clay; sparse ferromagnesian mineral sites; could this be altered tuffaceous rock

RMP 89135 Rc Talc-rich schist

RMP 89135 Rd Very altered medium-grained gabbro? - altered pyroxene up to 30 percent of rock; think other phase was plagioclase; entire rock has greenish tint; cleavages are indistinct even on pyroxene; possibly could be more mafic than gabbro; no quartz seen

RMP 89135 Rf Plagioclase-hornblende andesite porphyry

RMP 89136 R Altered medium-grained clinopyroxenite - augite cumulate - samples all sheared; pyroxene not glassy, talc-tremolite alteration?

RMP 89137 F Fine-grained skarn - calc silicate hornfels - no fabric; mottled pale brown and green colors

RMP 89137 R Hornblende andesite porphyry - 25 percent hornblende phenocrysts 3-10 mm long in aphanitic grey groundmass

RMP 89137 R Sheared ultramafic rock - foliated serpentinite - serpentine ranges from black to pale green in color; coated with black brown limonite; no relict textures preserved

RMP 89137 R2 Crushed, sheared ultramafic rock - no relict textures apparent; almost no rock chips larger than 1 cm; mostly fines; gouged slickenslided rock chips; magnetite present; sulfides and black limonite on shear surfaces; one fragment has matrix of green granular silicate with disseminated fine-grained oxide mineral (< 5 mm)

RMP 89137 R3 Plagioclase-hornblende andesite porphyry - aphanitic green groundmass with 15 percent plagioclase phenocrysts to 3 mm and 10 percent needle-like hornblende phenocrysts to 4 mm

RMP 89138 F Sheared and altered clinopyroxenite - outer surfaces weathered; sheared; internal slip surfaces coated with black limonite; pyroxene cleavages preserved; pale cream-green color

RMP 89139 R1 Breccia - cemented by calcite; extensively veined; fine-grained rock fragments as well as pale green soft fragments (altered volcanic rock)

RMP 89139 R2 Fine-medium-grained gnessic tonalite? - 10 percent ferromagnesian minerals (chlorite-biotite) flattered parallel to foliation; 20-25 percent quartz flattered parallel to foliation; only one feldspar (plagioclase) present

RMP 89139 R3 Breccia - angular rock fragments cemented by quartz; fragment supported; breccia texture most obvious on weathered surface where fragments standout in relief; fragments are dark; fine-grained to fine-medium-grained; mafic; one sample had large area that looked like fine-medium-grained clinopyroxenite; possibility that smaller fragments are recrystallized, retrograded clinopyroxenite; not sure on this one

RMP 89140 Ra Dunite - olivine adcumulate - sample surfaces all slicked; chipped away enough to see olivine-rich; trace-1 percent disseminated chromite; couldn't swear there isn't pyroxene but saw none; cut fragments to look at larger area

RMP 89140 Rb Medium-grained hornblende clinopyroxenite/gabbro? - all surfaces weathered could get only small areas of fresh rock exposed; rock has abundant altered pyroxene; enough waxy green material that could be altered pyroxene but may be plagioclase; approximately 10 percent post cumulus/interstial hornblende; need thin section for identification

RMP 89141 R Talc/tremolite altered fine-medium-grained clinopyroxenite - augite cumulate - phologopite oikocryst noted; difficult identification may want to check with thin section

RMP 89142 R Two lithologies: 1. dunite - olivine cumulate with trace-2 percent chromite; 2. fine-medium-grained very dense siliceous rock; < 1 mm ferromagnesian minerals (spinel?) approximately 10 percent

RMP 89143 F Medium-grained tonalitic (fine-grained-quartz-chlorite) gneiss; weathered and coated with hematite wash

RMP 89145 F Massive magnetite - appears to either be cut by subparallel veins or is sheared or foliated

RMP 89145 R Fine-medium-grained dunite - olivine adcumulate - no pyroxene; may have < 1 mm phlogopite crystals in matrix

RMP 89146 R Weathered fine-medium-grained to medium-grained tonalitic gneiss - couldn't see any ferromagnesian minerals; only plagioclase and quartz; strong lineation in rock

RMP 89147 R Fine-grained chlorite (biotite)-feldspar-quartz? schist

RMP 89147 R2 Fine-grained chlorite-rich schist

RMP 89148 F Fine-grained quartz-garnet-spinel hornfels; no fabric; metapsammite?

RMP 89149 R Sheared and weathered medium-grained clinopyroxenite - augite cumulate

RMP 89150 F Jasperoid - pale brown; hummocky outer surface similar to weathered vesicular volcanic

RMP 89150 R Sheared and altered medium-grained clinopyroxenite - augite cumulate

RMP 89151 R Andesite porphyry - altered; 20-25 percent phenocrysts 3-5 mm largely replaced by secondary ferromagnesian mineral (chlorite + ?); habit suggests both augite and hornblende present

RMP 89152 R Fine-grained diorite - 15 percent hornblende to 1 mm; 5 percent plagioclase microphenocrysts to 2 mm; no quartz seen

RMP 89153 A Bullquartz from vein

RMP 89153 B Medium-grained tonalite? - 20 percent ferromagnesian minerals (hornblende-chlorite); feldspar very glassy; difficult to discern individual quartz grains in matrix

RMP 89154 F Very large specimen of massive magnetite

RMP 89154 R Massive magnetite

RMP 89155 F Massive magnetite -weathering along surfaces joints to yellow brown goethite

RMP 89156 F Plagioclase-hornblende andesite porphyry - no quartz seen; plagioclase phenocrysts (to 2 mm) 20 percent and hornblende phenocrysts (to 1-2 mm) 5 percent of rock in aphanitic pale gray granular, fine-grained groundmass

RMP 89157 R? Weathered rock - now Fe oxides but pseudomorphs of medium-grained phase; quartz veins (< 5 percent approximately 2mm wide) very discontinuous

RMP 89158 R Quartz vein with specimens of quartz -chlorite (biotite) schist - all ferromagnesian minerals weathered out or as minor pale colored mica

RMP 89159 RA Sheared altered rock - can't get enough area exposed to see texture definitively; possibly porphyritic volcanic

RMP 89159 RB Argillically altered fine-medium-grained tonalite? - all ferromagnesian minerals leached; feldspar altered to clay; approximately 15-20 quartz in matrix

RMP 89160 R1 Fine-grained altered diorite; ferromagnesian minerals (now chlorite) to 35 percent; no quartz seen

RMP 89160 R2 Fine-grained basalt/basaltic andesite - almost aphanitic

RMP 89161 R Argillized volcanic rock - matrix now all clay; Fe oxide spots probably were ferromagnesian mineral phenocrysts; clay psuedomorphs of feldspar phenocrysts; no quartz as phenocrysts or in matrix

RMP 89161 R Augite-hornblende andesite porphyry - dark aphanitic groundmass; 3-5 mm phenocrysts of augite and hornblende up to 30 percent of rock; hornblende rims on some augite phenocrysts

RMP 89162 R Fine-grained aphanitic andesite/basalt - one specimen cut by thin quartz veinlets; the other an angular breccia of < 1-3 cm andesite/basalt fragments cemented by quartz

RMP 89163 R Extremely altered clinopyroxenite - augite cumulate

RMP 89164 R Leached gneiss? - coated with lateritic soil; feldspar and ferromagnesian minerals leached; slightly porous; mostly medium-grained quartz cemented by some clay; some quartz grains extremely elongated and flattened

RMP 89166 R Mineralized andesite porphyry - fine-grained green gray aphanitic matrix; 20-30 percent phenocrysts mostly augite; some hornblende; 3-5 percent disseminated sulfide minerals in groundmass and in some phenocryst sites; no quartz seen; sulfides dominantly pyrite; perhaps some chalcocite?

RMP 89167 F Weakly foliated, nearly massive quartz - minor chlorite on foliation surfaces; probably metamorphic segregation vein

RMP 89168 F Mineralized andesite porphyry - 20-25 phenocrysts of augite (and hornblende) in aphanitic groundmass; groundmass is greenish/greasy looking; is the groundmass silicified?; 5-10 percent disseminated pyrite

RMP 89169 F Fine-medium-grained quartz-hornblende? (-chlorite) gneiss with 5-10 percent disseminated pyrite

RMP 89170 F Fine-medium-grained quartz-feldspar-chlorite gneiss

RMP 89170 R Weathered quartz-chlorite gneiss with 15 percent plus disseminated pyrite

RMP 89171 F Porphylitized volcanic rock - hornblende dacite?/andesite porphyry? aphanitic matrix; phenocrysts of altered hornblende up to 30 percent; epidote "phenocrysts" psuedomorphs after plagioclase; greenish tint to rock; 3-5 percent disseminated pyrite in rock; perhaps some quartz in matrix

RMP 89172 R1 Basaltic andesite - hornblende phenocrysts, aphanitic matrix; quartz-filled amygdules; epidote also in amygdules; vugs

RMP 89172 R2 Porphylitized volcanic rock - pervasively altered; aphanitic matrix; pale cream-colored; soft; small vugs with glassy limonite; epidote as psuedomorphs after phenocrysts and as veins

RMP 89173 R Altered and sheared fine-medium-grained clinopyroxenite - augite cumulate - hornblende may be present

RMP 89173 R1 Crushed and sheared ultramafic rock; mostly angular friable to competent rock chips; largest fragment 5 cm; most < 1 cm; limonite on surfaces; striated; green vitreous matrix; relict cleavage locally; clinopyroxenite?

RMP 89173 R2 Fine-medium-grained clinopyroxenite - augite cumulate

RMP 89174 R sheared ultramafic rock - most likely a fine-medium-grained clinopyroxenite - augite cumulate - slightly flattered competent rock fragments rarely exceed 5 cm; most < 1 cm; very clean, little mud or fines; variably magnetic (suggest magnetite veinlets); all surfaces coated with black serpentine and black limonite

RMP 89174 R1 Sheared serpentinite - couldn't see anything that would allow me to determine original rock type; maybe cutting larger fragments would be helpful

RMP 89175 F Sheared, argillized quartz-chlorite gneiss?

RMP 89175 R Two lithologies in bag - altered quartz-chlorite gneiss and intermediate-silicic composition volcanic rock with aphanitic groundmass containing 5 percent hornblende and 10-15 percent quartz phenocrysts

RMP 89176 R Hornblende dacite/tonalite - hornblende phenocrysts altered to chlorite in fine-grained phaneritic matrix of quartz and feldspar; difficult to determine quartz/feldspar ratios

RMP 89177 R Fine-medium-grained olivine-clinopyroxenite - olivine-augite cumulate - at least 30 percent 2-3 mm subhedral pyroxene; undeformed

RMP 89178 F Nearly massive magnetite and hematite-magnetite - probably from iron skarn

RMP 89179 R Fine-medium-grained gneiss? - coated with lateritic soil; elongated flattered quartz; altered sheet silicate (biotite-chlorite -?); feldspar leached out of rock leaving open space; gneiss determination based on elongated, flattered quartz grains

RMP 89180 R Laterized intermediate composition volcanic rock - all feldspar leached leaving < 1 mm quartz grains loosely cemented by clay; Fe oxide spots approximately 10-20 percent of rock probably were ferromagnesian mineral microphenocrysts

RMP 89181 R 1-1.5 cm quartz vein in very weathered volcanic rock

RMP 89181 R1 Irregular spongy framework of quartz - fibrous, hydrothermal, with vugs filled with limonite; part of quartz vein or silicified rock near veins

RMP 89181 R2-RMP 89181 RQ Quartz vein - vein up to 10 cm wide; vuggy in part; cocks comb structure; quartz crystals perpendicular to vein margin; limonite stained vugs

RMP 89182 R Dunite - olivine adcumulate - no pyroxene; 1-3 percent disseminated chromite; trace phlogopite?

RMP 89185 F Sample of massive, dense, compact, dark brown goethite and yellow brown limonite - dense goethite appears to form veins in softer goethite

RMP 89186 R Fine-medium-grained equigranular hornblende biotite tonalite - very fresh; subhedral plagioclase; quartz in matrix, 10 percent hornblende (euhedral) to 5 mm and 5 percent biotite (euhedral books) to 3 mm; trace chalcopyrite

RMP 89188 R Rounded pieces of mud-coated foliated gouge? - clay and Fe oxides define foliation; soft; can cut with knife

RMP 89189 R Quartz-muscovite schist

RMP 89190 F Quartz vein up to cm wide - limonite pseudomorphs of breccia fragments in vein are aligned en echelon

RMP 89190 F Quartz vein - quartz crystals perpendicular to vein wall; open cavity; Fe oxide filled angular voids

RMP 89190 R Dunite - olivine adcumulate - no pyroxene; 1-3 percent disseminated chromite

RMP 89191 F Rounded, water transported cobble of vein quartz

RMP 89191 F Vuggy jasparoid with lots of Fe oxide boxworks after pyrite

RMP 89191 F3 Vuggy jasparoid - disseminated pyrite; Fe oxides after pyrite; euhedral quartz growing into vugs

RMP 89191 R Very intensely weathered (red colored, porous) rock - largely Fe oxides and clay with dark 2-3 mm crystals about 20 percent of rock

RMP 89192 R Deformed websterite - olivine-augite cumulate - 5-7 percent 3-4 mm pyroxene; all with strongly curved cleavage; pyroxene across width of sample seem to have similar curvature

RMP 89193 R Extremely weathered clinopyroxenite - very friable; all surfaces coated with black limonite spots; green gray; relict cleavage in some grains

RMP 89194 R Very friable quartz-talc schist

RMP 89195 R Deformed websterite - olivine-augite cumulate - 5-10 percent deformed pyroxene; cut by serpentine veinlets; cobble has pale-brown core with dark serpentinized rind; weakly magnetic

RMP 89196 R Talc schist - cut by quartz vein parallel to schistocity

RMP 89196 R1 Talc-rich schist

RMP 89196 R2 Highly weathered porphyritic volcanic rock - 20-30 percent phenocrysts (up to 5 mm); two alteration styles: first is mixture of hematite and sheet silicate (sericite); second is porous dark hematite; blocky crystal shape; matrix of granular quartz cemented by Fe oxides or, very rarely, clay; quartz makes up approximately 40 percent of matrix; intermediate composition?

RMP 89196 R3 Weathered quartz-chlorite schist

RMP 89197 R Very fine-grained dense structureless chert or jasporoid - pink; coated with black limonite; red Fe oxides; faint lens-like layering on one surface

RMP 89198 F Sheared (fractured) quartz vein material with lens of pyrite and Fe oxides after pyrite

RMP 89199 R Hornblende andesite porphyry - 5-10 percent hornblende phenocrysts in fine-grained, dark gray aphanitic groundmass; very hard to see texture; altered?

RMP 89200 R Anthophyllite schist? - very weathered schist; all phases pale cream brown; no cleavage; may have been fibrous; 1 piece of dark foliated granular rock; couldn't get past weathered coating to see what it was; the mineral in the schist isn't serpentine or talc

RMP 89201 R Two lithologies: 1. sheared dunite - olivine cumulate; one piece with some texture; other largely foliated serpetinite; 2. very altered hornblende andesite? with 1- 3 percent disseminated pyrite; greasy green matrix with faint darker spots (relict ferromagnesian mineral phenocrysts); sheared and slickenslided

RMP 89202 R Very altered rock - slickenslided and sheared outer surface; low density; pale green gray; irregular clots of chlorite approximately 10 percent of rock; pale green phase 3-5 mm with relict cleavage; granular matrix (perhaps green phase where don't see cleavage); could be altered clinopyroxenite; could be altered volcanic porphyry?

RMP 89203 R Fine-grained to fine-medium-grained hornblende? diorite - 5-7 percent ferromagnesian minerals; granular textures; several pieces show extreme weathering or argillic alteration

RMP 89204 R Crushed and sheared ultramafic rock - no relict textures readily apparent; closely spaced fractures largely coated with black limonite; rock between fractures appears pale green, granular; magnetite veinlets present, parallel to shear surfaces; no slickenslides or serpentine coating; matrix not magnetic; magnetite concentrated in shear planes

RMP 89205 A Material from either sheared quartz vein or more likely sheared zone with disrupted quartz veins - very light rock; lens of quartz vein material bounded by slip surfaces; matrix is very altered; Fe oxide-stained and clay-rich; black limonite on slip surfaces

RMP 89206 R Crushed and sheared ultramafic rock - rock chips to 3 cm are angular, slightly flattered, competent; coated with serpentine and black limonite; slickenslides on some surfaces; no veinlets visible but variably magnetic; no matrix material seen

RMP 89207 F Gossan with remnants of massive magnetite

RMP 89207 F Nearly massive pieces of specular hematite - coated with hematite powder; non magnetic

RMP 89207 R Plagioclase andesite porphyry? - 10-15 percent plagioclase phenocrysts to 2-3 mm in fine-grained gray, granular groundmass; 3-5 percent ferromagnesian mineral- biotite?; ferromagnesian mineral and plagioclase are altered; calcite filled vugs either are vesicles or plagioclase sites

RMP 89208 Ra Massive magnetite

RMP 89208 Rb Gossan - yellow-brown goethite with hematite-rich veinlets and lenses

RMP 89209 R Extremely weathered clinopyroxenite? - pale yellow-brown to green rock; some relict cleavage

APPENDIX H: X-RAY ENERGY SPECTRUM FOR PGM AND CHROMITE FROM S. RAMBAS, S. PIRIK, AND S. DANAU DJINGAH AREAS

Robert Oscarson
U.S. Geological Survey in Menlo Park, California.

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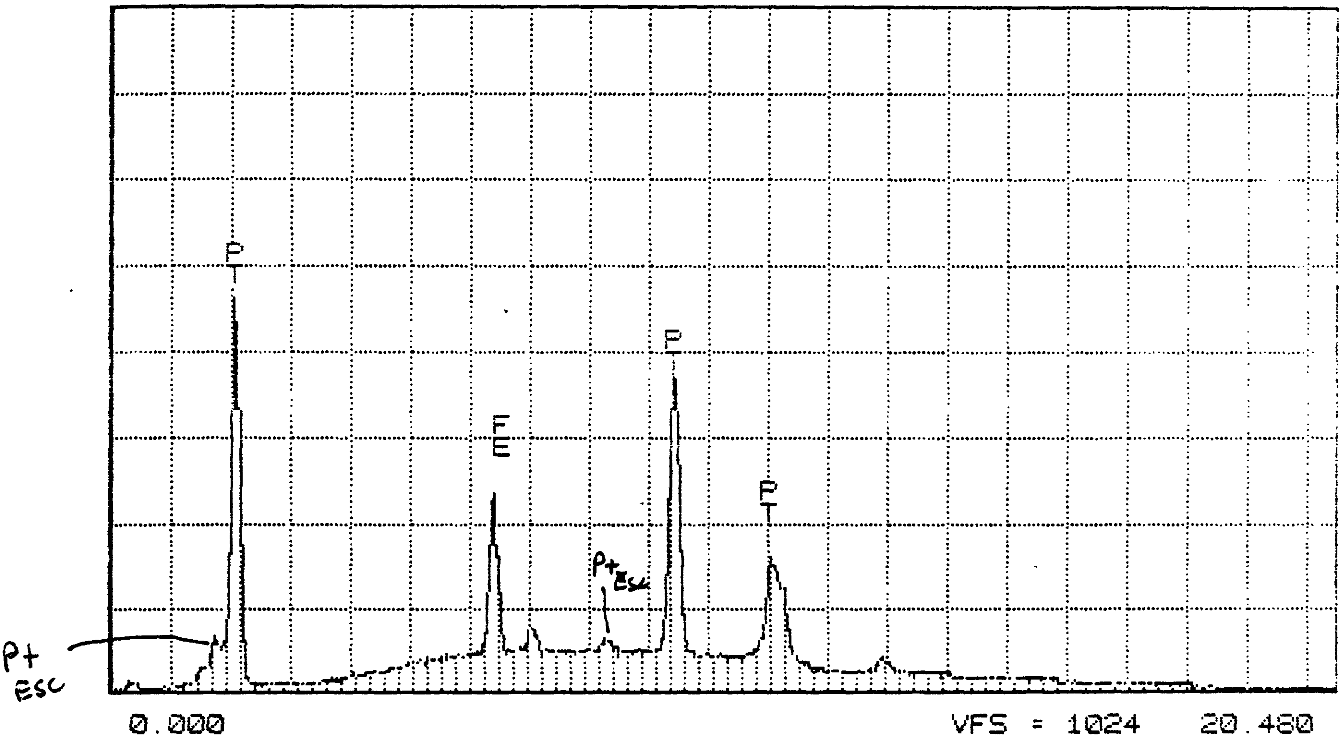

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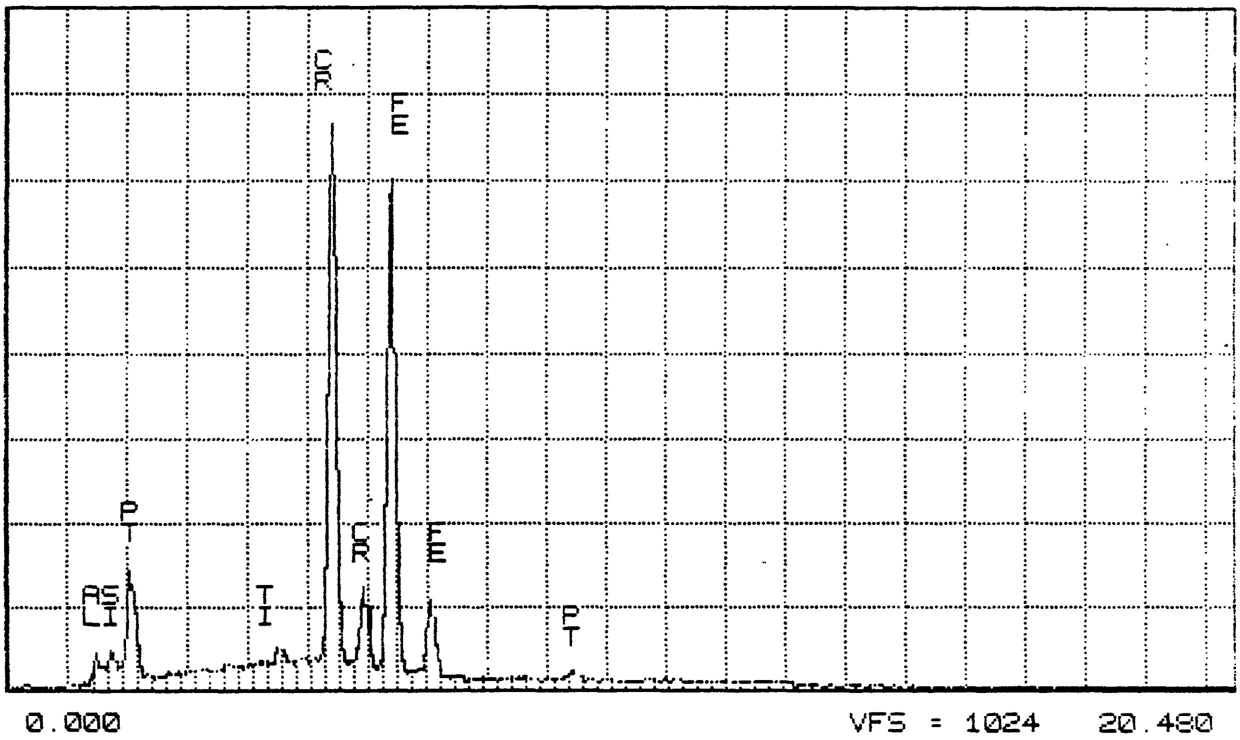

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Chromium Spinel(?)

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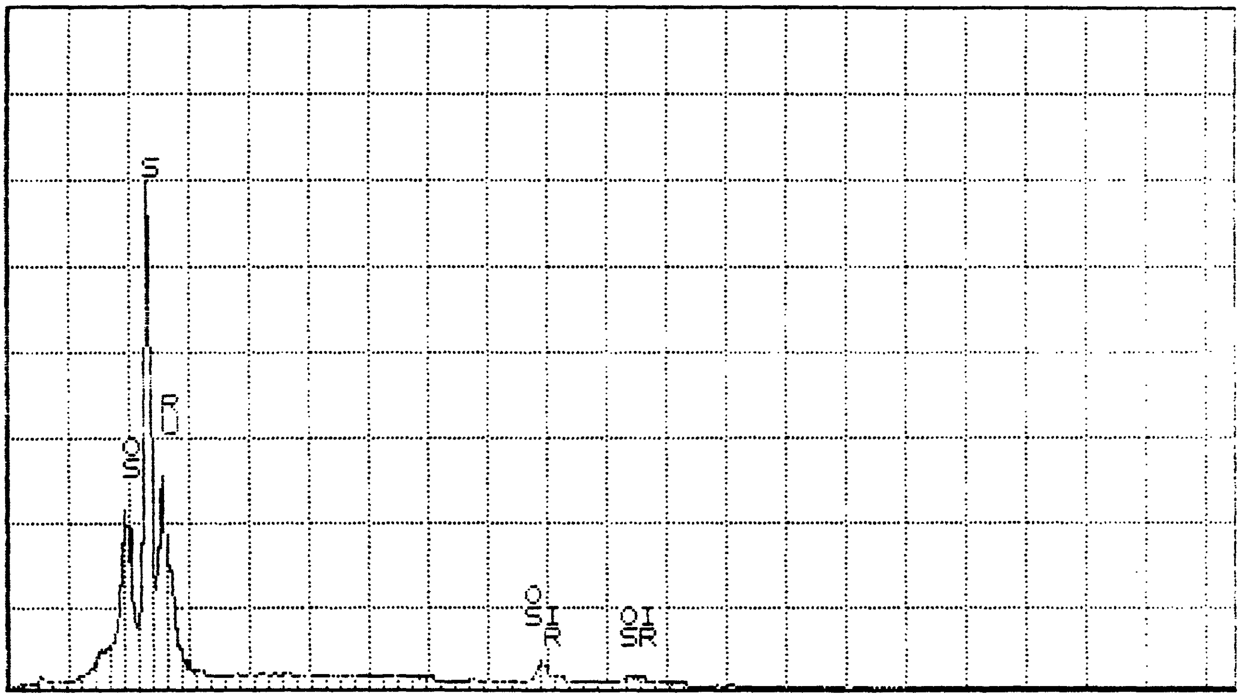

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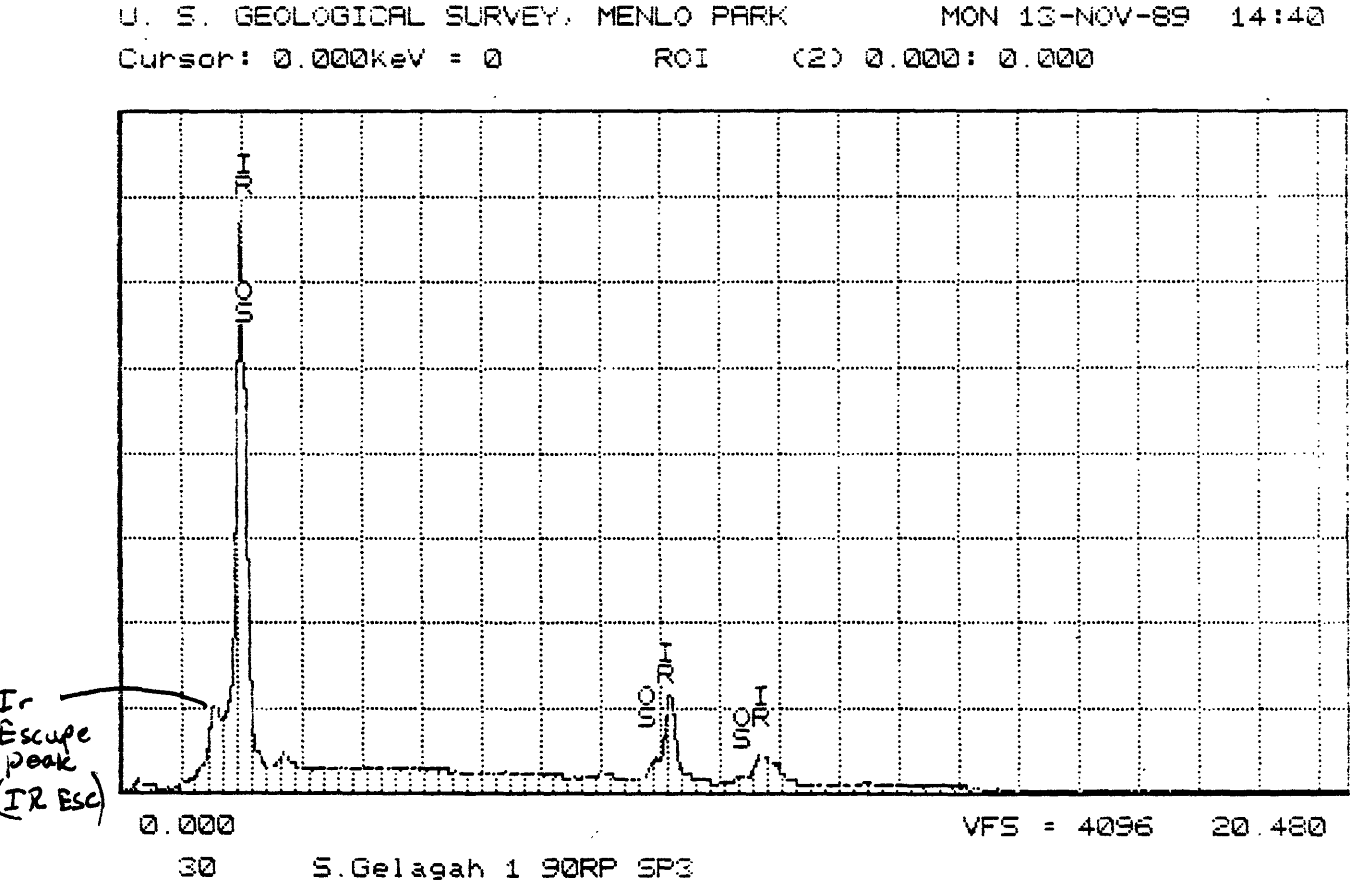

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78\8\7

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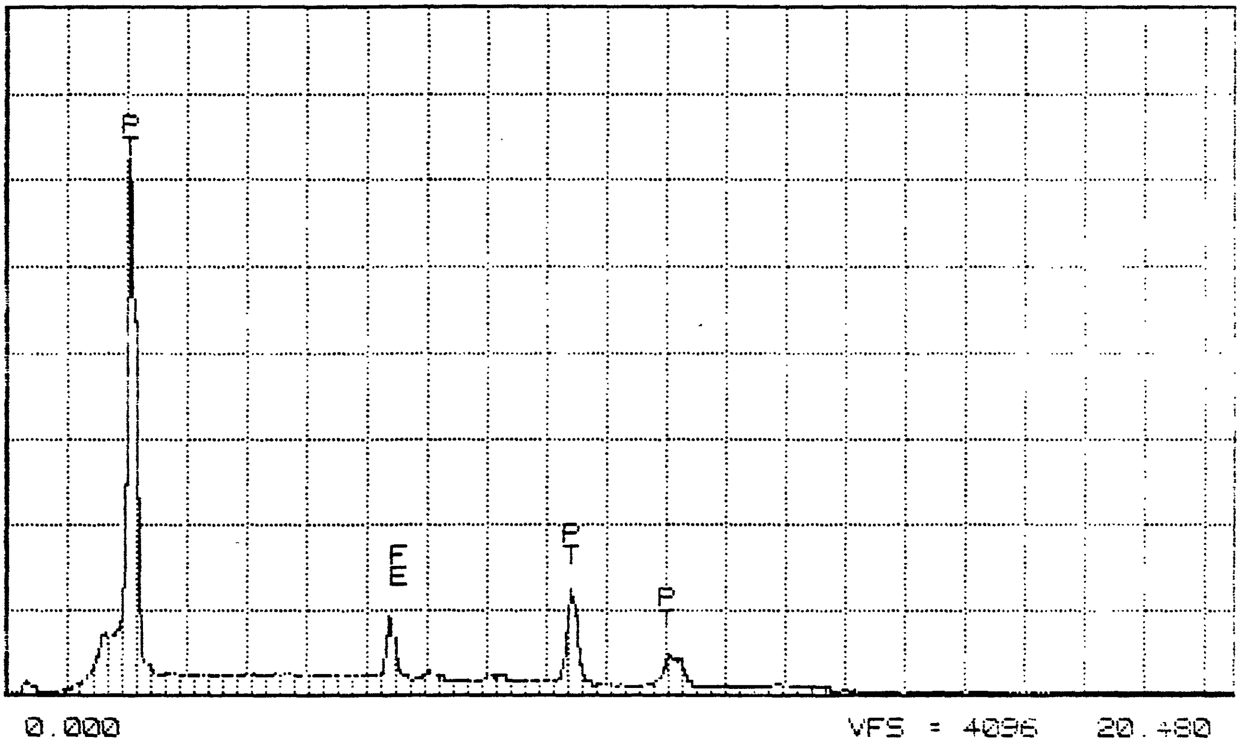

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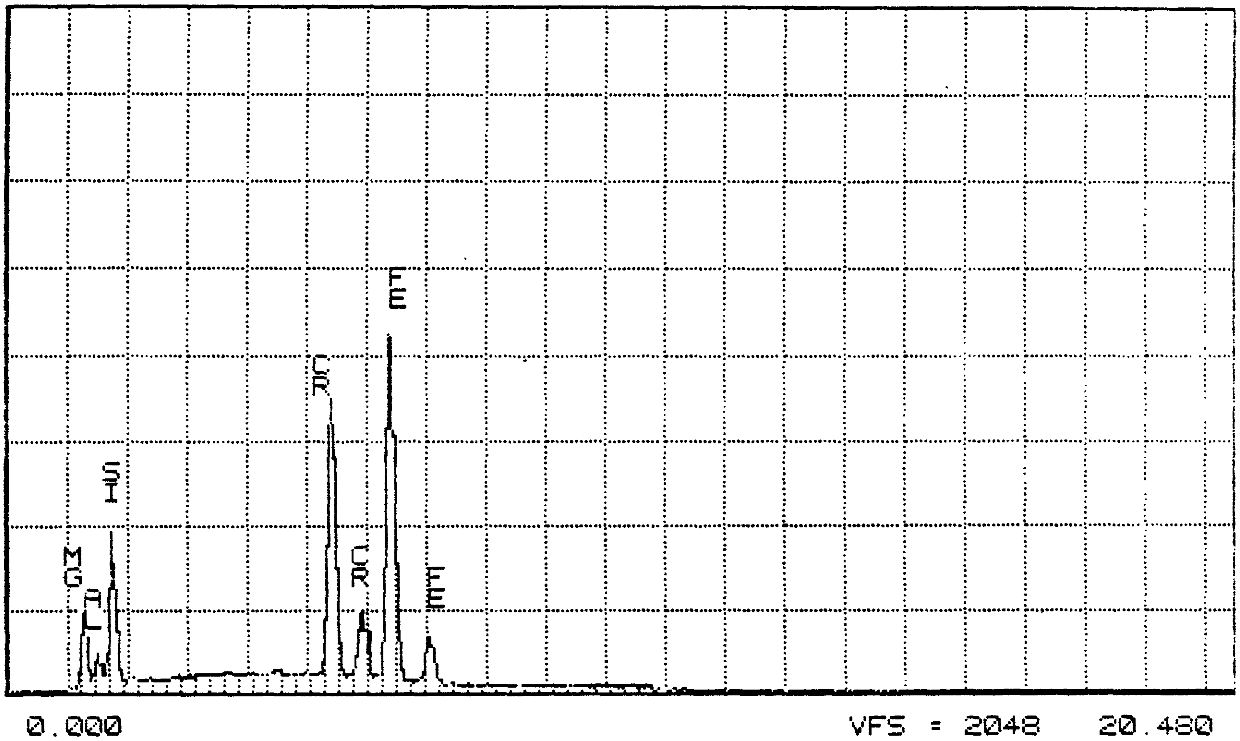

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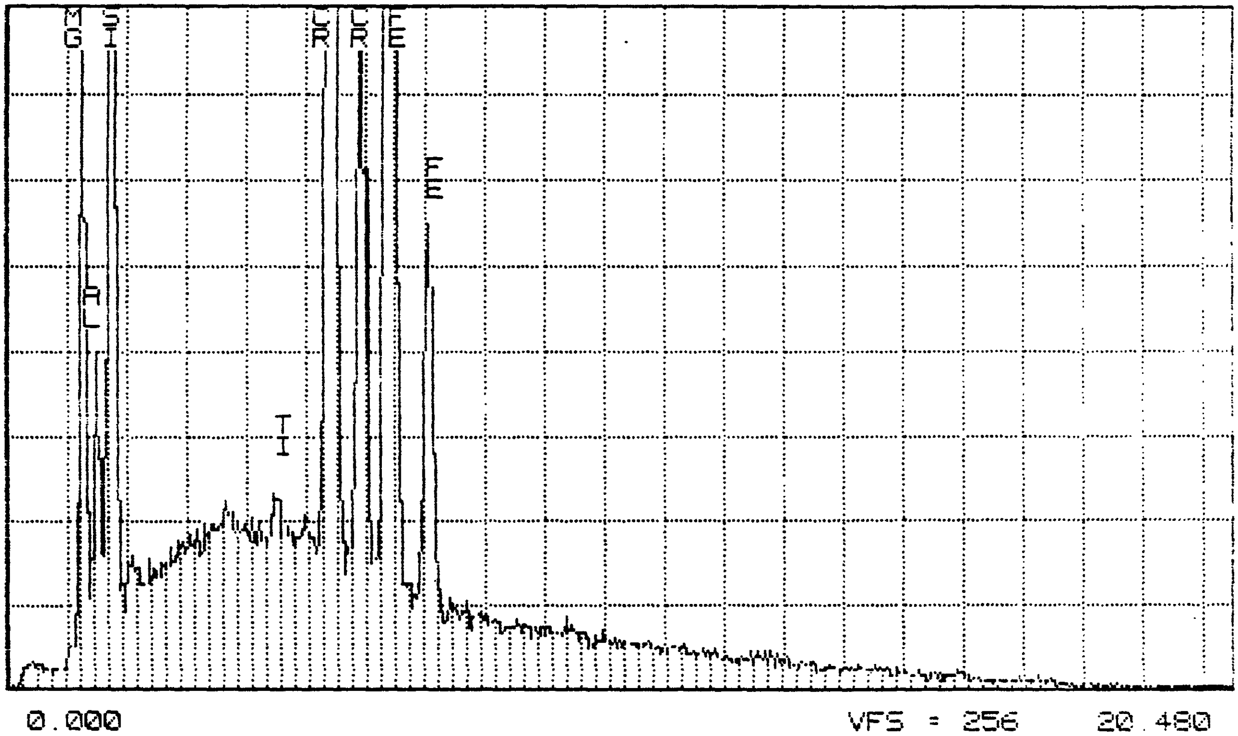

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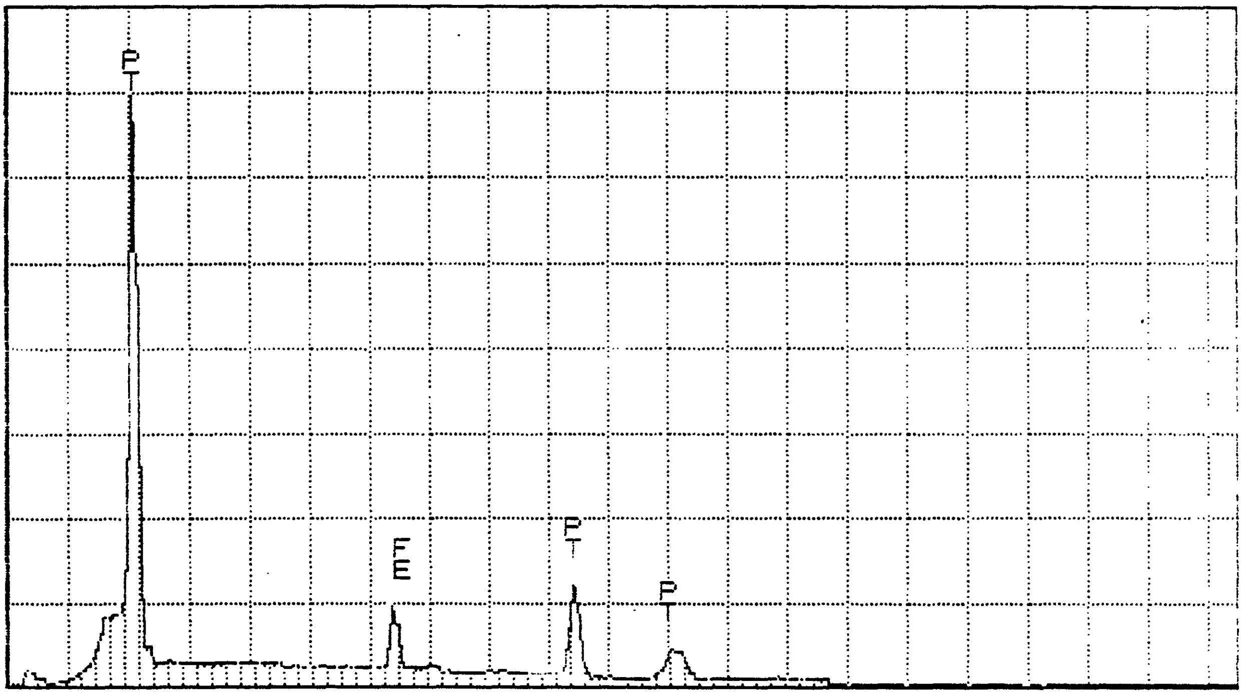

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30 Rambas alluvial 65P SP6

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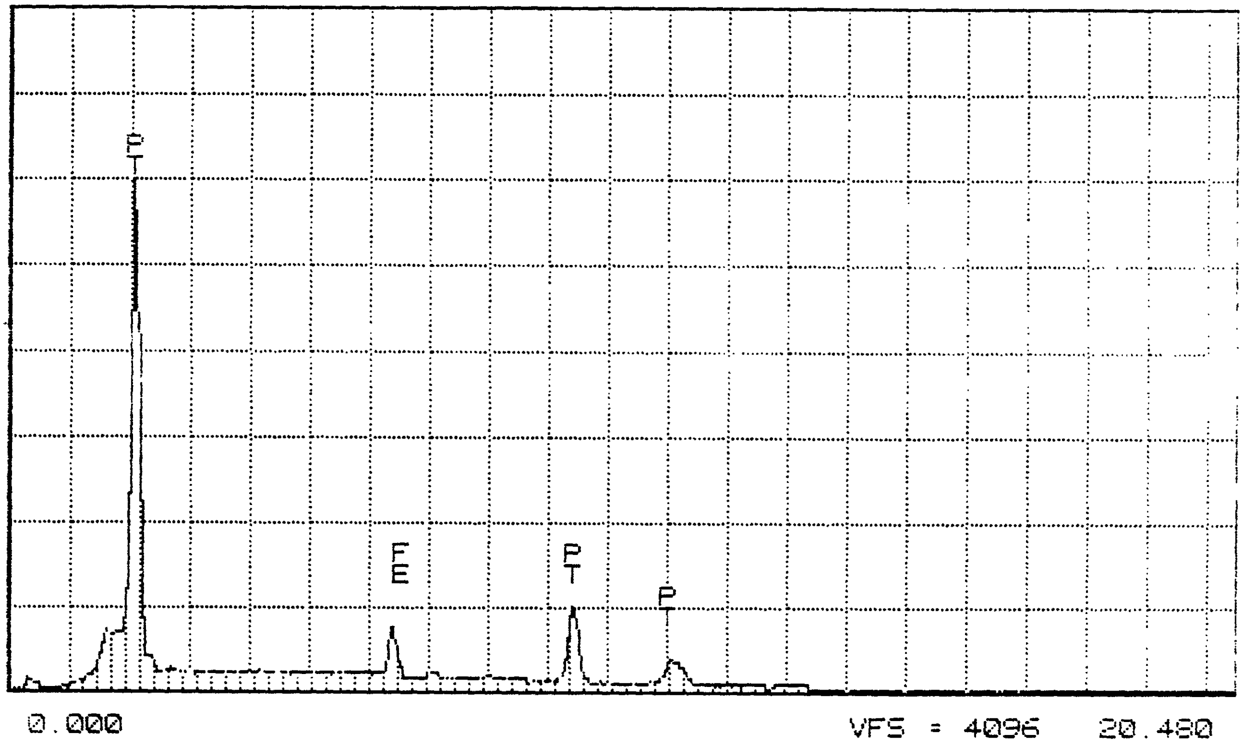

30 Rambas alluvial 65P SP7

no inclusions

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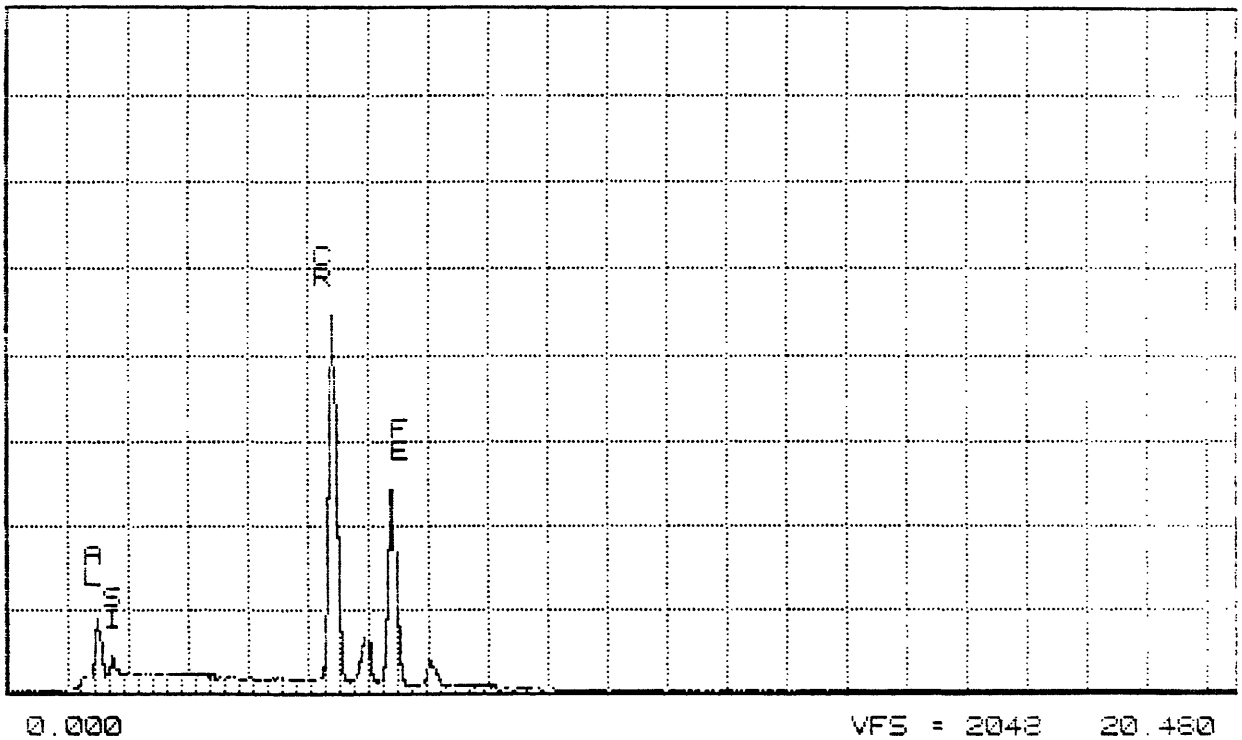

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octahedral inclusion seen in photo #011

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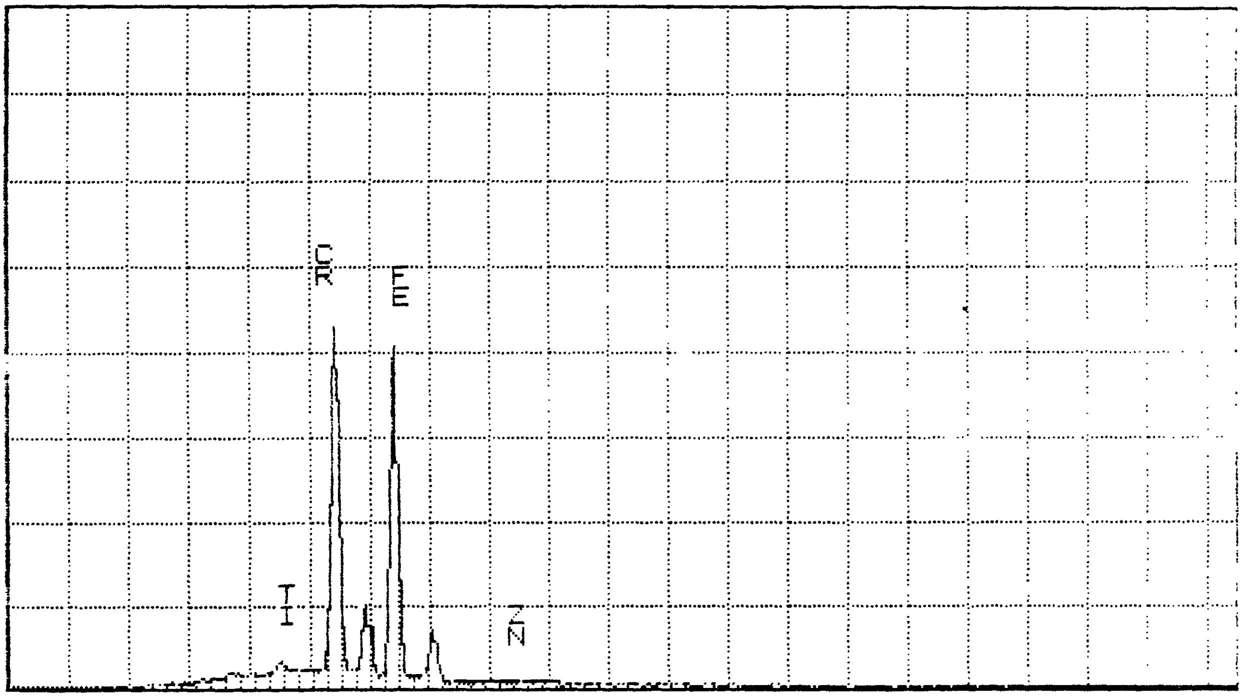

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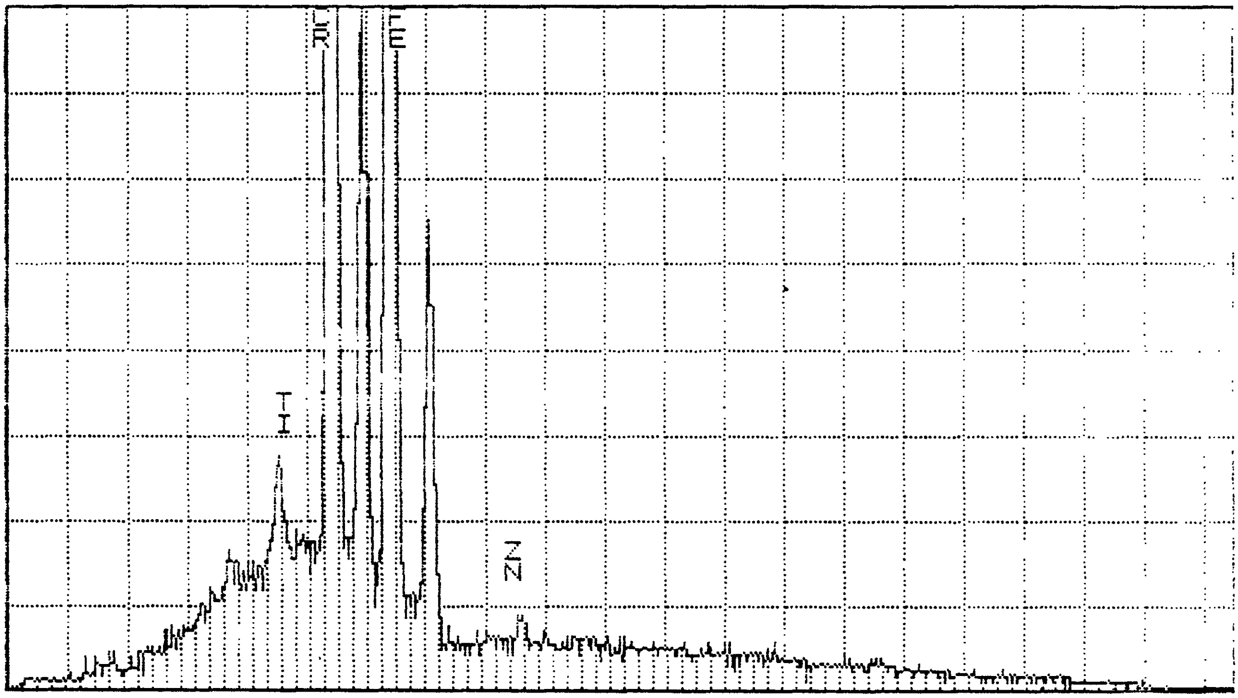

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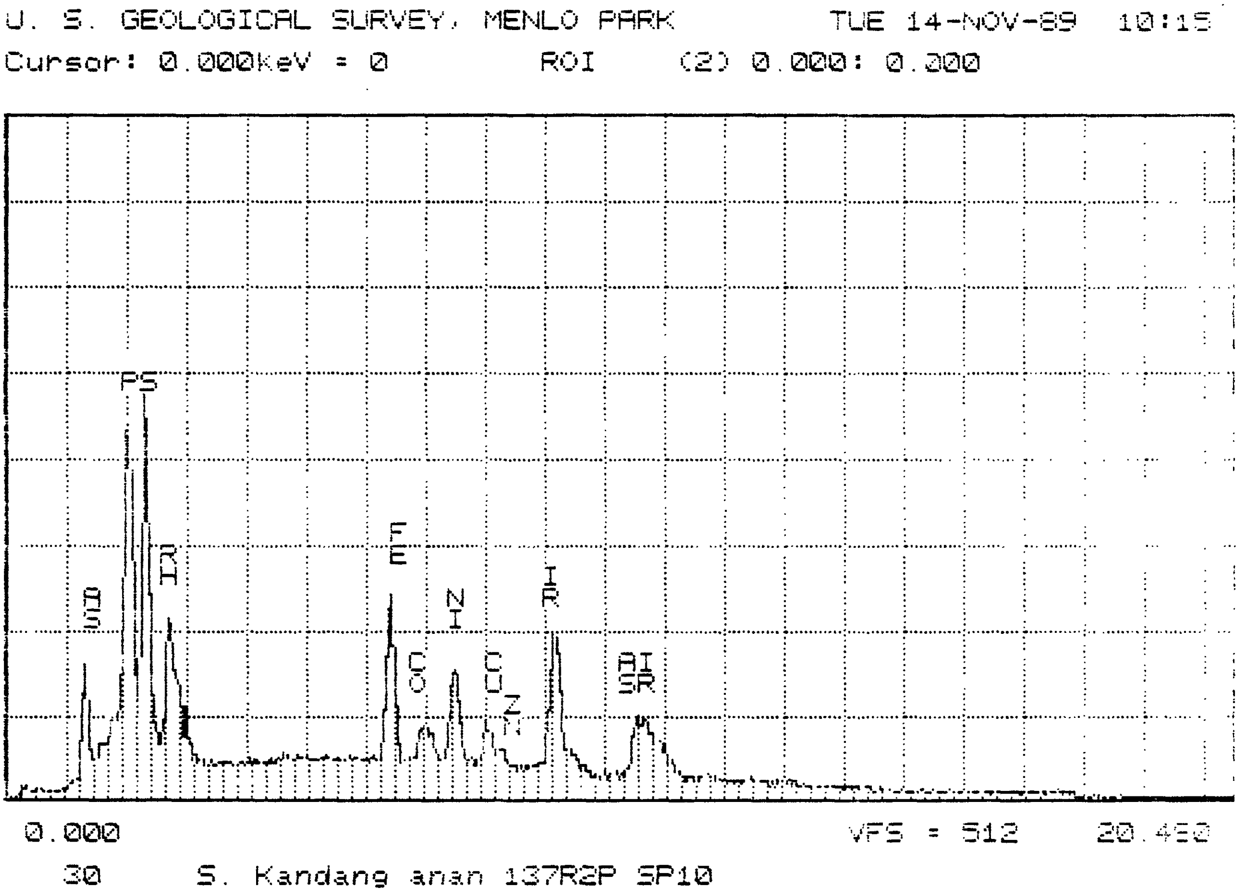

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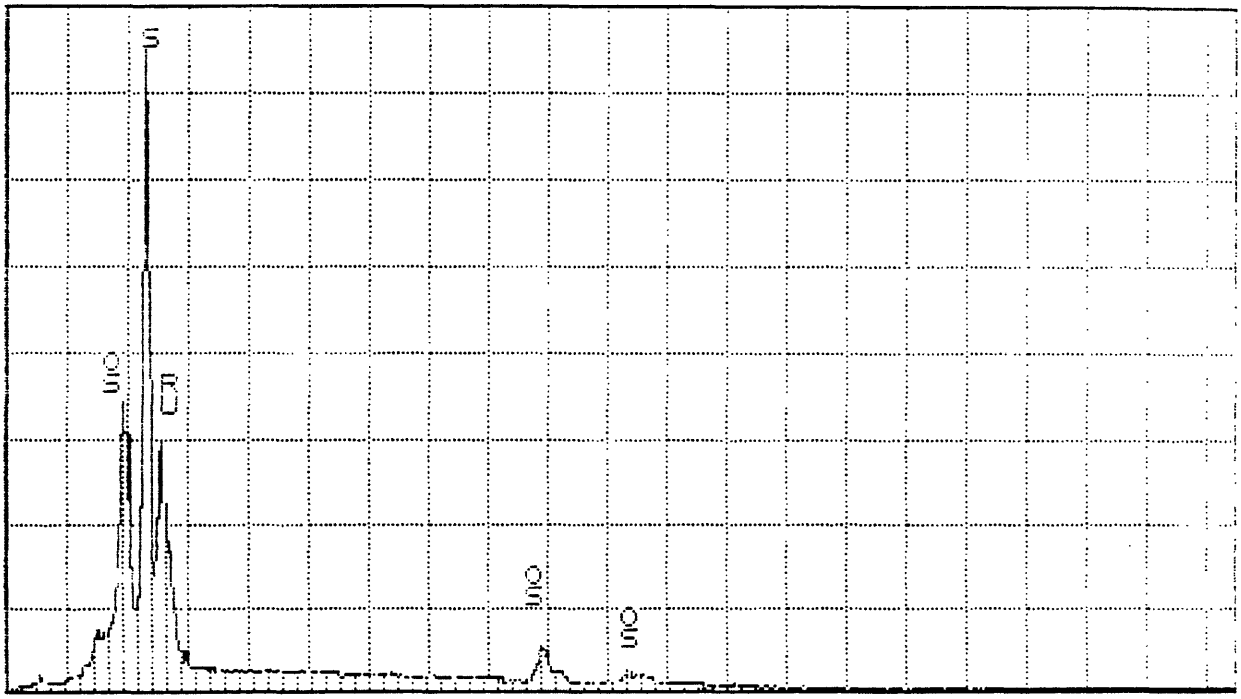

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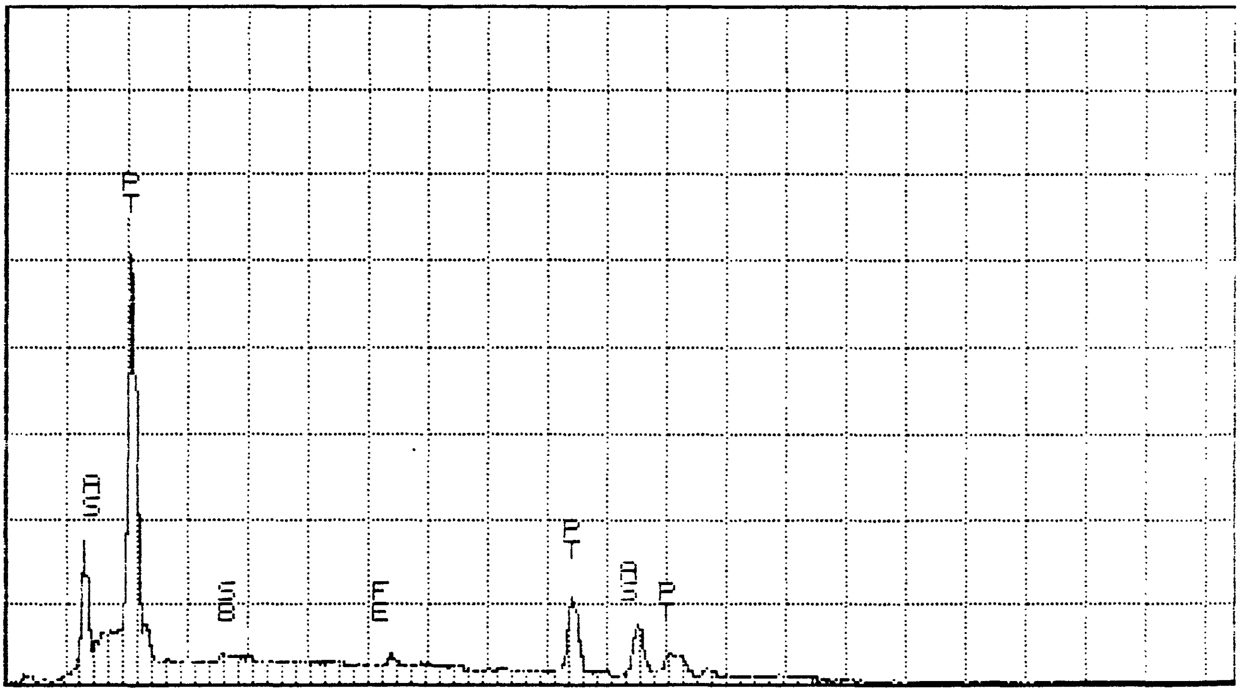

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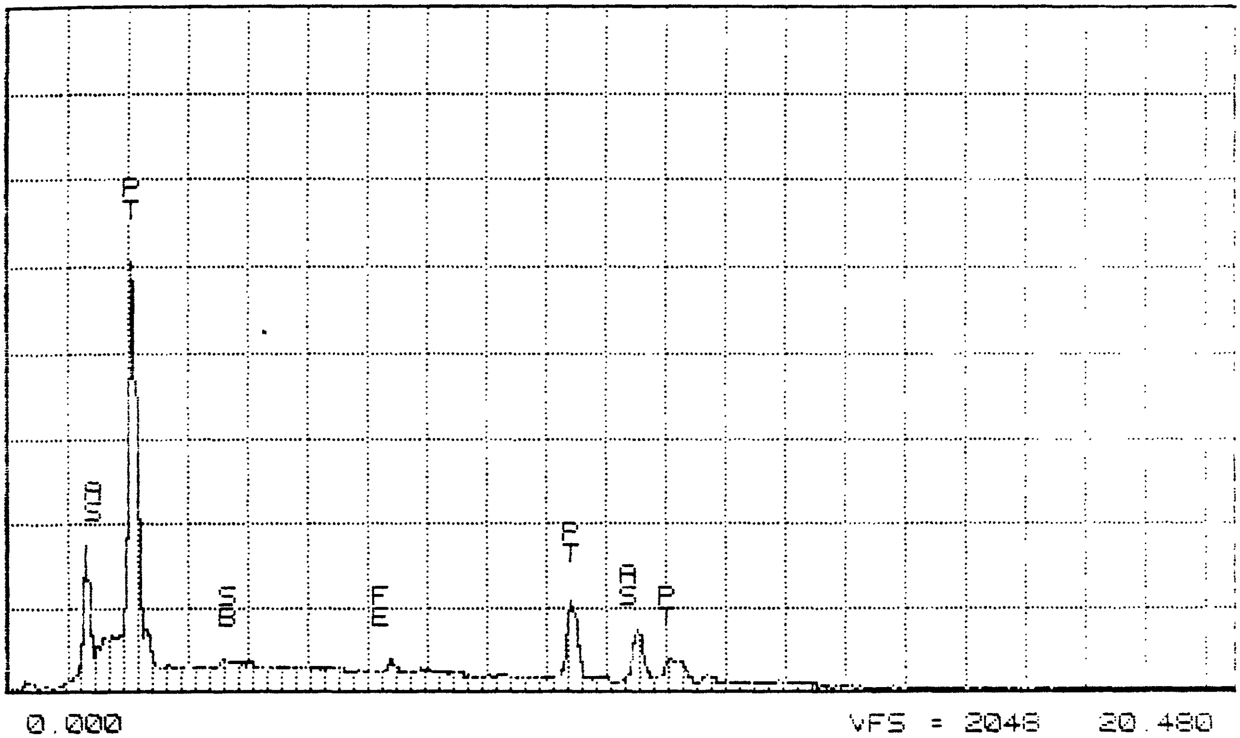

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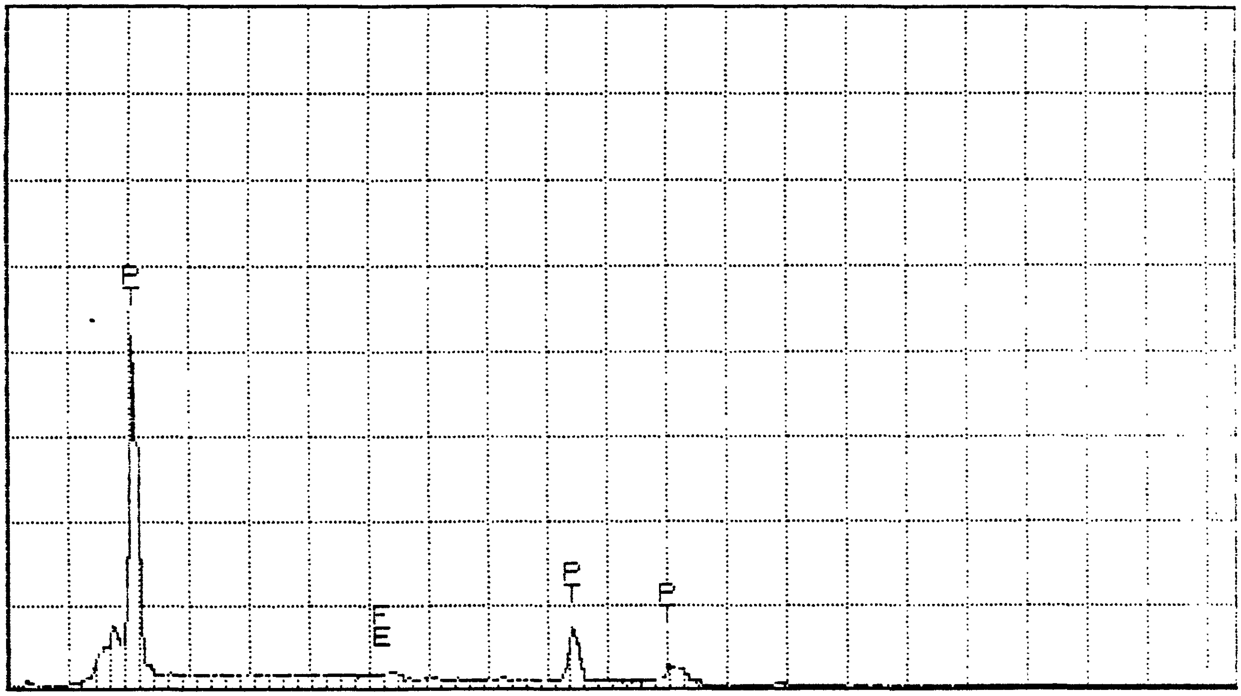

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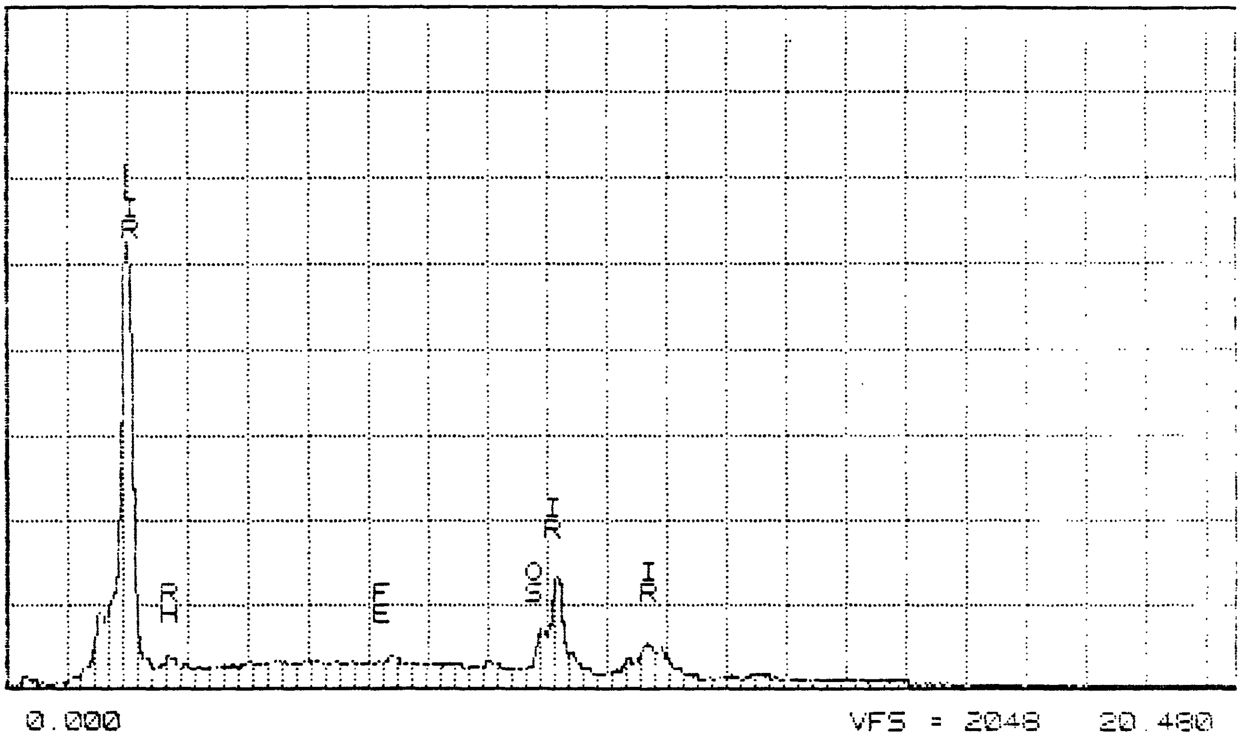
30 S. Kandang anan 137R2P SP13

Host grain

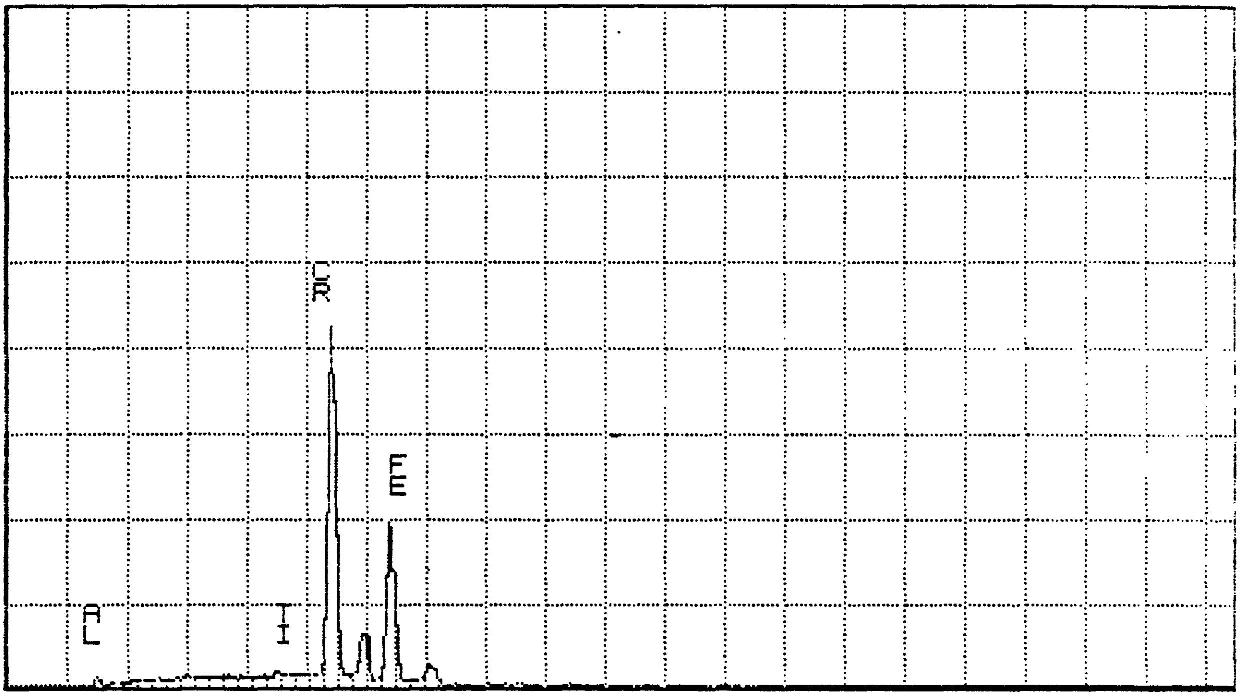
U. S. GEOLOGICAL SURVEY, MENLO PARK　　TUE 14-NOV-89　10:33
Cursor: 0.000KeV = 0　　ROI　(2) 0.000: 0.000



30　S. Kandang anan 137R2P SP14

inclusion seen better in photo # 012, BSE

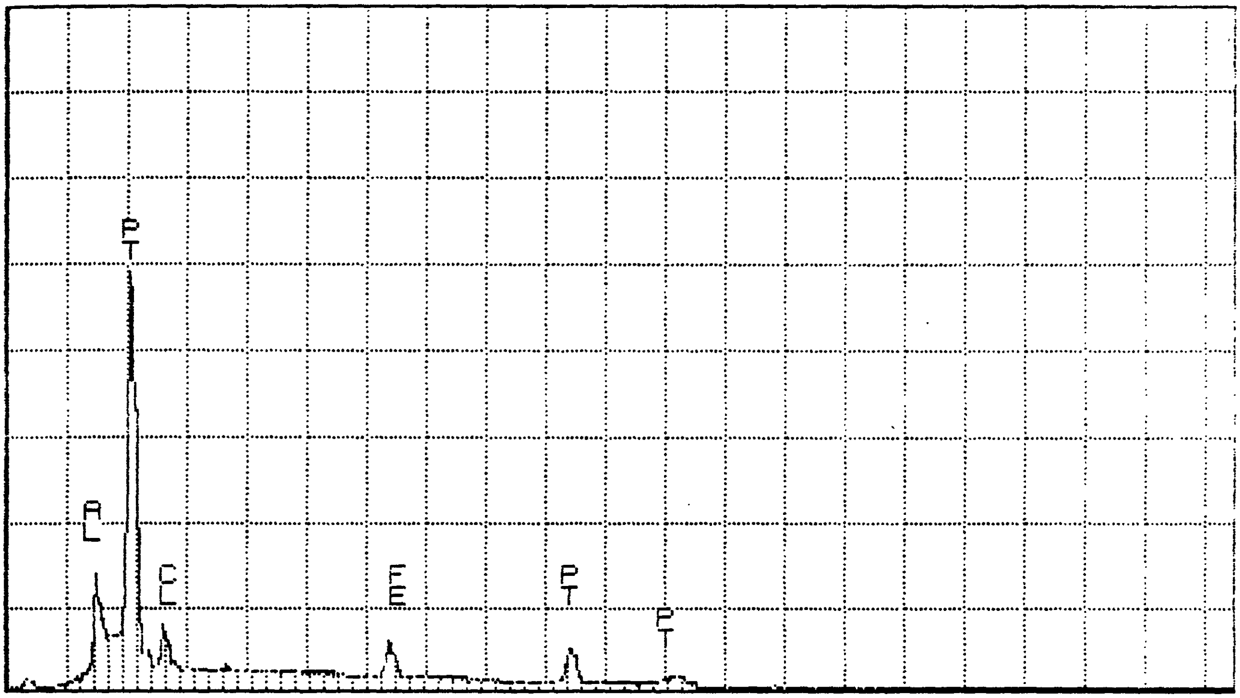
U. S. GEOLOGICAL SURVEY, MENLO PARK   TUE 14-NOV-89   11:10
Cursor: 0.030keV = 0   ROI   (2) 0.000: 0.000



0.000   VFS = 2048   20.480
30   S. Ayubat 166P SP15

chromium spinel (?)

U. S. GEOLOGICAL SURVEY, MENLO PARK   TUE 14-NOV-89   11:25
Cursor: 0.000keV = 0   ROI   (2) 0.000: 0.000

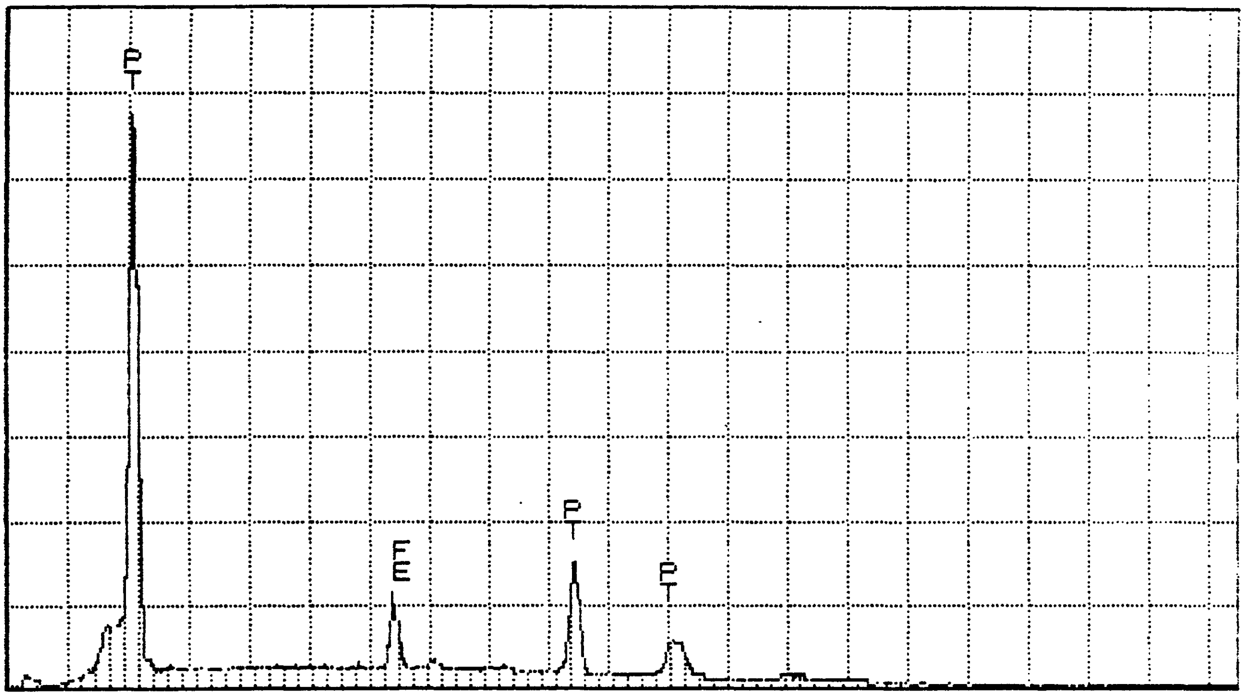


0.000   VFS = 2048   20.480
30   S. Ayubat 166P SP16

inclusions or surface contamination

U. S. GEOLOGICAL SURVEY, MENLO PARK TUE 14-NOV-89 11:30

Cursor: 0.000KeV = 0 ROI (2) 0.000: 0.000



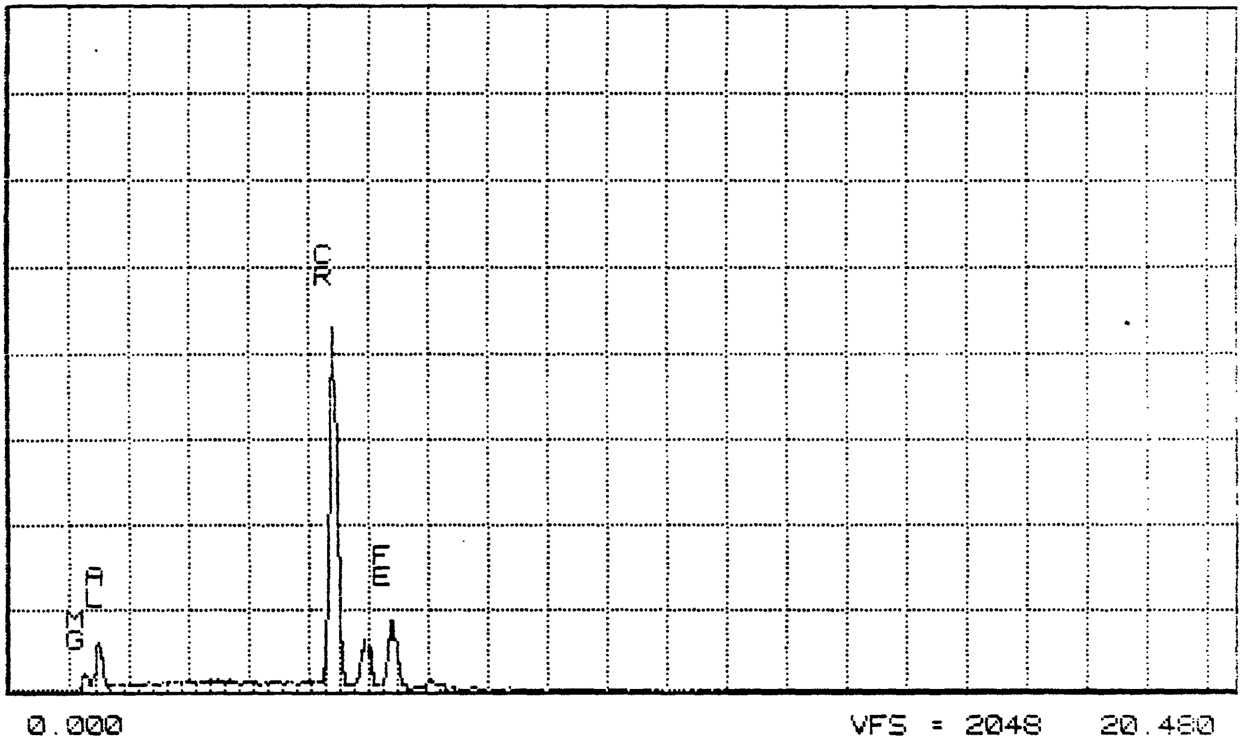
0.000 VFS = 2048 20.460

30 S. Ayubat 166P SP17

host grain

U. S. GEOLOGICAL SURVEY, MENLO PARK TUE 14-NOV-89 12:04

Cursor: 0.000keV = 0 ROI (2) 0.000: 0.000



30 C. M. Taylor chromite #5

ZIRCONIA SYNTHETIC ZrO_2

ZrO_2 = 98.0
TiO_2 = 0.04
HfO_2 = 1.85
MgO = 0.05
CaO = 0.02

CHROMITE #5

Al_2O_3 = 23.91
MgO = 17.26
Cr_2O_3 = 45.65
MnO = 0.13
Fe = 9.90
NiO = 0.17
As FeO = 12.72
V_2O_3 = 0.17
TiO_2 = 0.12
SiO_2 = 0.03
ZnO? = 0.01? NLD

HEMATITE High Purity 99.99+% Fe_2O_3 From Spectrographic Analysis and electron microprobe analysis.

WILLEMITE #1 Somewhat Inhomogenious, excellant for fluorescent standard

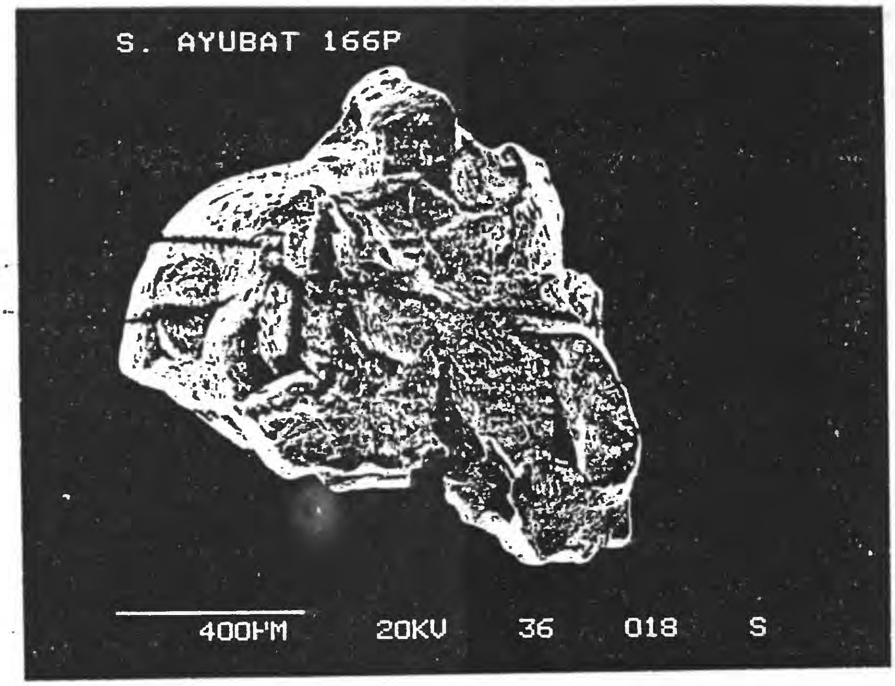
ZnO = 66.3
MgO = 0.26
MnO = 6.17
SiO_2 = 27.2
TOTAL = 99.93

DTS-1 OLIVINE

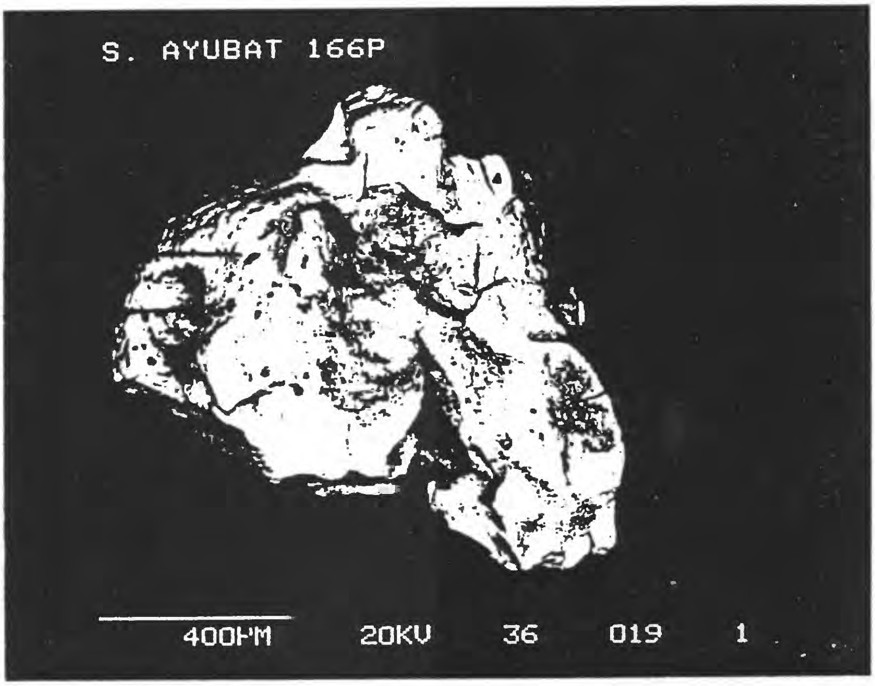
SiO_2 = 40.6
H_2O^+ = 0.43
Fe_2O_3 = 0.70
H_2O^- = 0.00
FeO = 7.3
MnO = 0.12
MgO = 50.7
NiO = 0.19

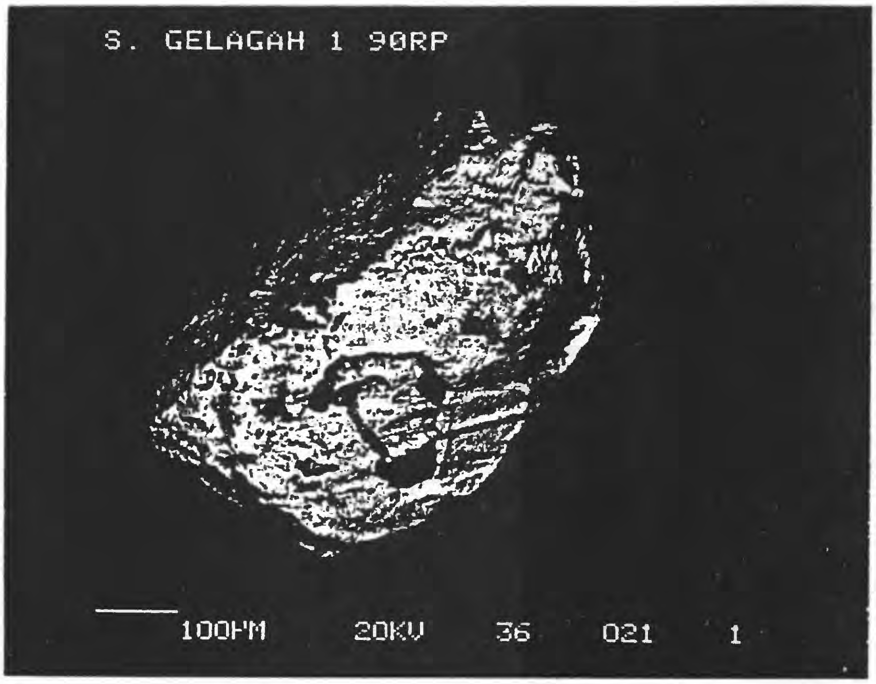
Total = 100.0

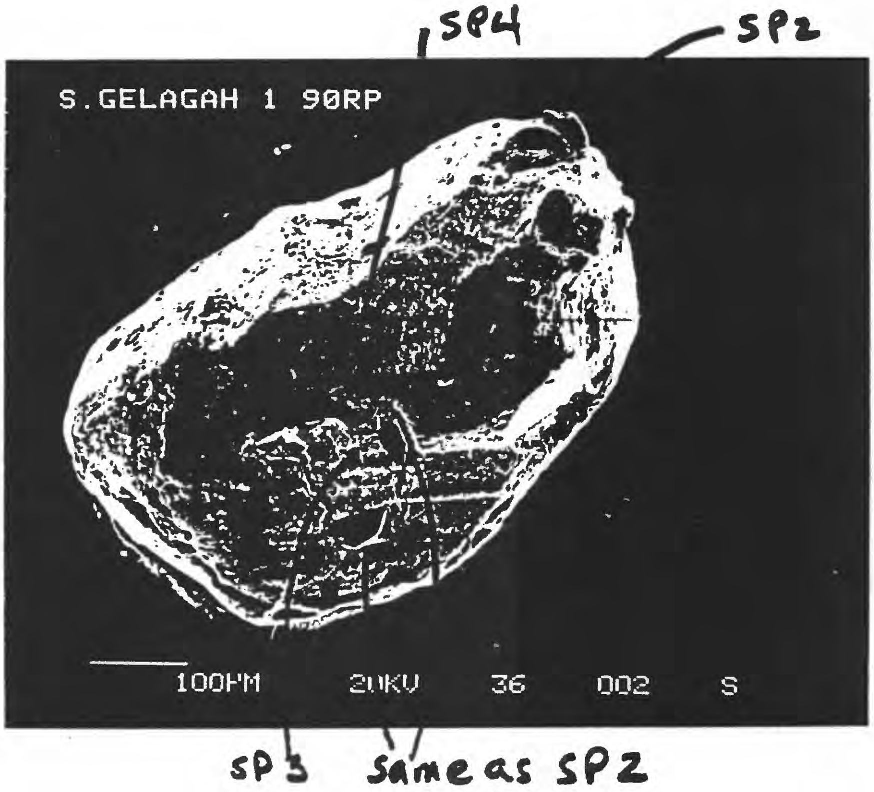
SP16

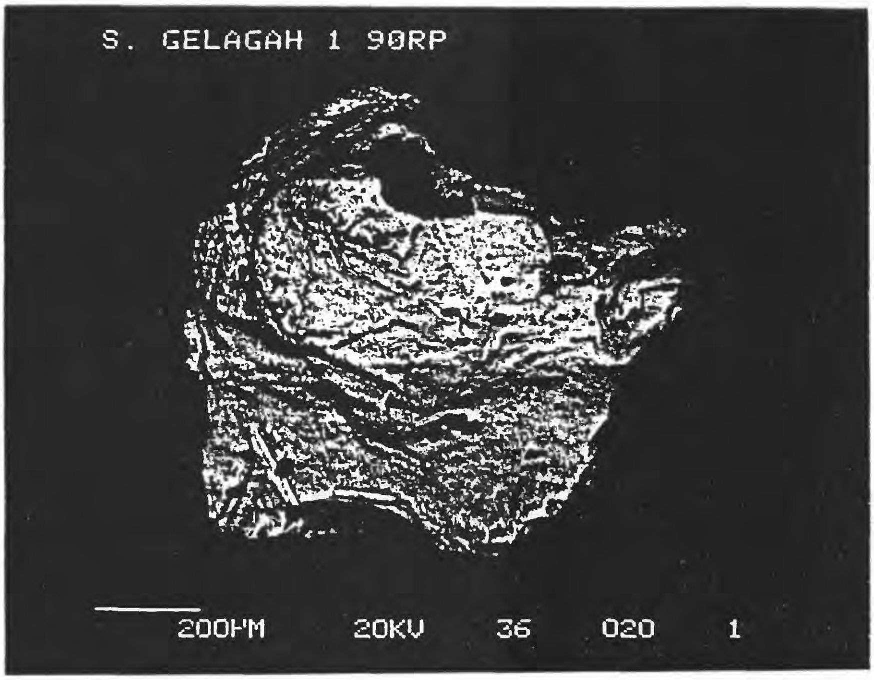

S. AYUBAT 166P
400µM
20KV
36
018
S

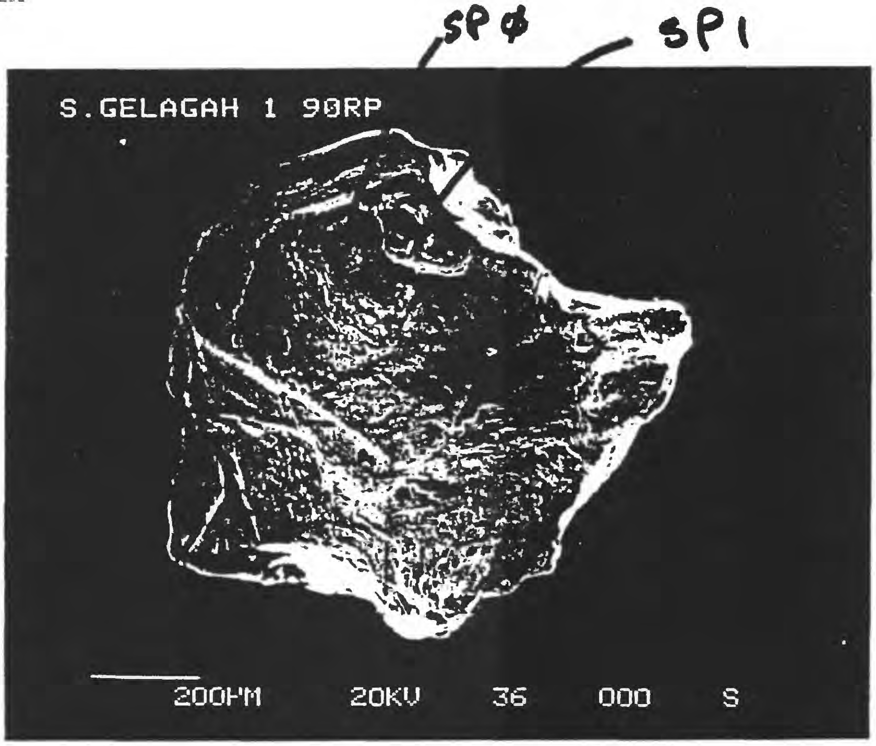
SP16


S. AYUBAT 166P
400µM
20KV
36
019
1

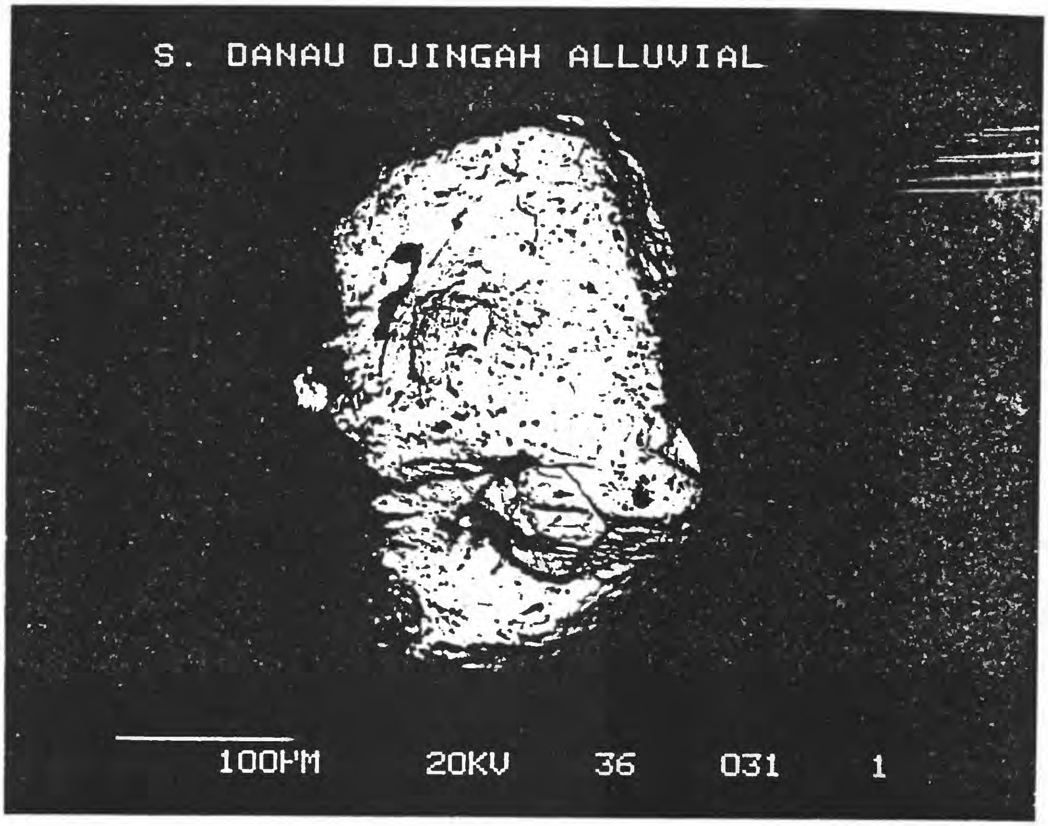

S. GELAGAH 1 90RP
100PM 20KV 36 021 1


SP4
SP2
S.GELAGAH 1 90RP
100PM 20KV 36 002 S
SP3
Same as SP2

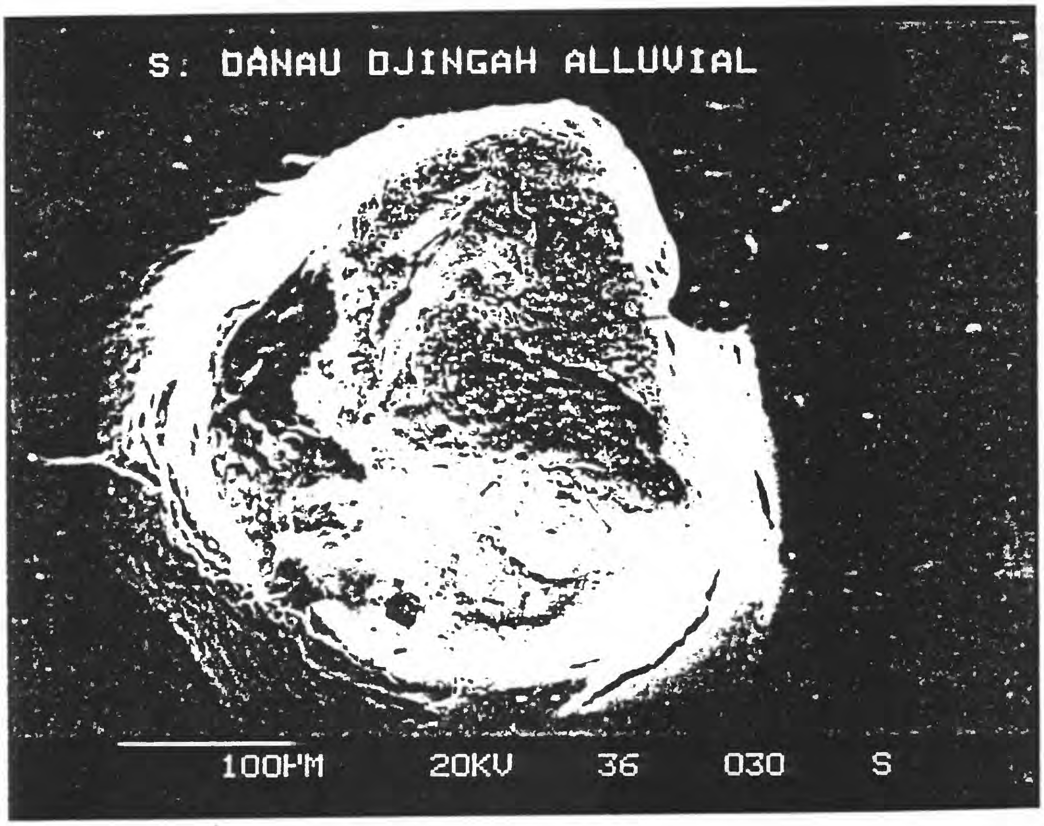

S. GELAGAH 1 90RP
200µM 20KV 36 020 1

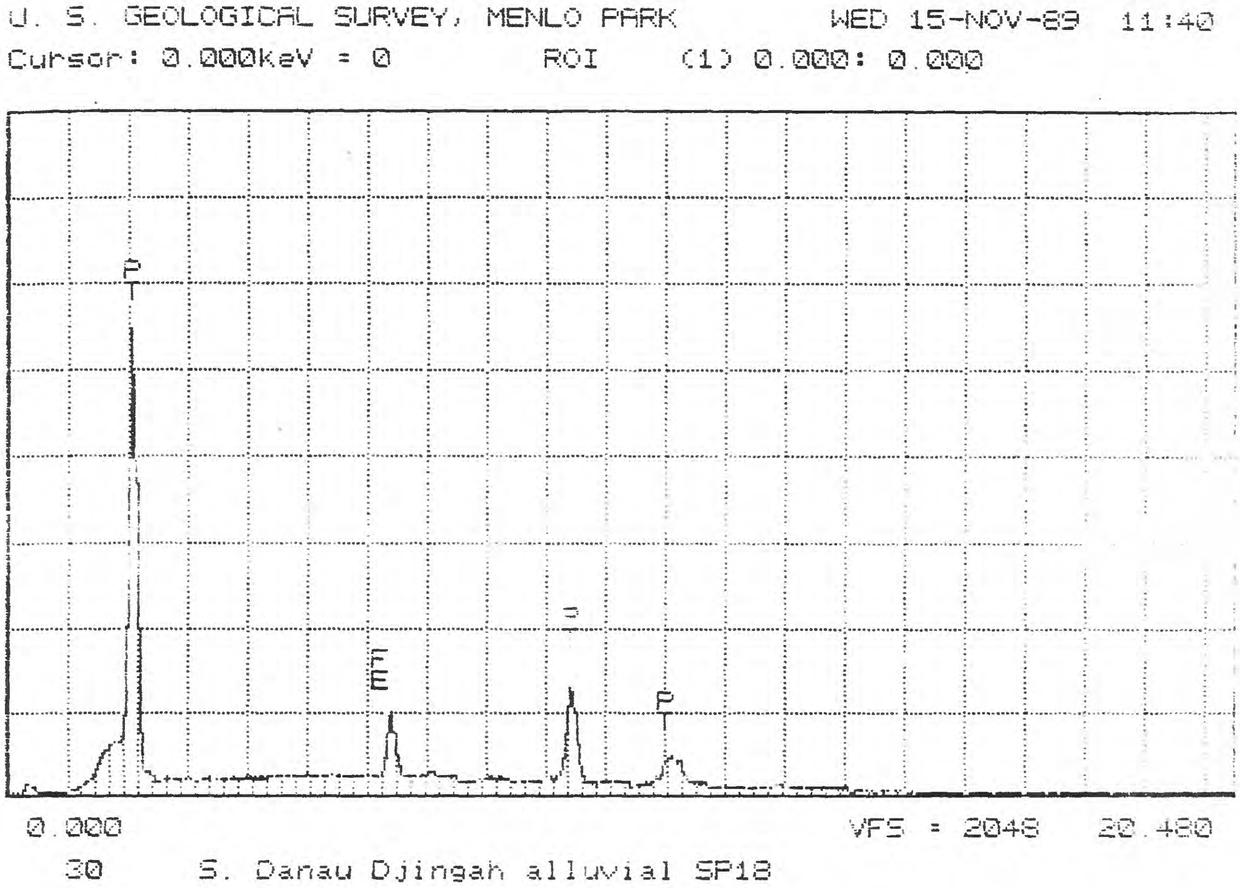

SP0
SP1
S.GELAGAH 1 90RP
200µM 20KV 36 000 S

3E


S. DANAU DJINGAH ALLUVIAL
100µM 20KV 36 031 1

5C19


S. DANAU DJINGAH ALLUVIAL
100µM 20KV 36 030 S

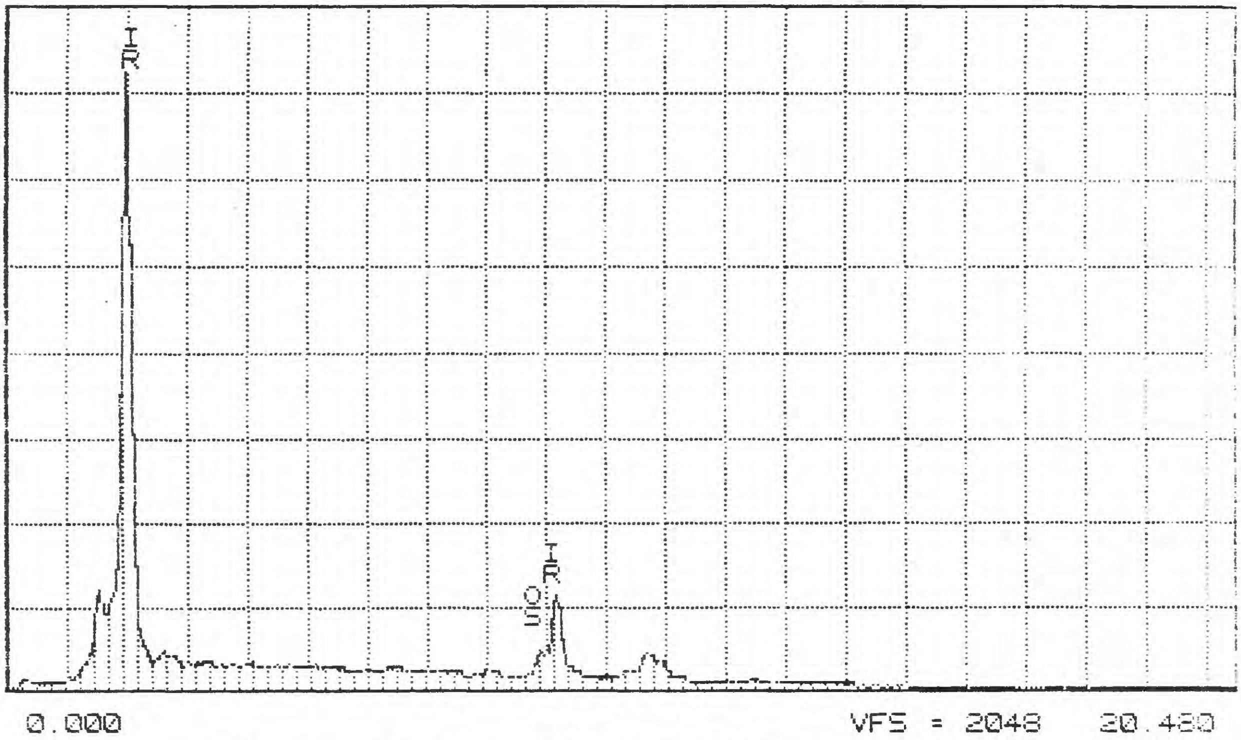


U. S. GEOLOGICAL SURVEY, MENLO PARK WED 15-NOV-89 11:40

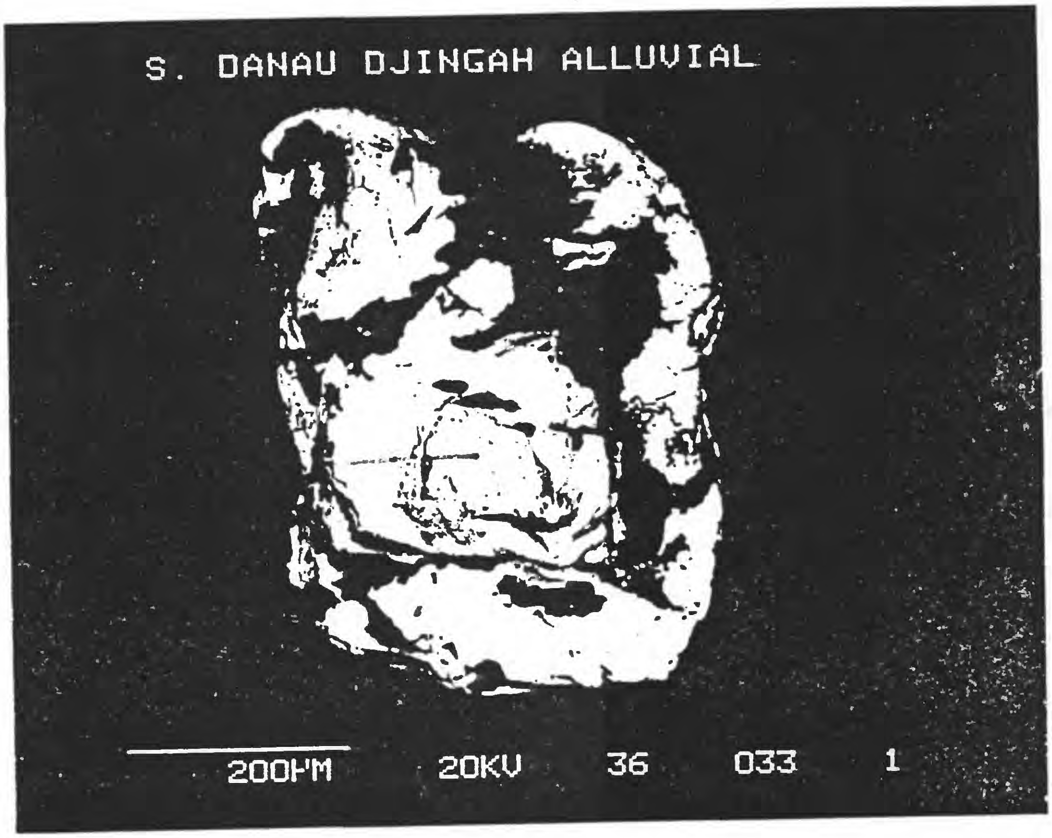
Cursor: 0.000keV = 0 ROI (1) 0.000: 0.000

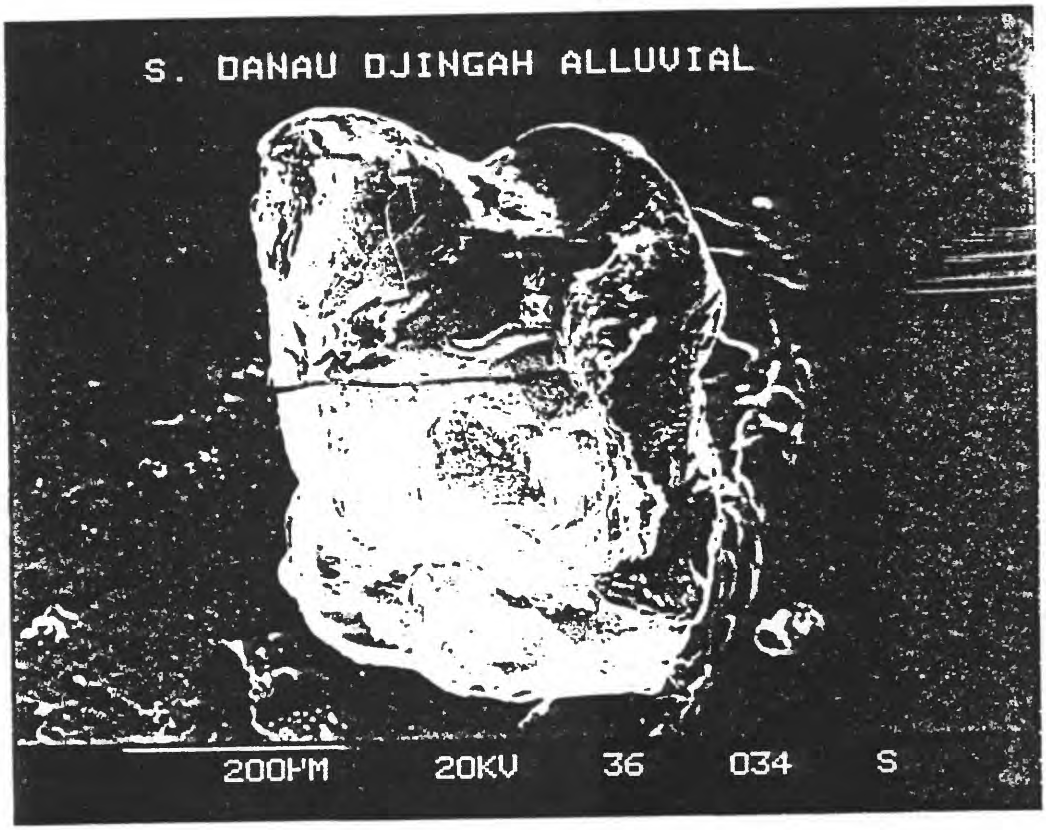
30 S. Danau Djingah alluvial SP18

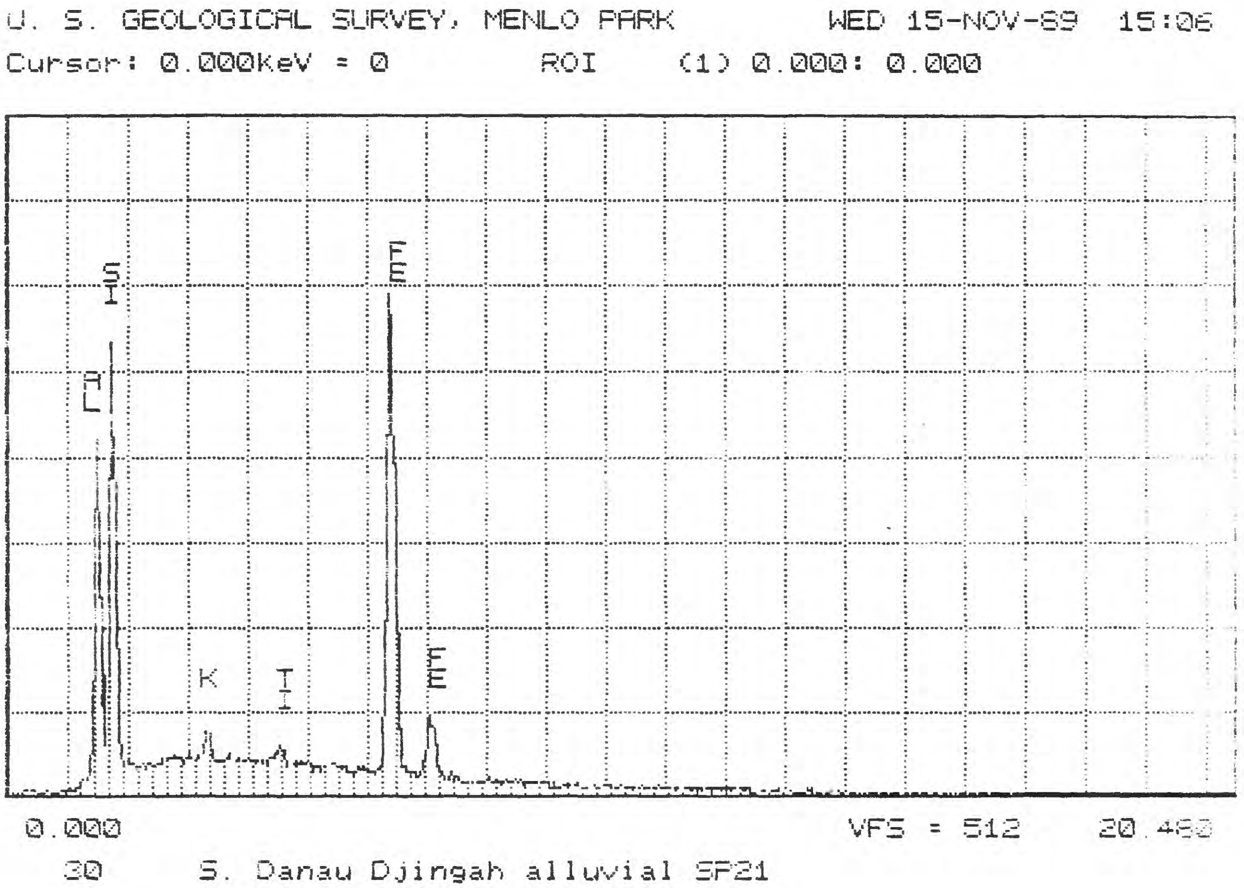
```
U. S. GEOLOGICAL SURVEY, MENLO PARK          WED 15-NOV-89   11:55
Cursor: 0.000keV = 0         ROI     (1) 0.000: 0.000
```



30 S. Danau Djingah alluvial SP19


S. DANAU DJINGAH ALLUVIAL
200µM
20KV
36
033
1


S. DANAU DJINGAH ALLUVIAL
200µM
20KV
36
034
S

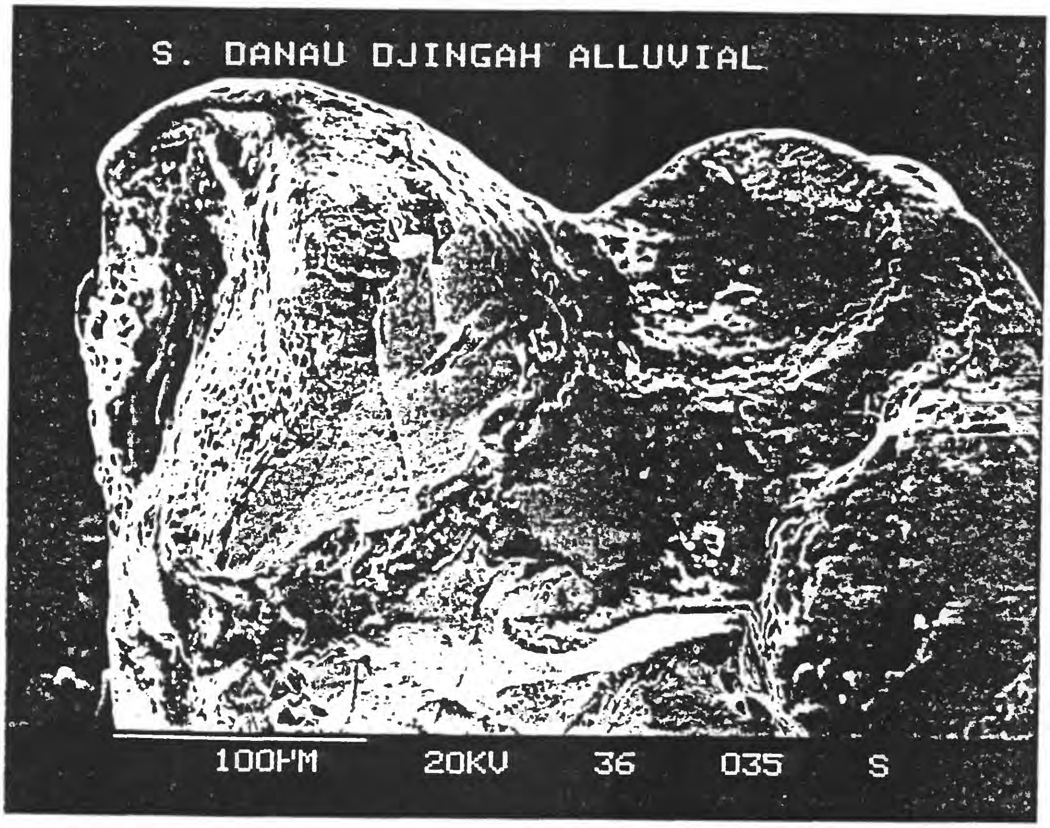


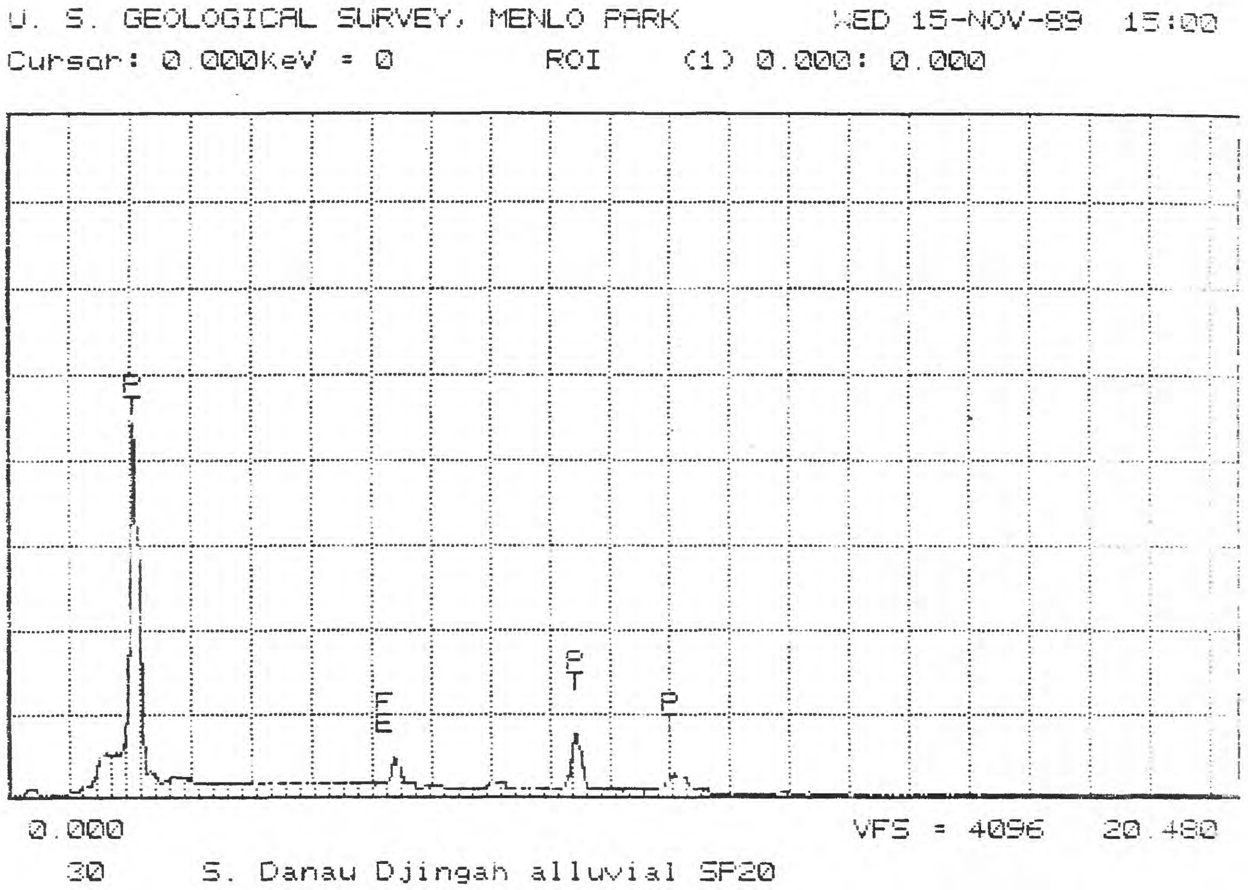
U. S. GEOLOGICAL SURVEY, MENLO PARK WED 15-NOV-89 15:06

Cursor: 0.000keV = 0 ROI (1) 0.000: 0.000

0.000 VFS = 512 20.480

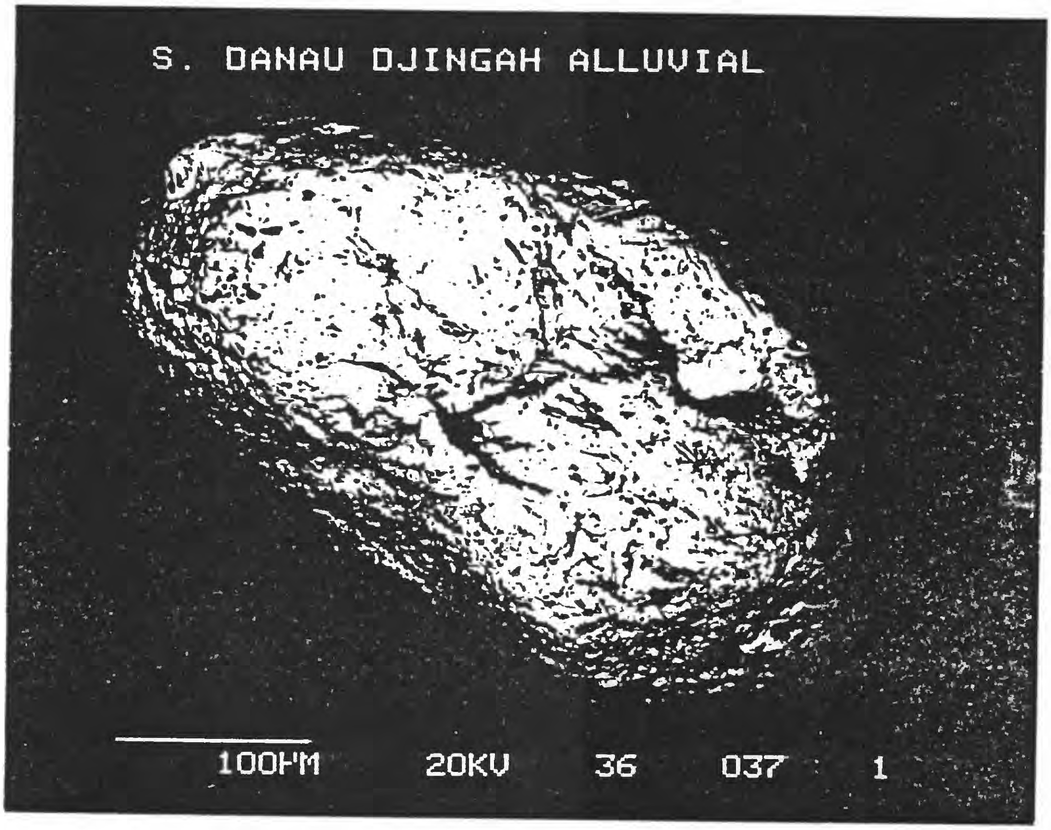
30 S. Danau Djingah alluvial SP21

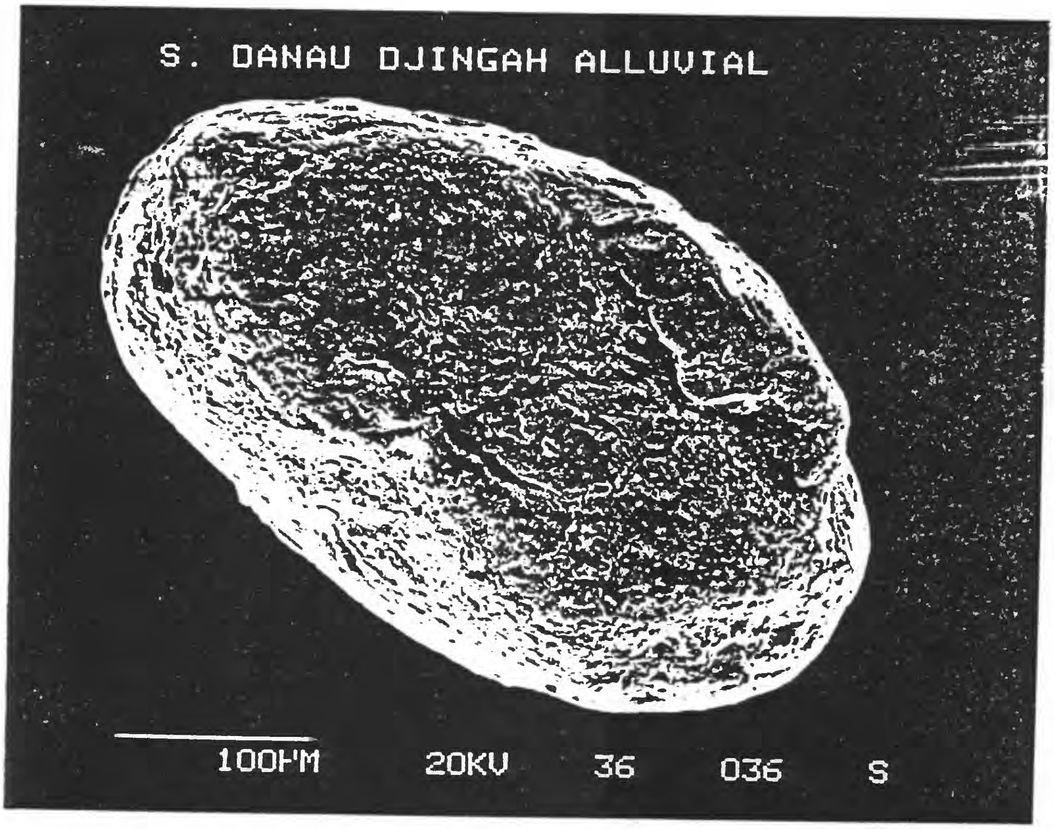

S. DANAU DJINGAH ALLUVIAL
100µM
20KV
36
035
S

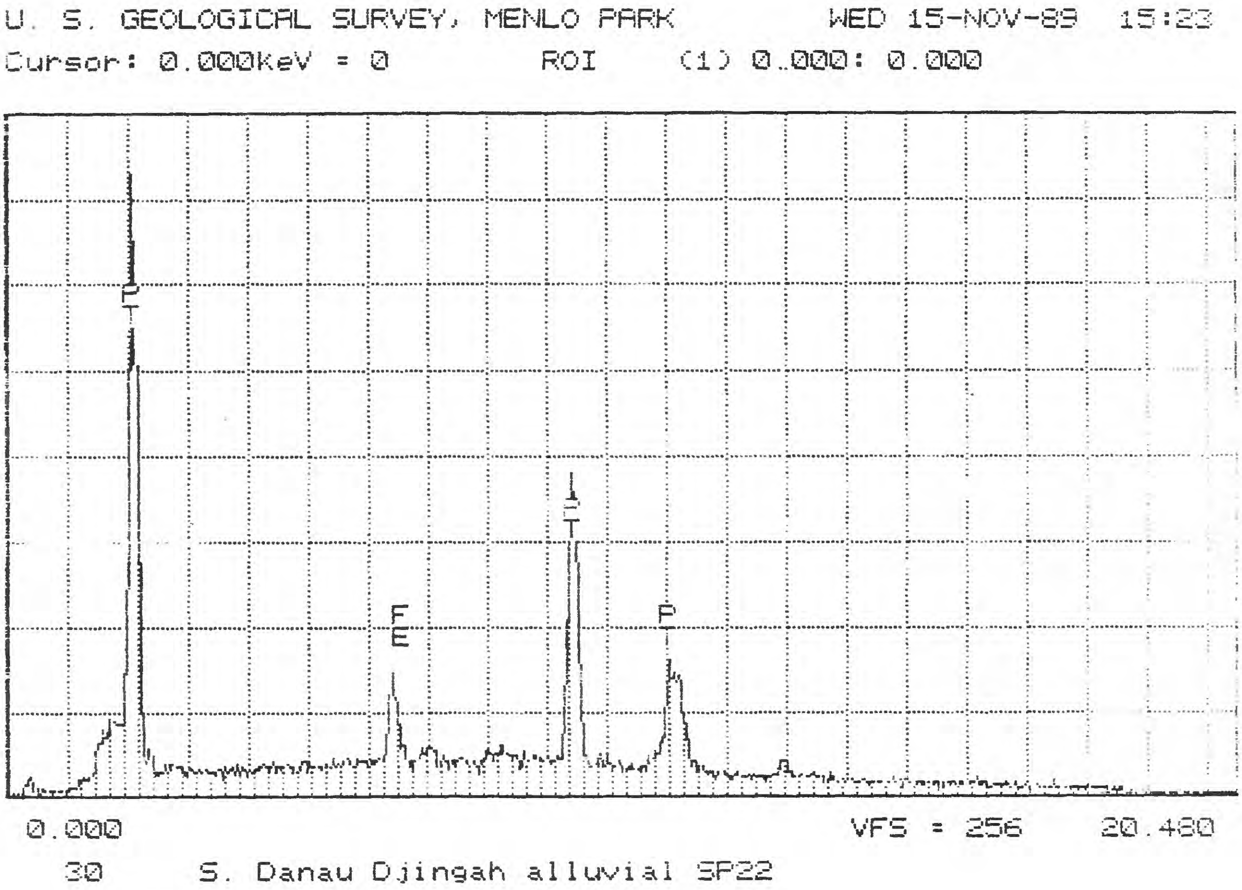


```
U. S. GEOLOGICAL SURVEY, MENLO PARK          WED 15-NOV-89  15:00
Cursor: 0.000KeV = 0          ROI    (1) 0.000: 0.000
```

```
 0.000                                        VFS = 4096   20.480
   30      S. Danau Djingah alluvial SP20
```

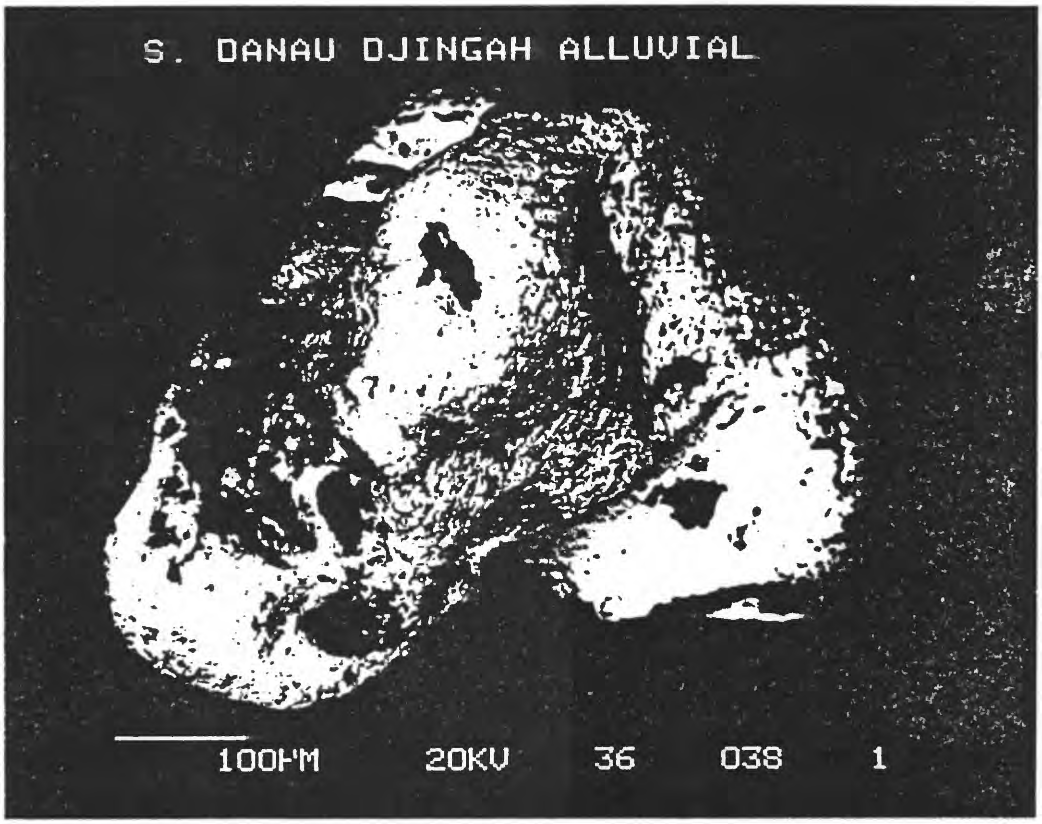

S. DANAU DJINGAH ALLUVIAL
100µM 20KV 36 037 1

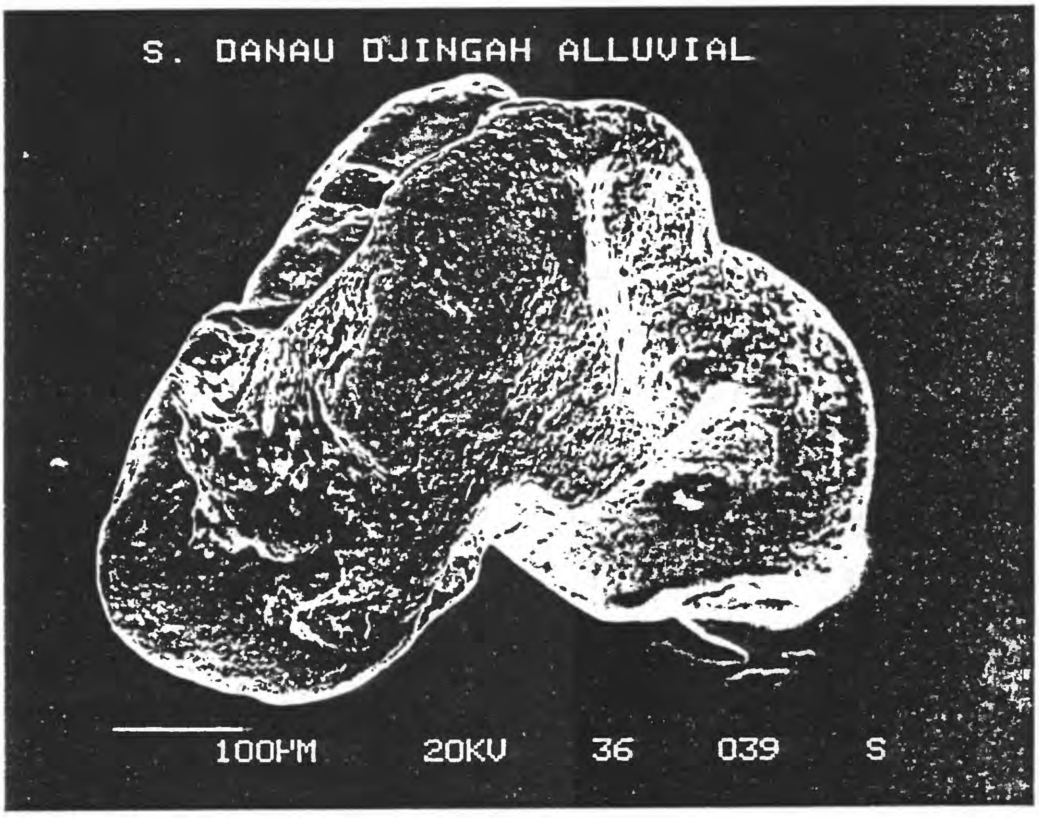

S. DANAU DJINGAH ALLUVIAL
100µM 20KV 36 036 S

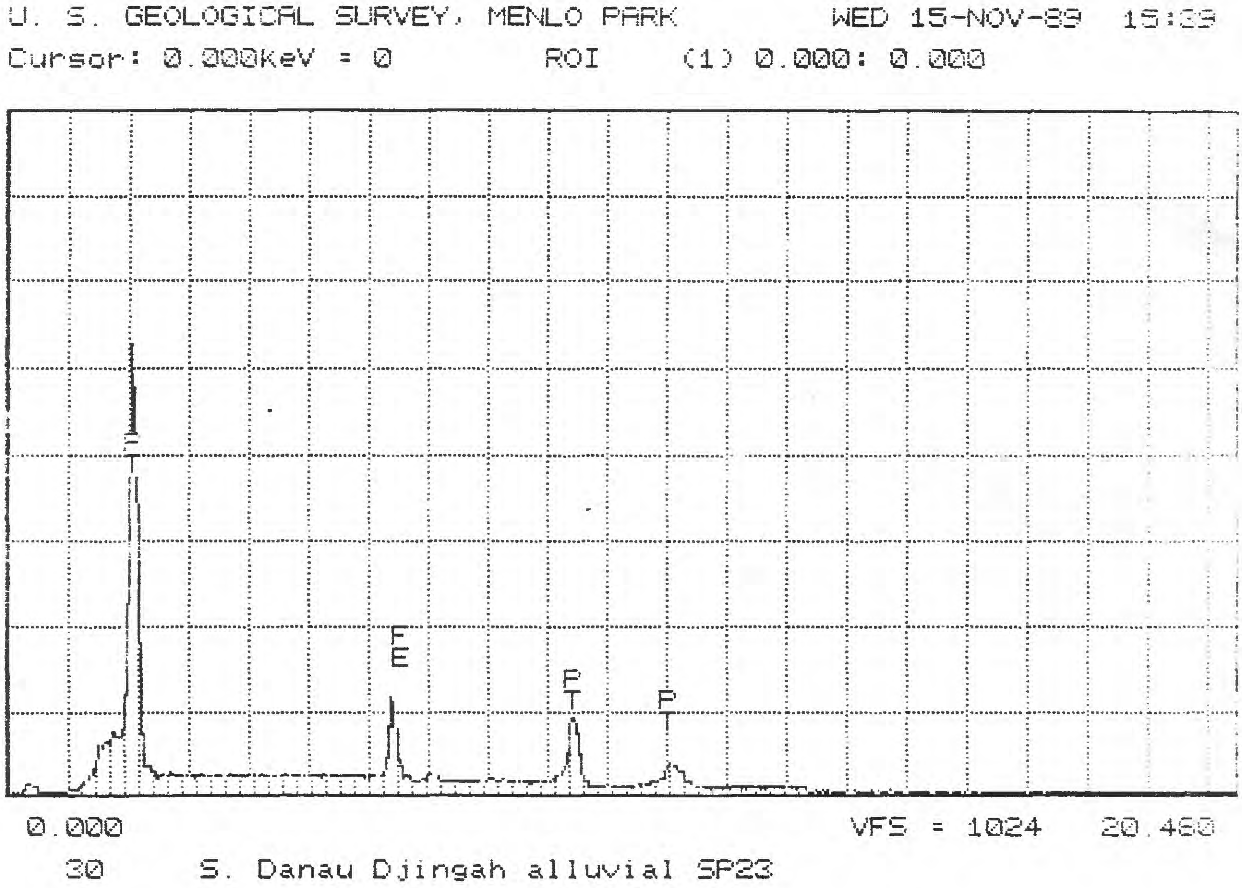

U. S. GEOLOGICAL SURVEY, MENLO PARK WED 15-NOV-89 15:23

Cursor: 0.000KeV = 0 ROI (1) 0.000: 0.000

30 S. Danau Djingah alluvial SP22

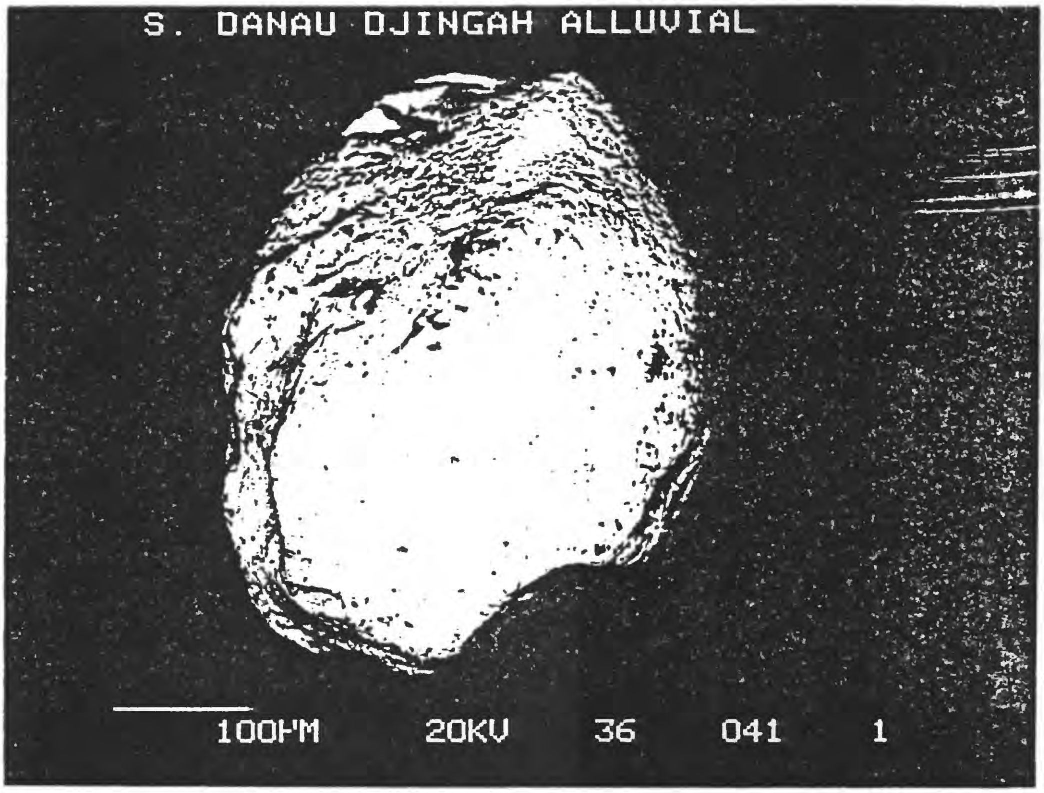

S. DANAU DJINGAH ALLUVIAL
100µM 20KV 36 038 1

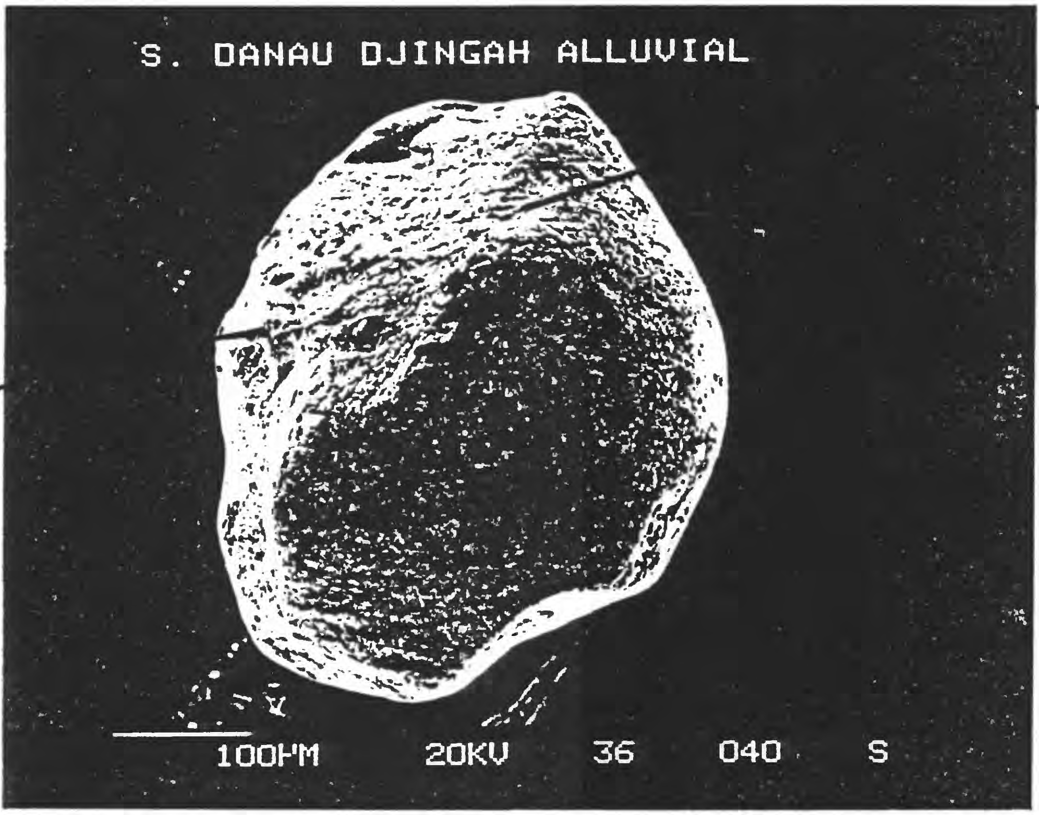

S. DANAU DJINGAH ALLUVIAL
100µM 20KV 36 039 S



```
U. S. GEOLOGICAL SURVEY, MENLO PARK        WED 15-NOV-89  15:39
Cursor: 0.000keV = 0         ROI    (1) 0.000: 0.000

0.000                                   VFS = 1024    20.480
  30     S. Danau Djingah alluvial SP23
```



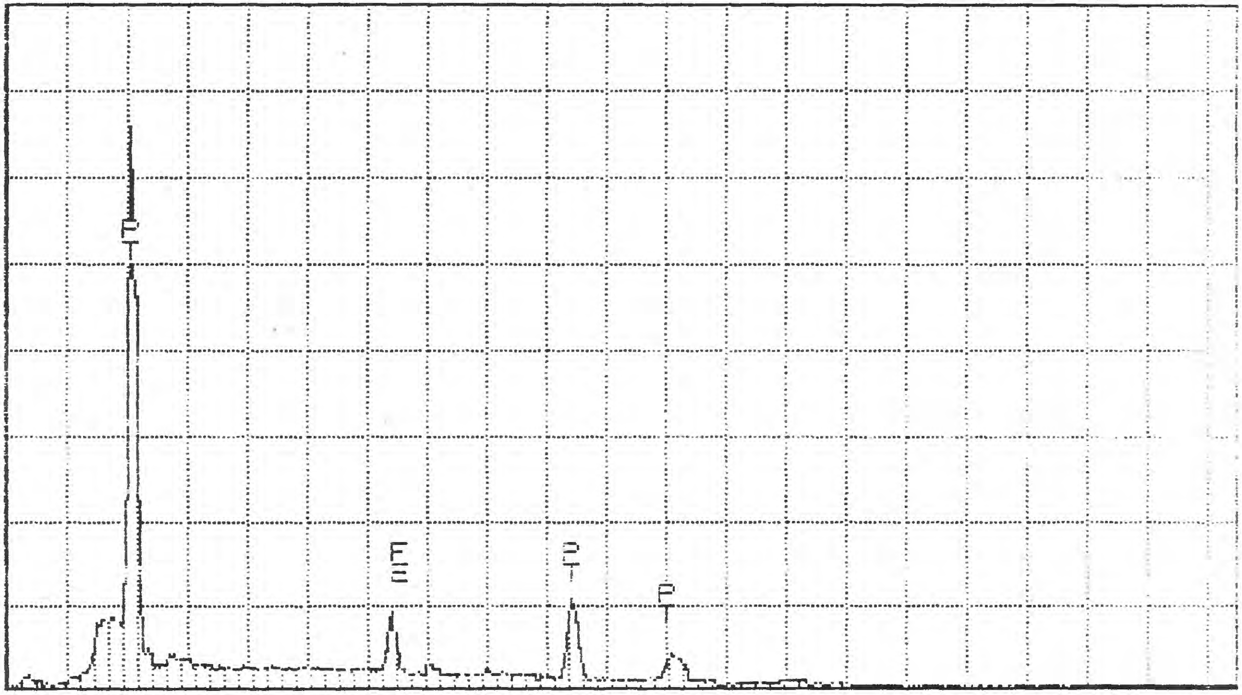


SP24

Same as SP24

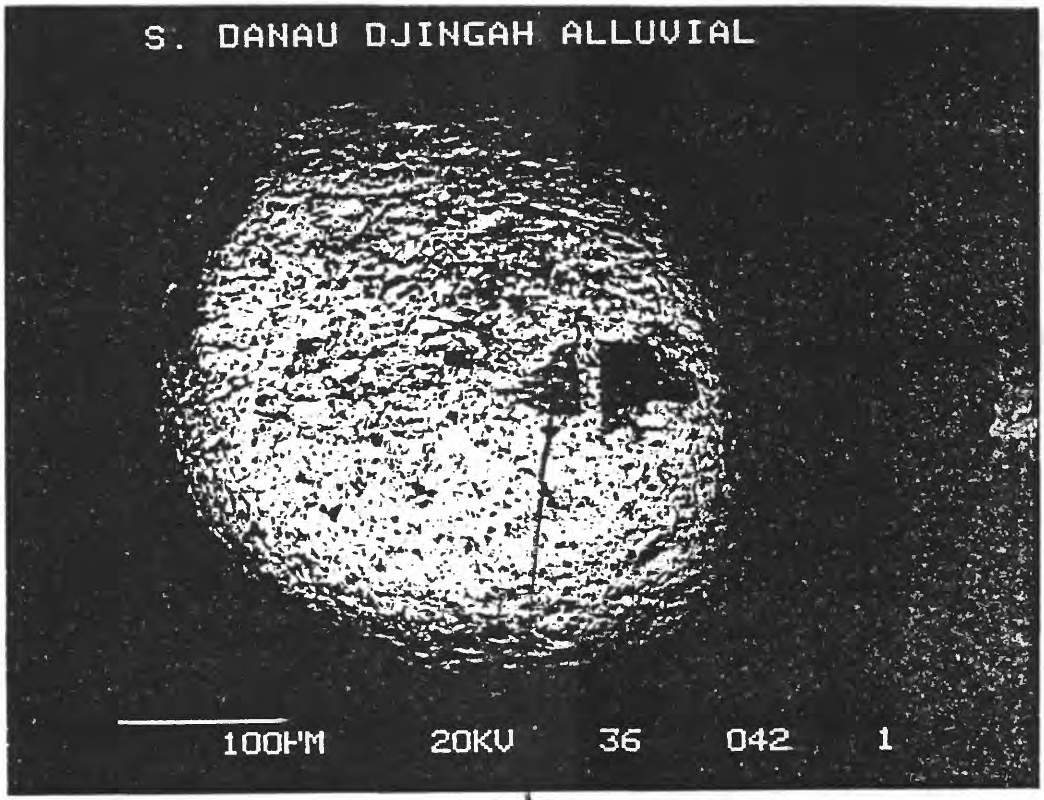
U. S. GEOLOGICAL SURVEY, MENLO PARK WED 15-NOV-89 15:48

Cursor: 0.000keV = 0 ROI (1) 0.000: 0.000

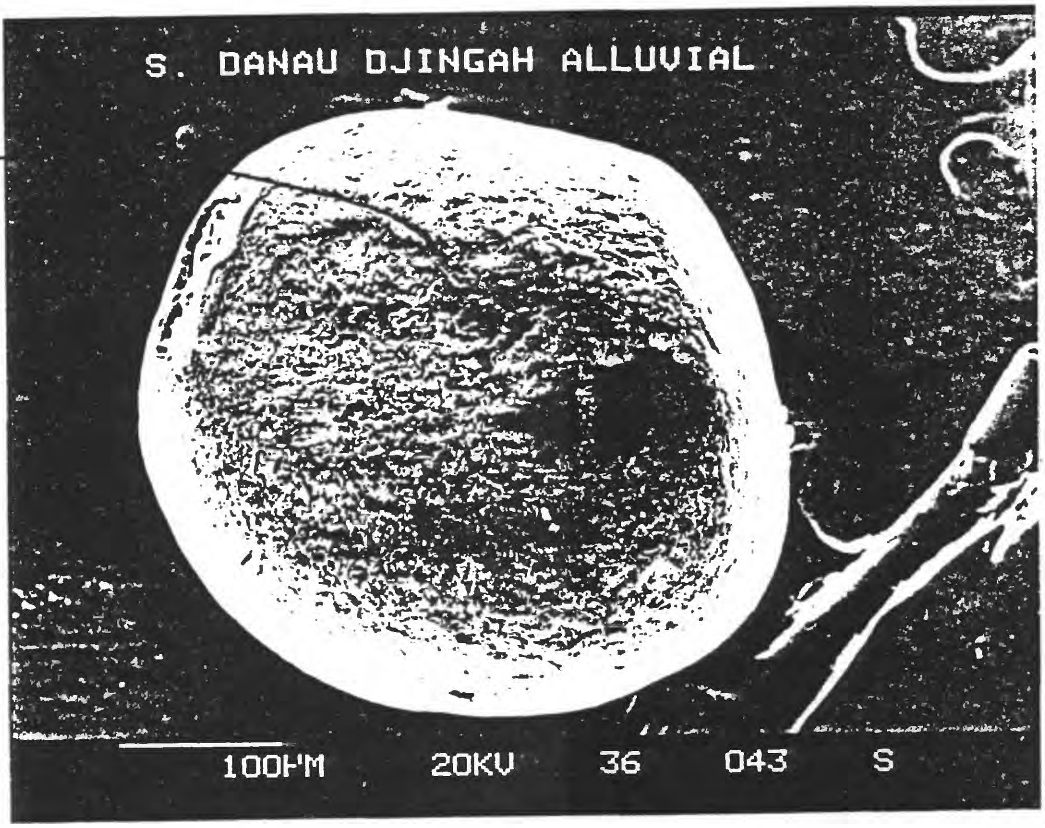


0.000 VFS = 1024 20.480

30 S. Danau Djingah alluvial SP24

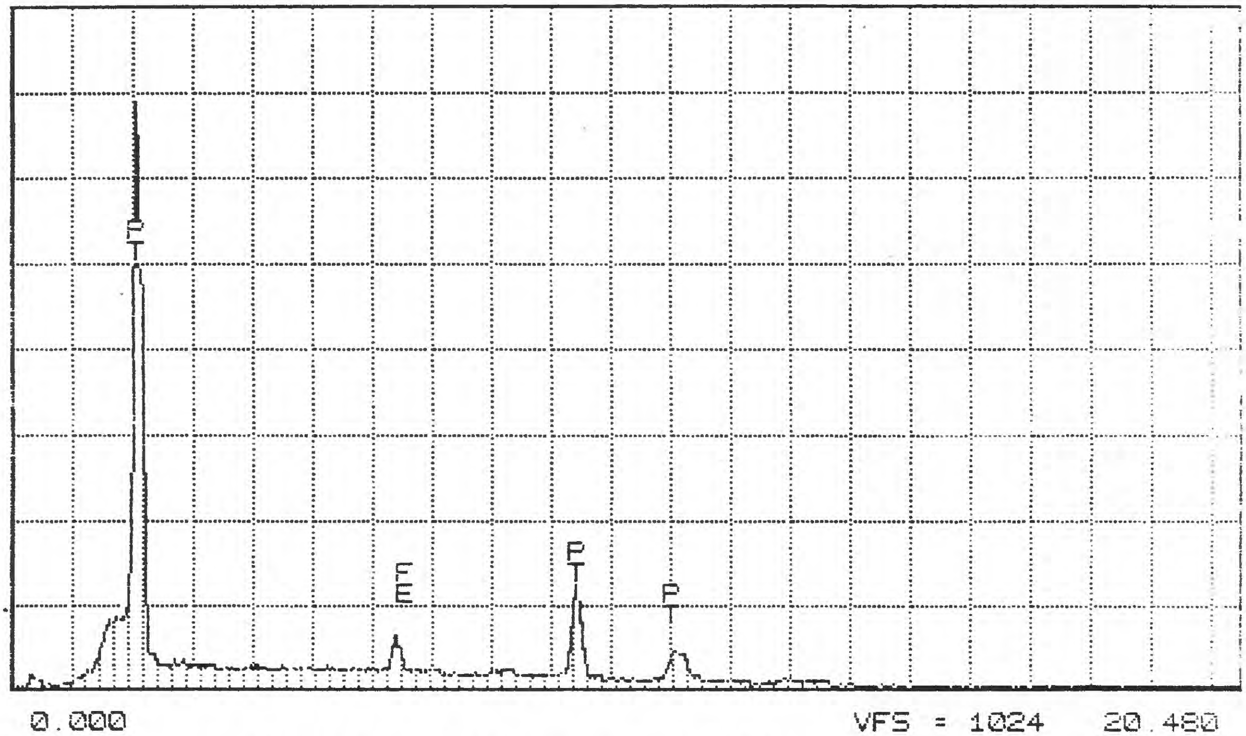

S. DANAU DJINGAH ALLUVIAL
100ΜM
20KV
36
042
1

SP24

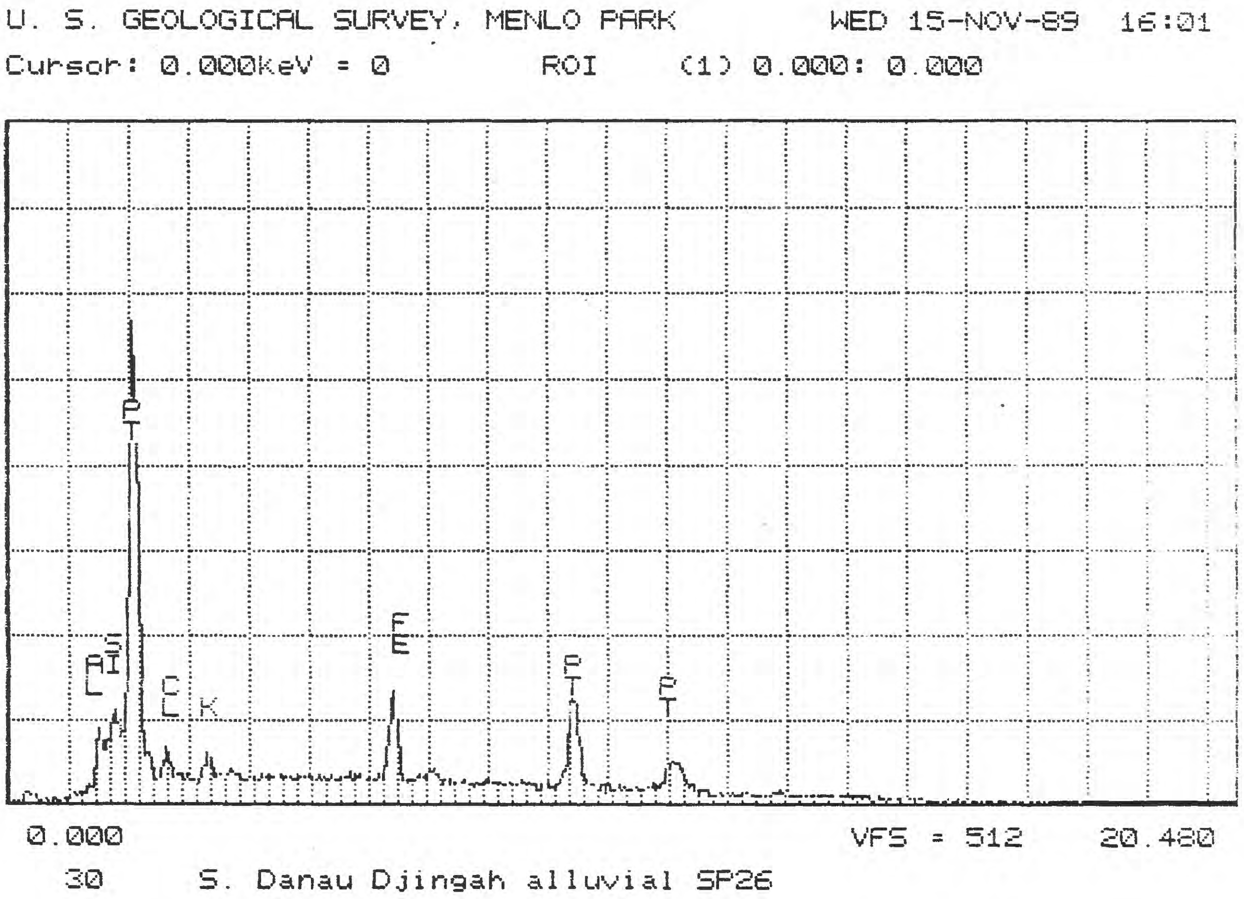

S. DANAU DJINGAH ALLUVIAL
100ΜM
20KV
36
043
S

SP25

U. S. GEOLOGICAL SURVEY, MENLO PARK   WED 15-NOV-89   16:05
Cursor: 0.000keV = 0   ROI   (1) 0.000: 0.000



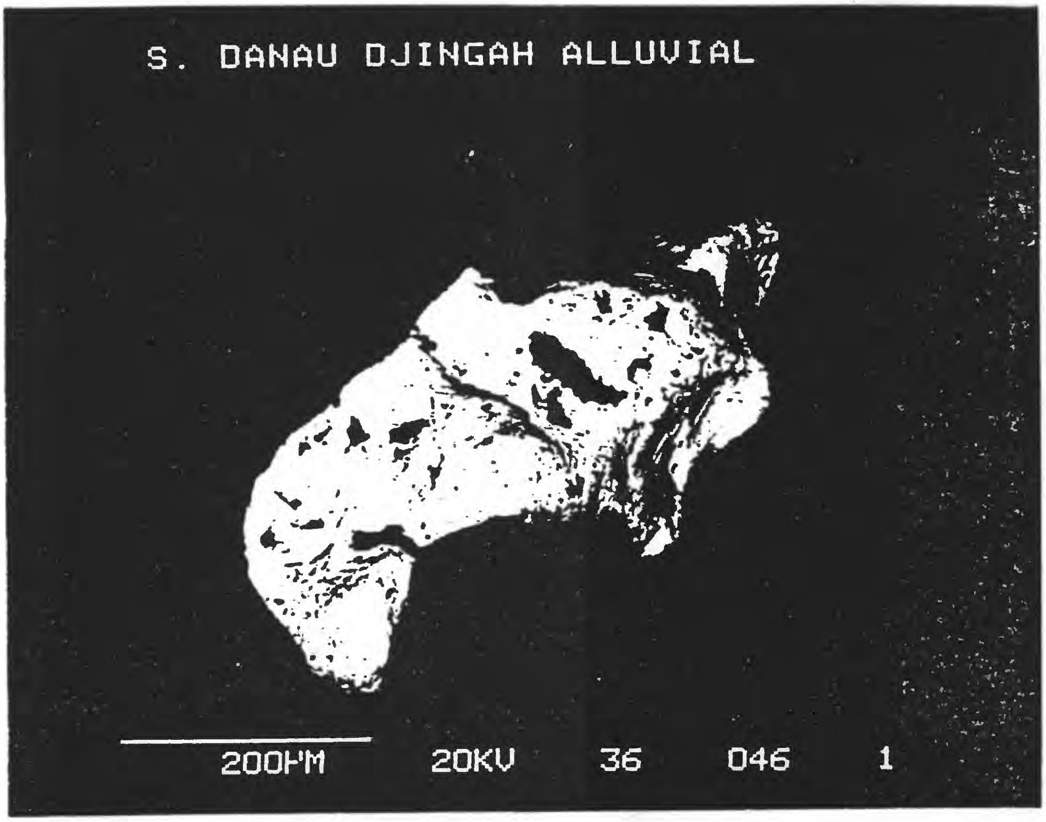
30   S. Danau Djingah alluvial SP25

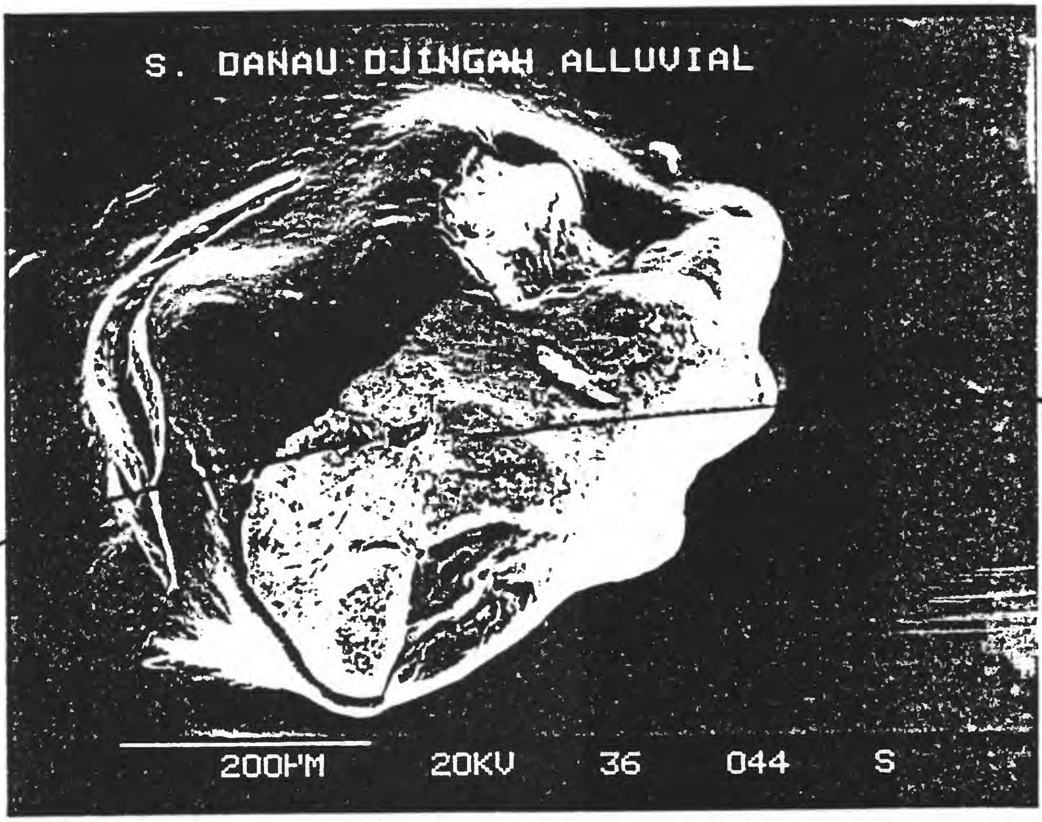


U. S. GEOLOGICAL SURVEY, MENLO PARK WED 15-NOV-89 16:01

Cursor: 0.000keV = 0 ROI (1) 0.000: 0.000

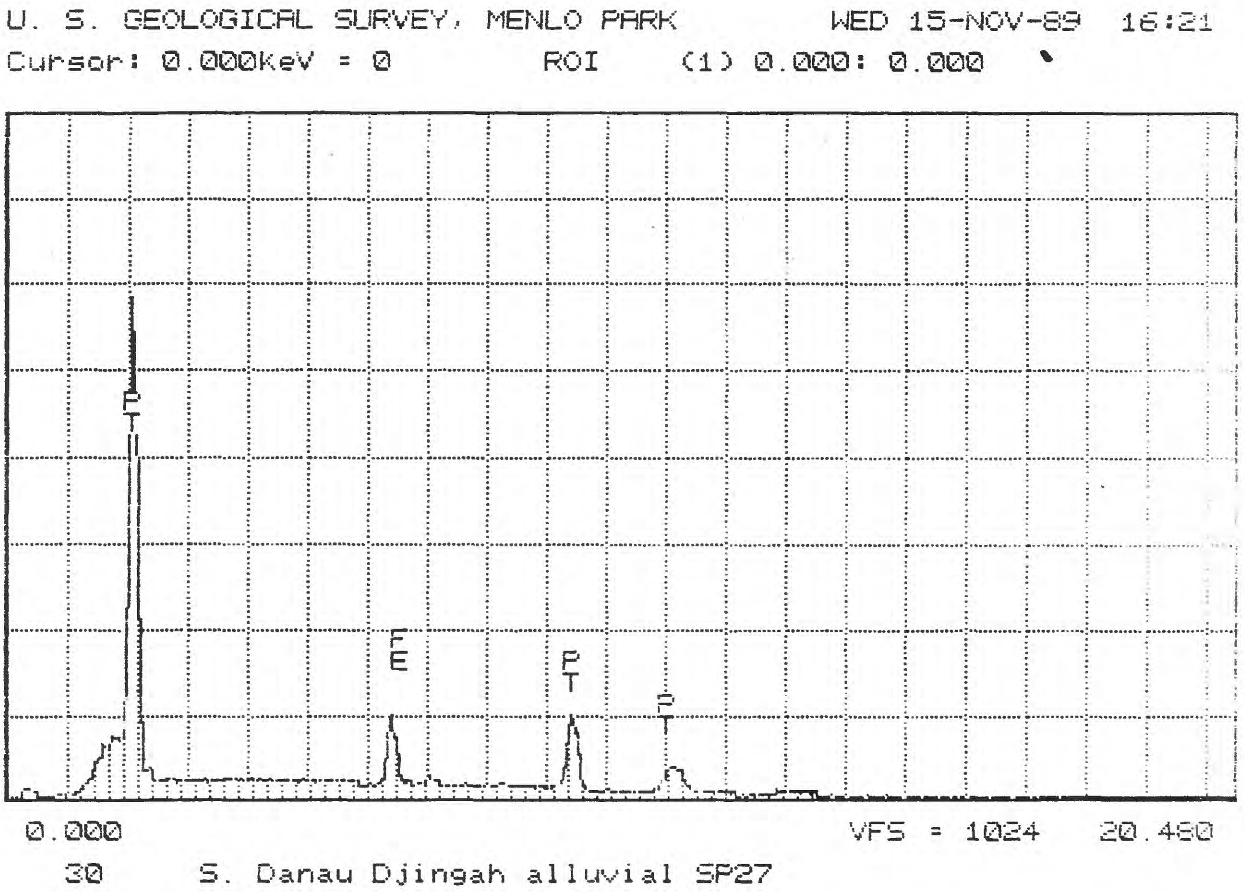
30 S. Danau Djingah alluvial SP26





SP27

Al, Si, Fe
Same as
SP21



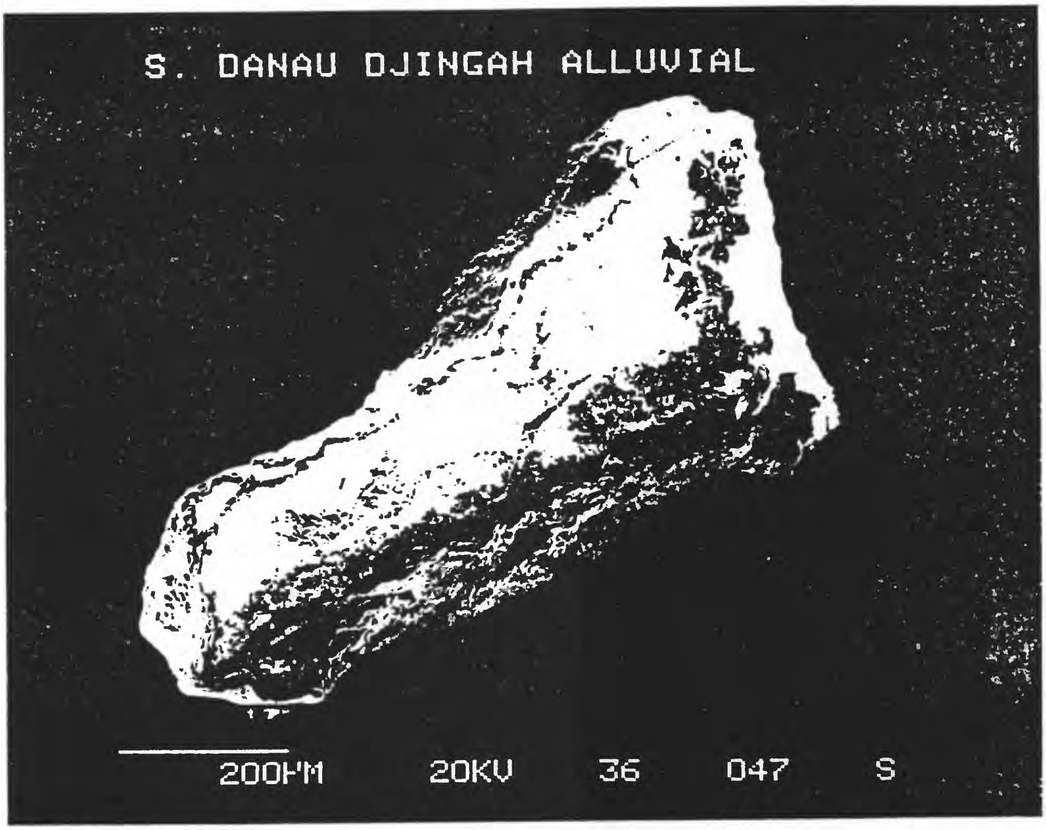
U. S. GEOLOGICAL SURVEY, MENLO PARK WED 15-NOV-89 16:21

Cursor: 0.000KeV = 0 ROI (1) 0.000: 0.000

0.000 VFS = 1024 20.480

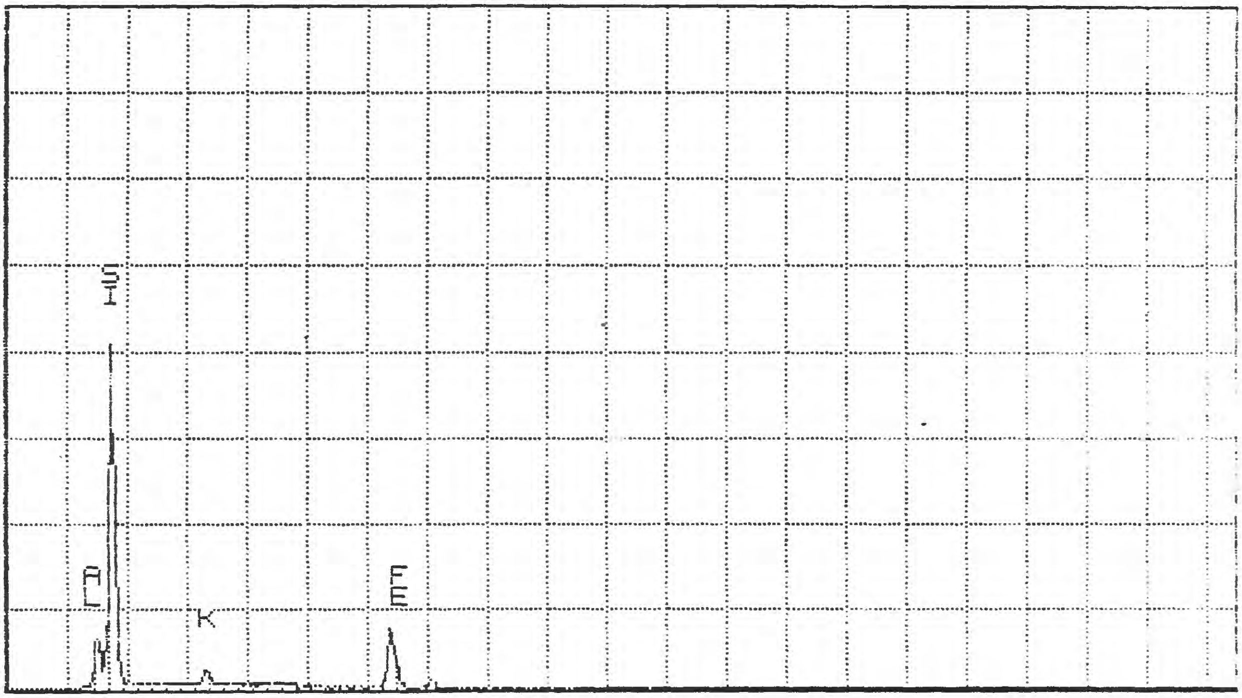
30 S. Danau Djingah alluvial SP27

[illegible]

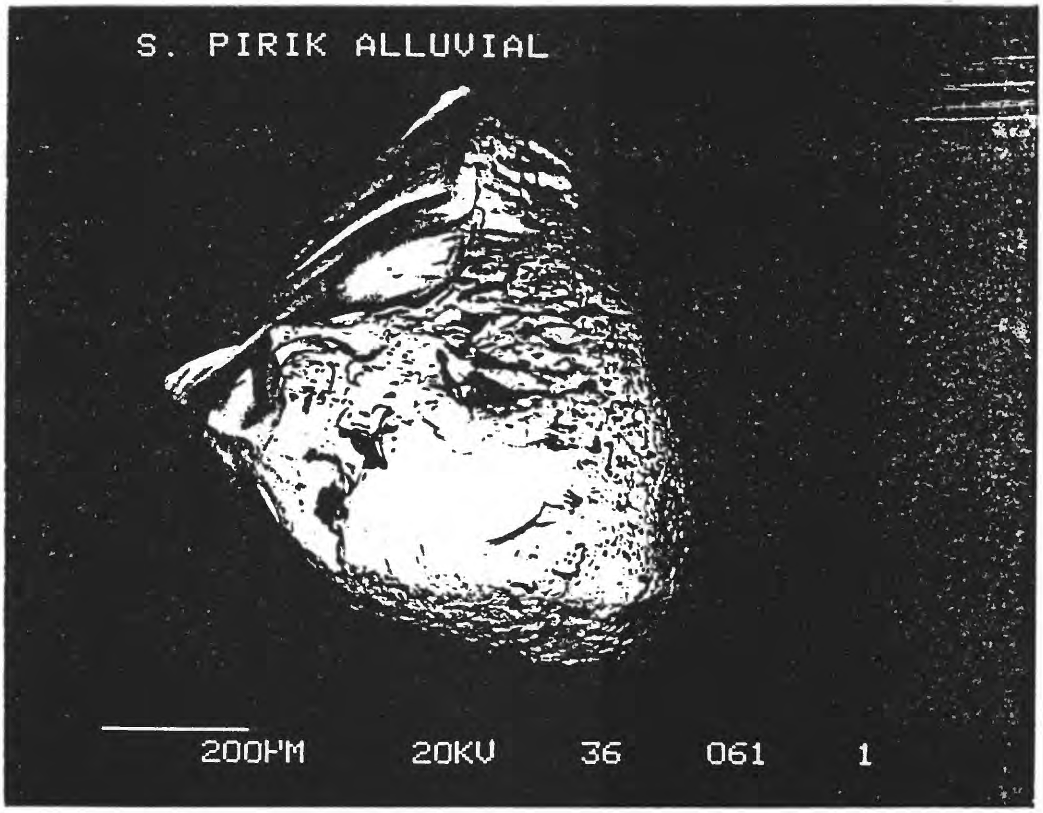


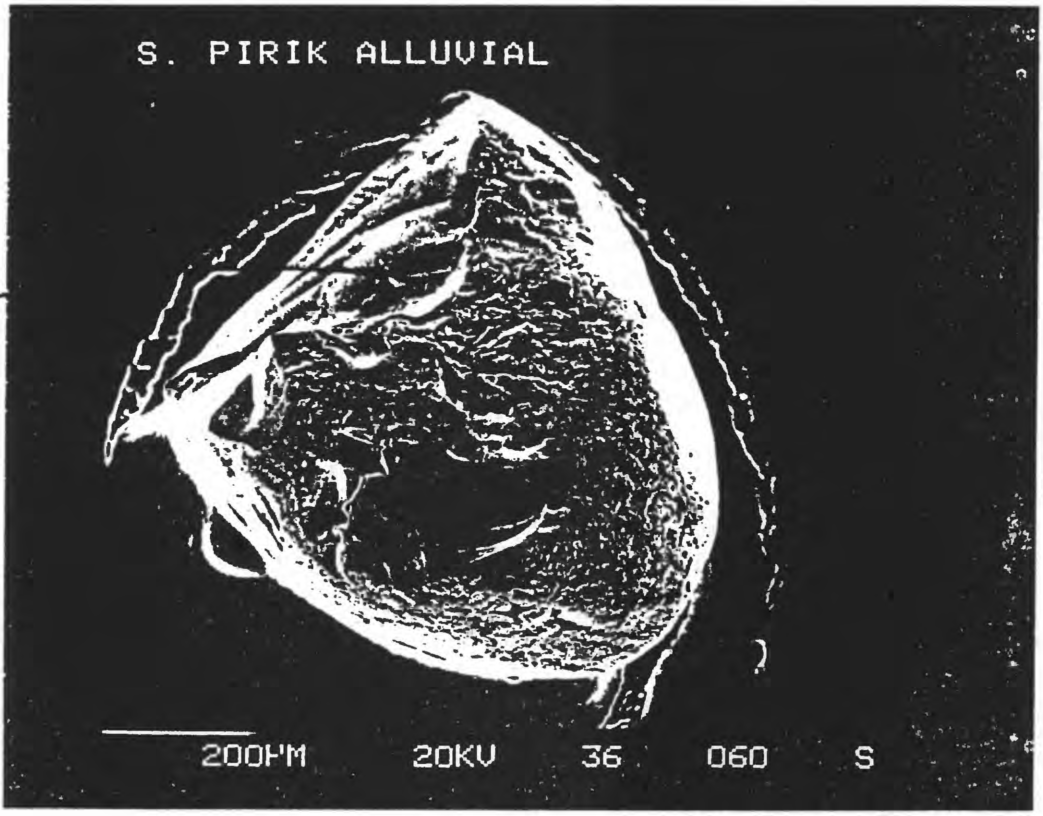
Low Z
not a PGM
No BSE
severe charging

```
U. S. GEOLOGICAL SURVEY, MENLO PARK          WED 15-NOV-89  16:32
Cursor: 0.000keV = 0          ROI     (1) 0.000: 0.000
```

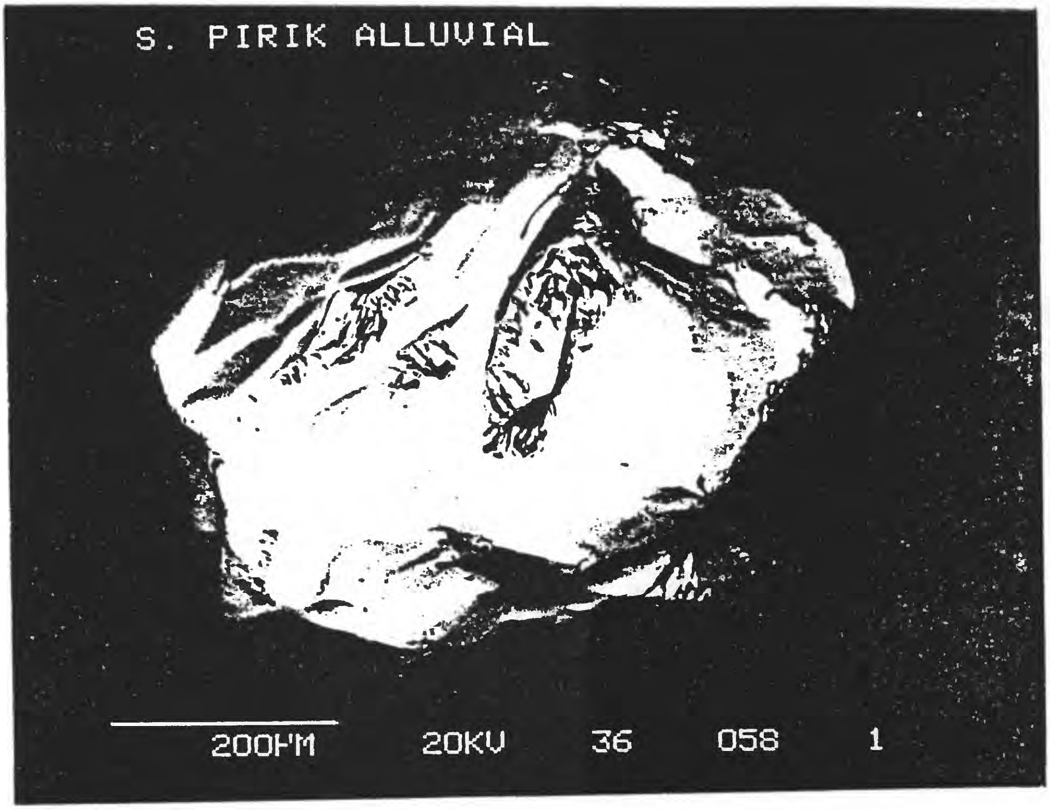


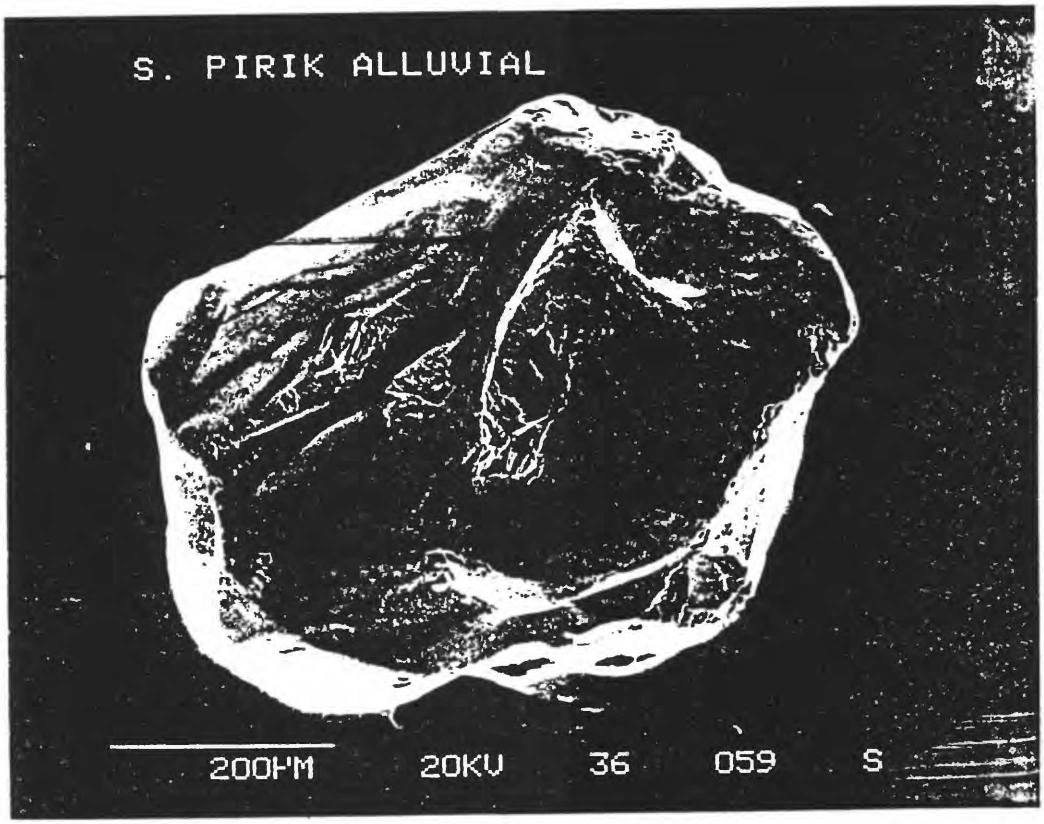
```
 0.000                                        VFS = 1024    20.480
   30      S. Danau Djingah alluvial SP28
```


S. PIRIK ALLUVIAL
200µM 20KV 36 061 1


S. PIRIK ALLUVIAL
200µM 20KV 36 060 S

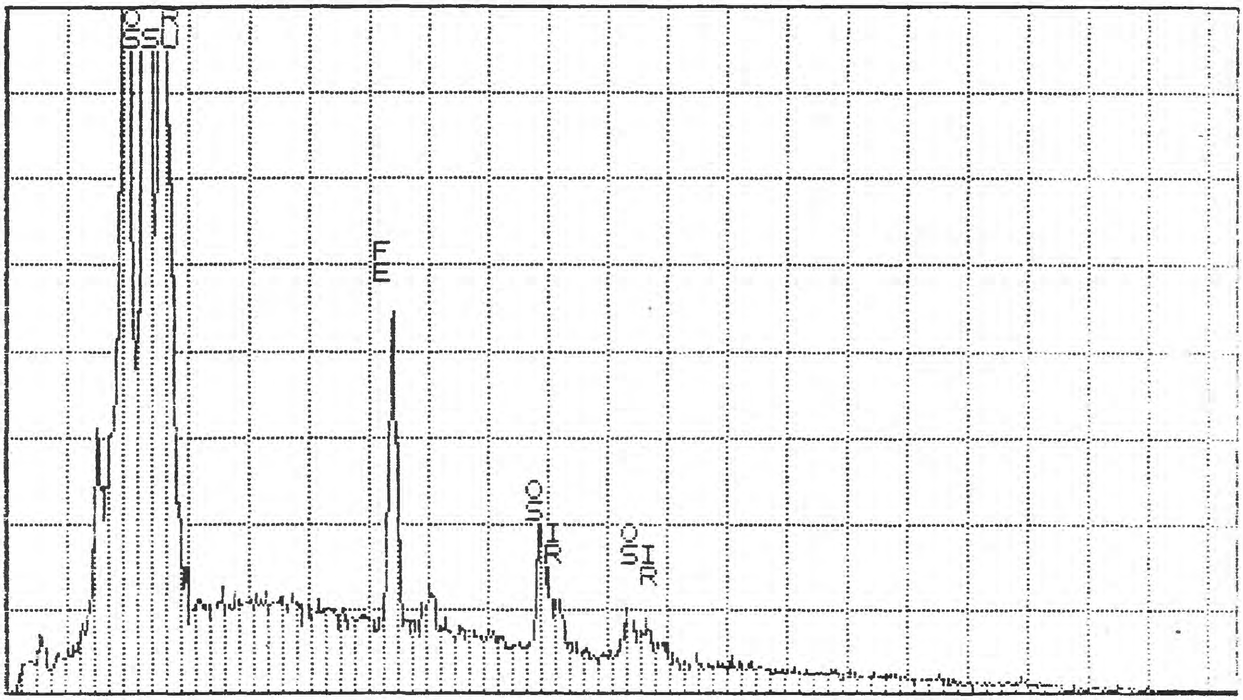
Same as SP31


S. PIRIK ALLUVIAL
200µM
20KV
36
058
1


S. PIRIK ALLUVIAL
200µM
20KV
36
059
S

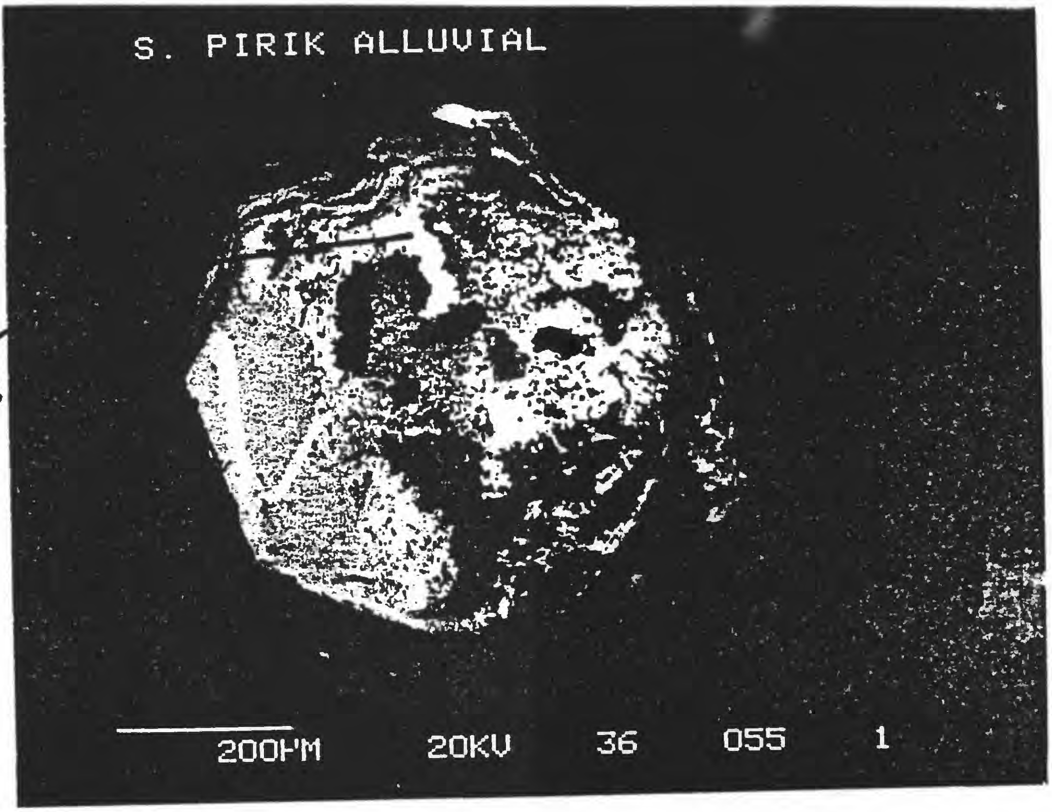
Same as SP31

U. S. GEOLOGICAL SURVEY, MENLO PARK   WED 15-NOV-89   17:23
Cursor: 0.000KeV = 0   ROI   (1) 0.000: 0.000

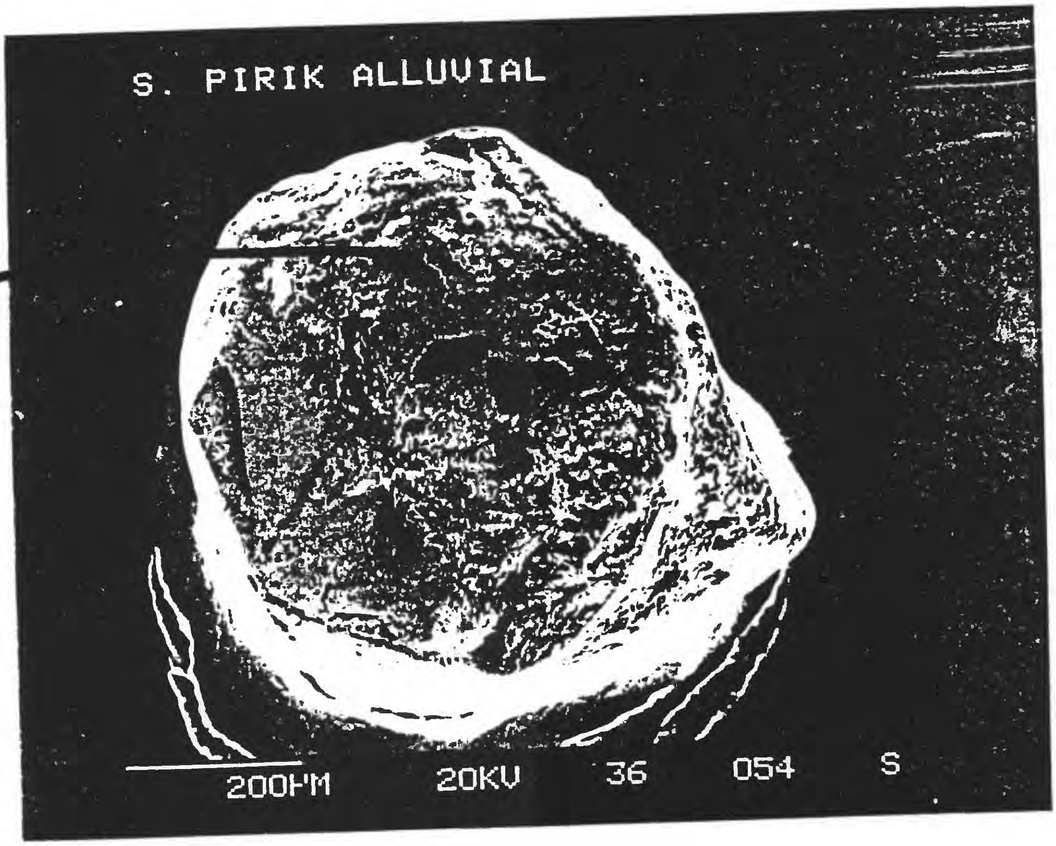


30   S. Pirik allluvial SP31

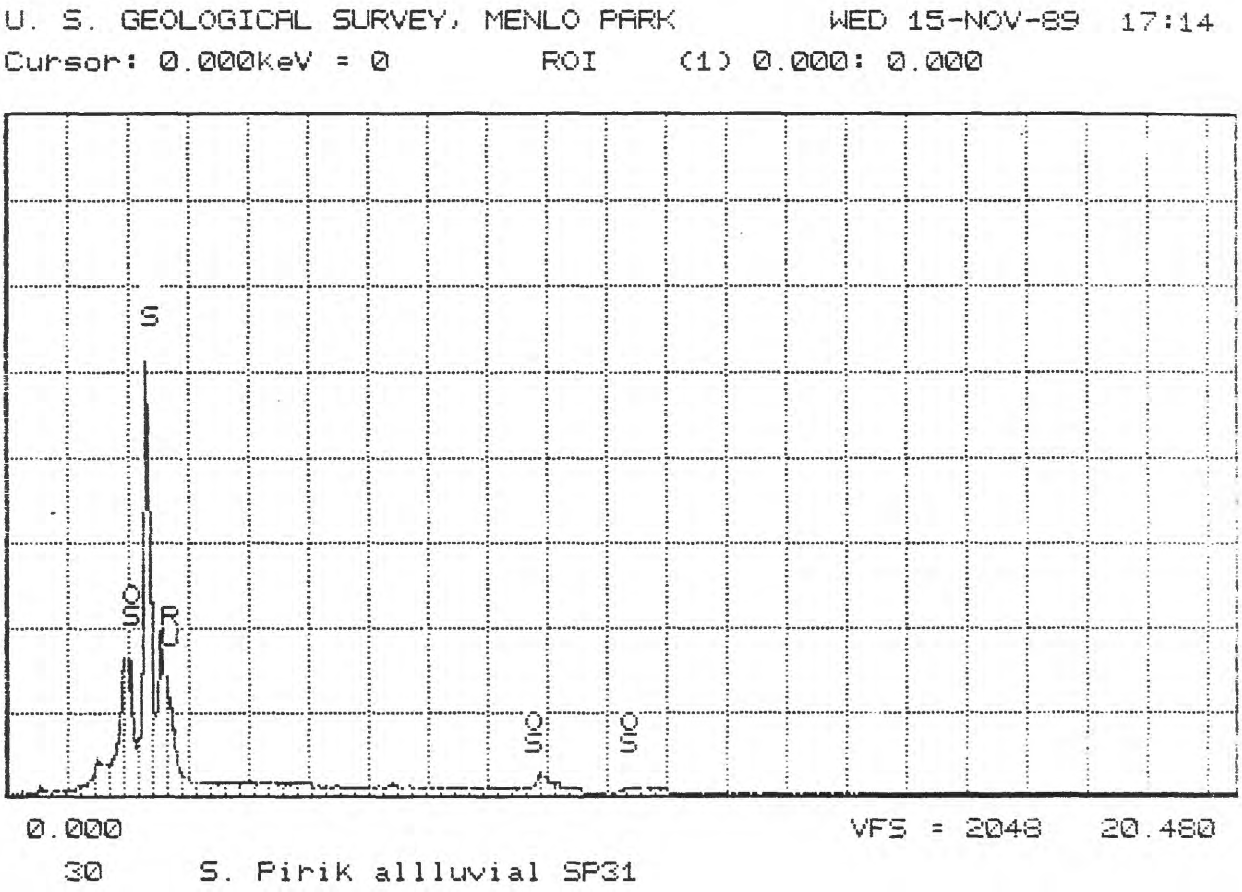
expanded, reveals Ir peaks



Same as SP31



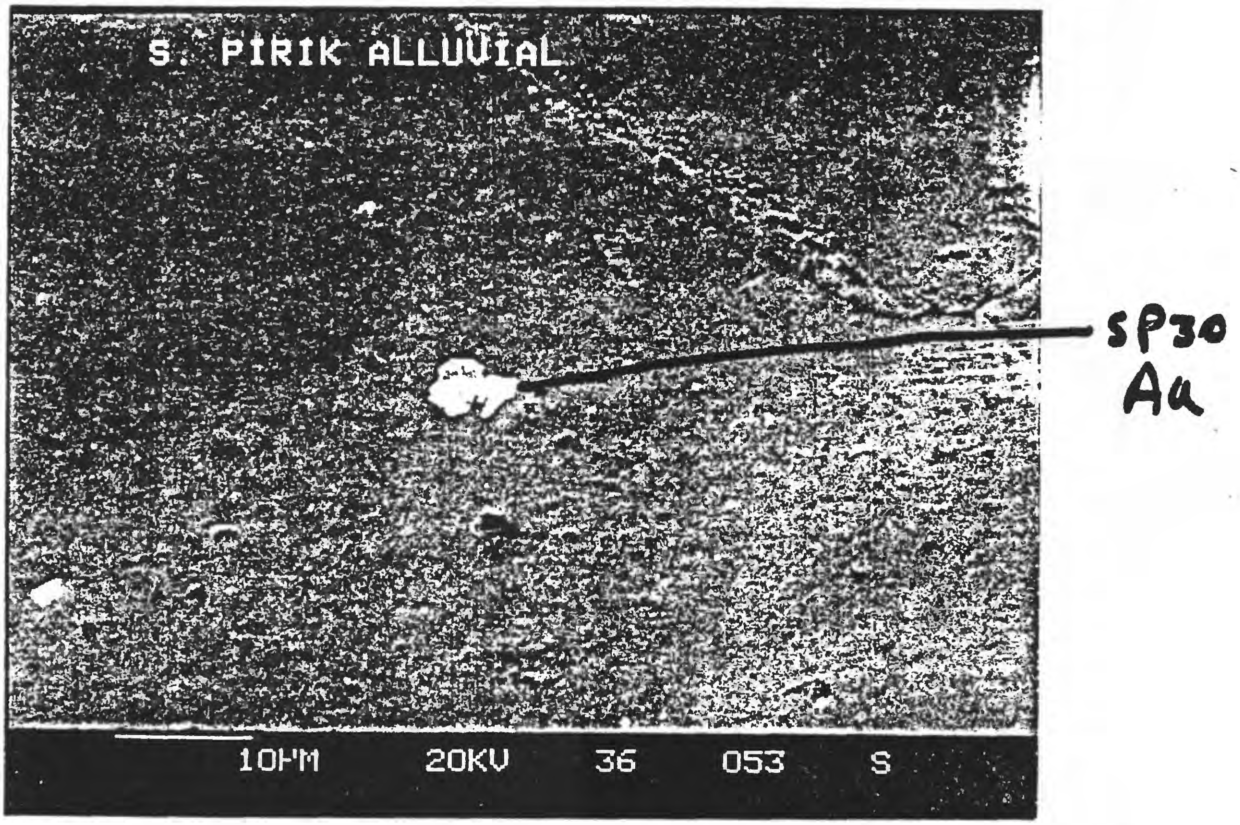
SP 31



U. S. GEOLOGICAL SURVEY, MENLO PARK WED 15-NOV-89 17:14

Cursor: 0.000keV = 0 ROI (1) 0.000: 0.000

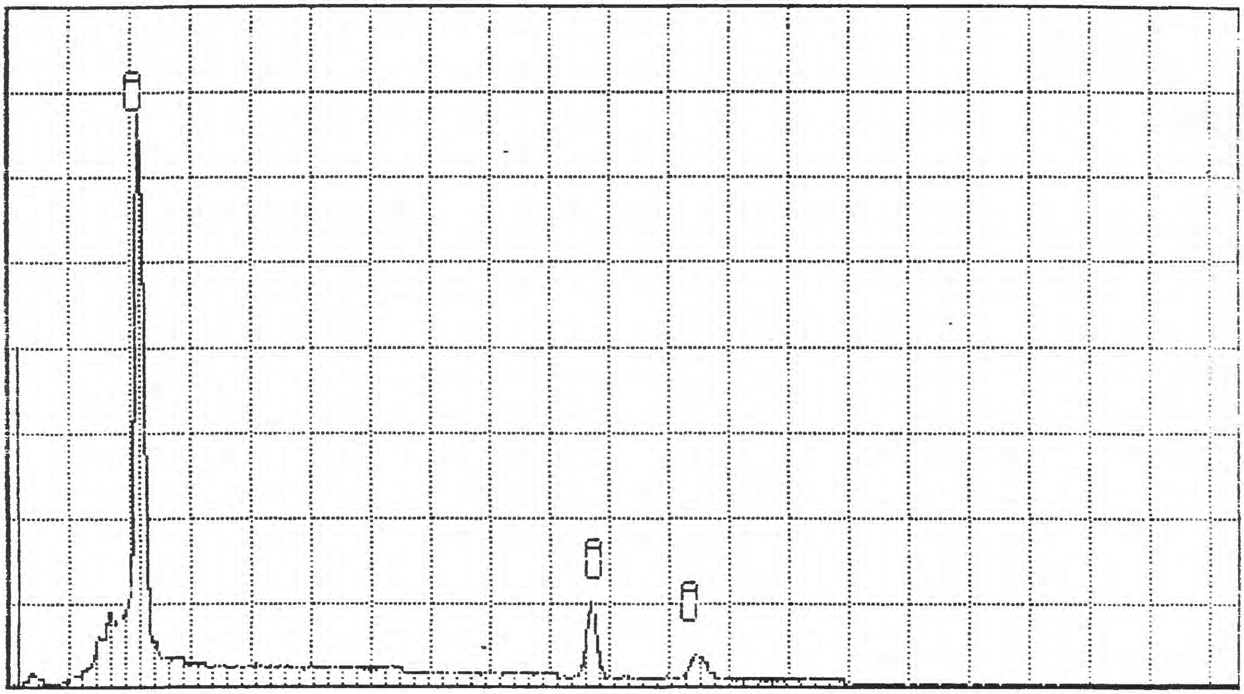
30 S. Pirik allluvial SP31



partocle does not lock like an inclusion in host grain.

U. S. GEOLOGICAL SURVEY, MENLO PARK   WED 15-NOV-89   17:06

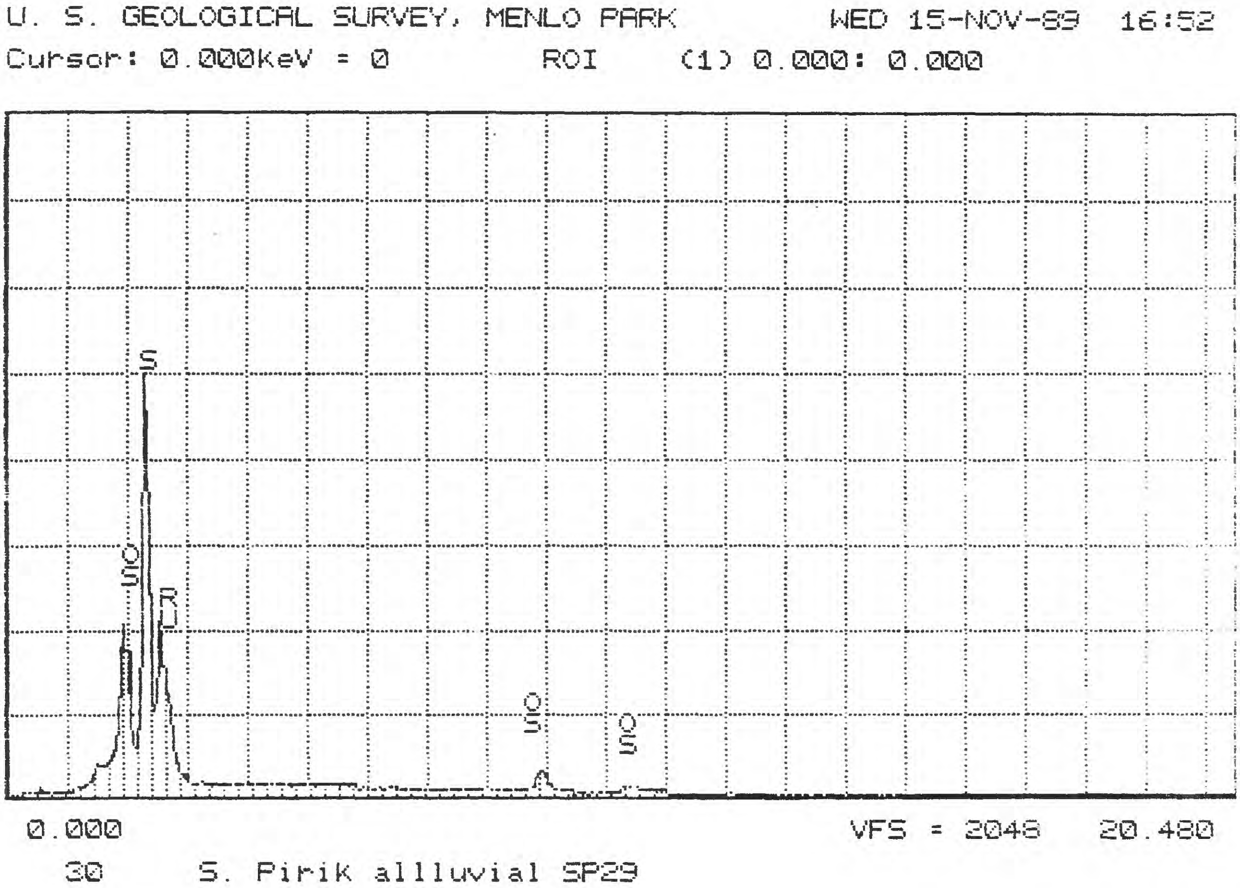
Cursor: 0.000KeV = 0   ROI   (1) 0.000: 0.000



0.000   B- 5   VFS = 2048   20.480

30   S. Pirik allluvial SP30

Au particle could be surface contamination

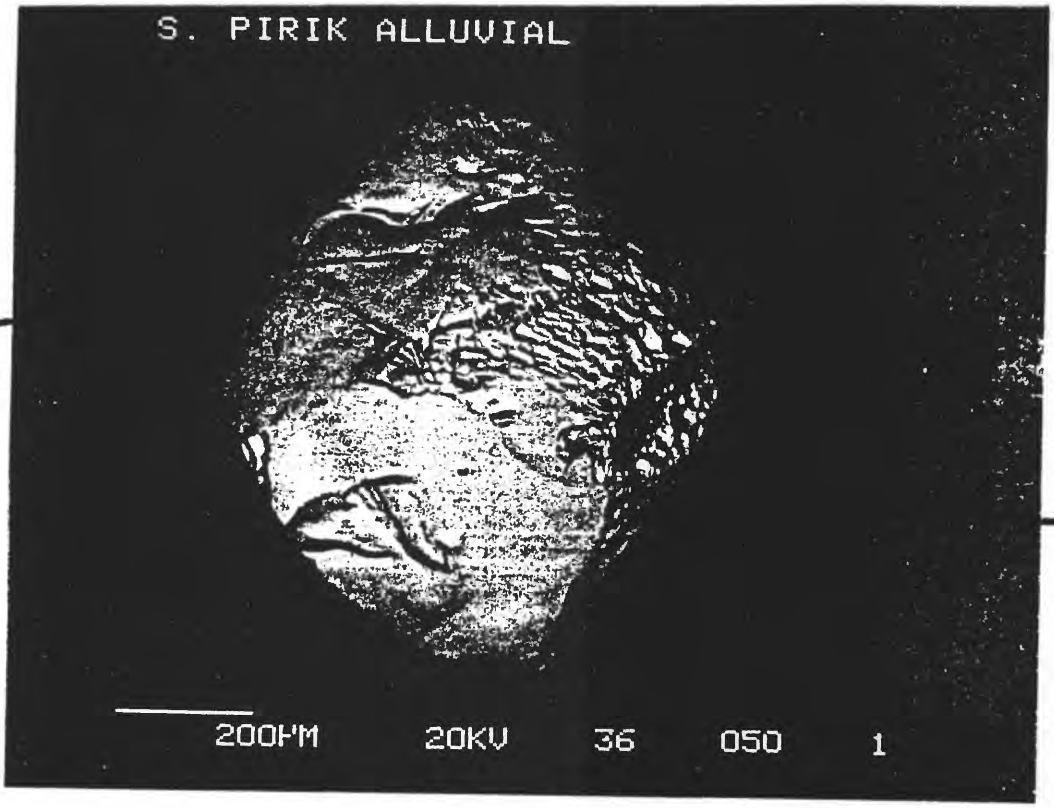


U. S. GEOLOGICAL SURVEY, MENLO PARK WED 15-NOV-89 16:52

Cursor: 0.000keV = 0 ROI (1) 0.000: 0.000

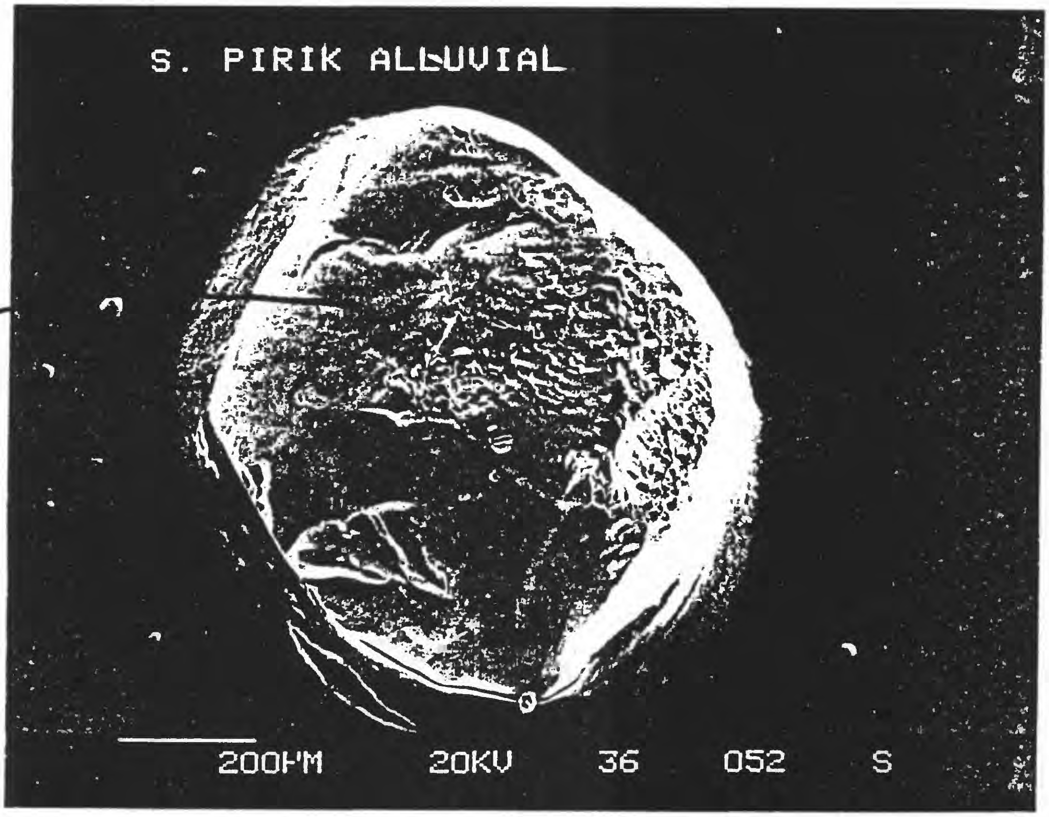
0.000 VFS = 2048 20.480

30 S. Pirik alllluvial SP29

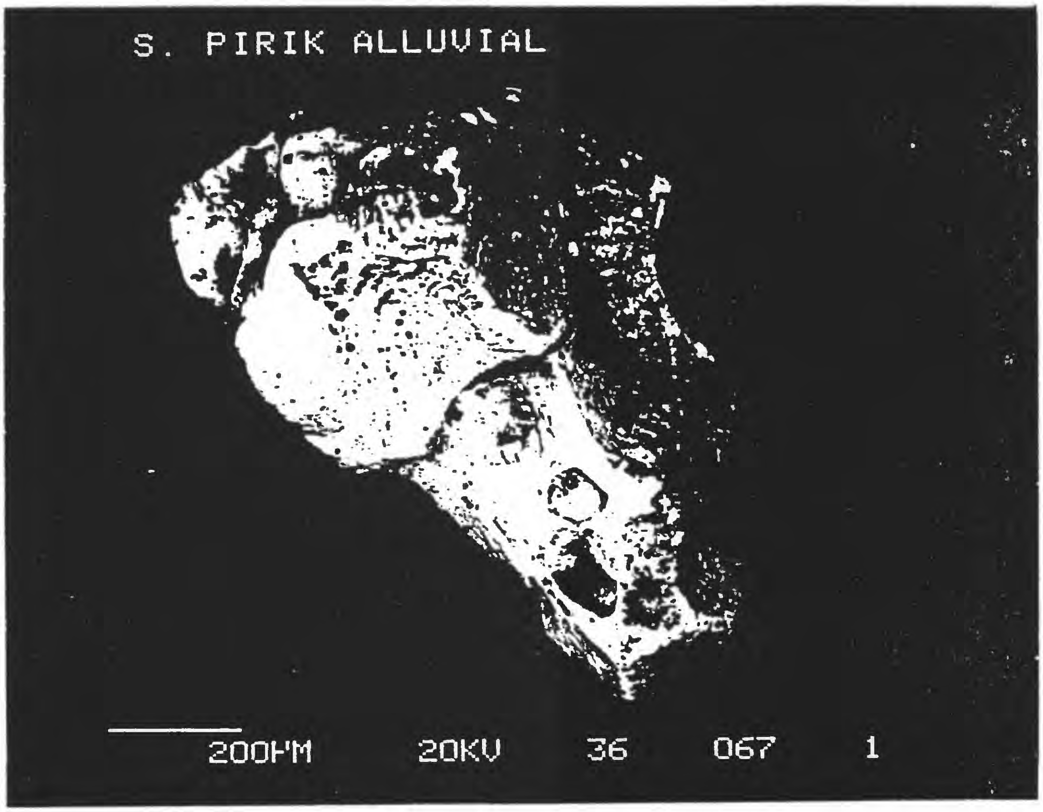


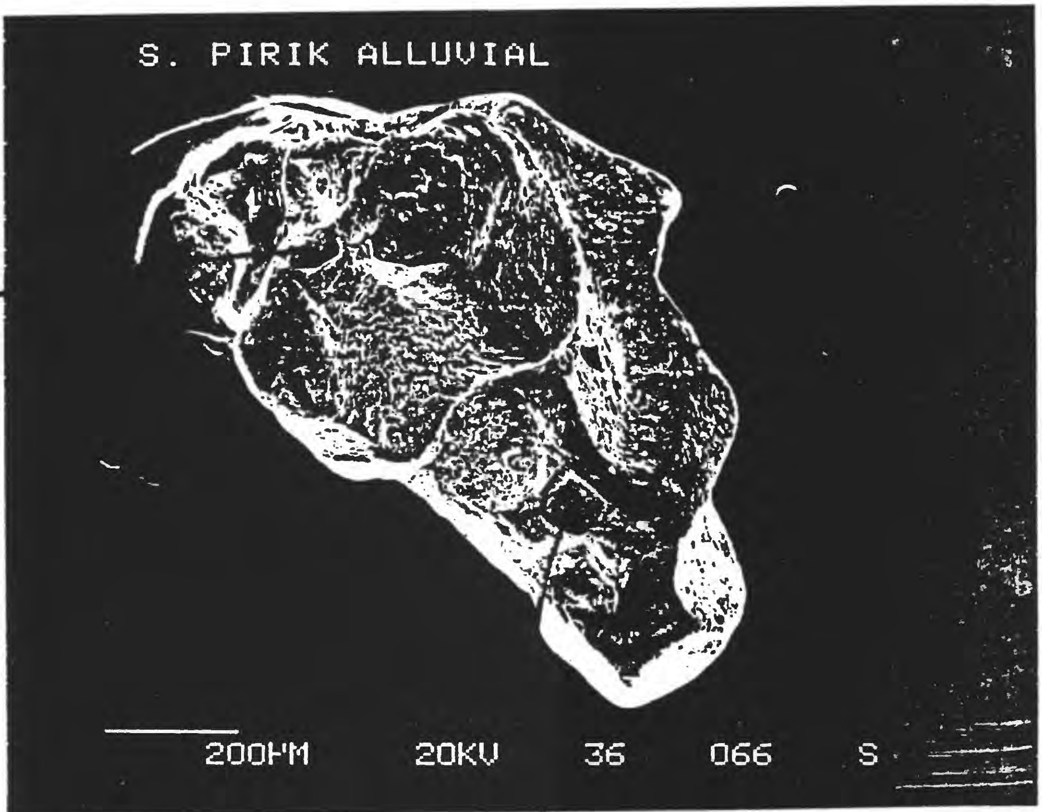
SP30

Topa



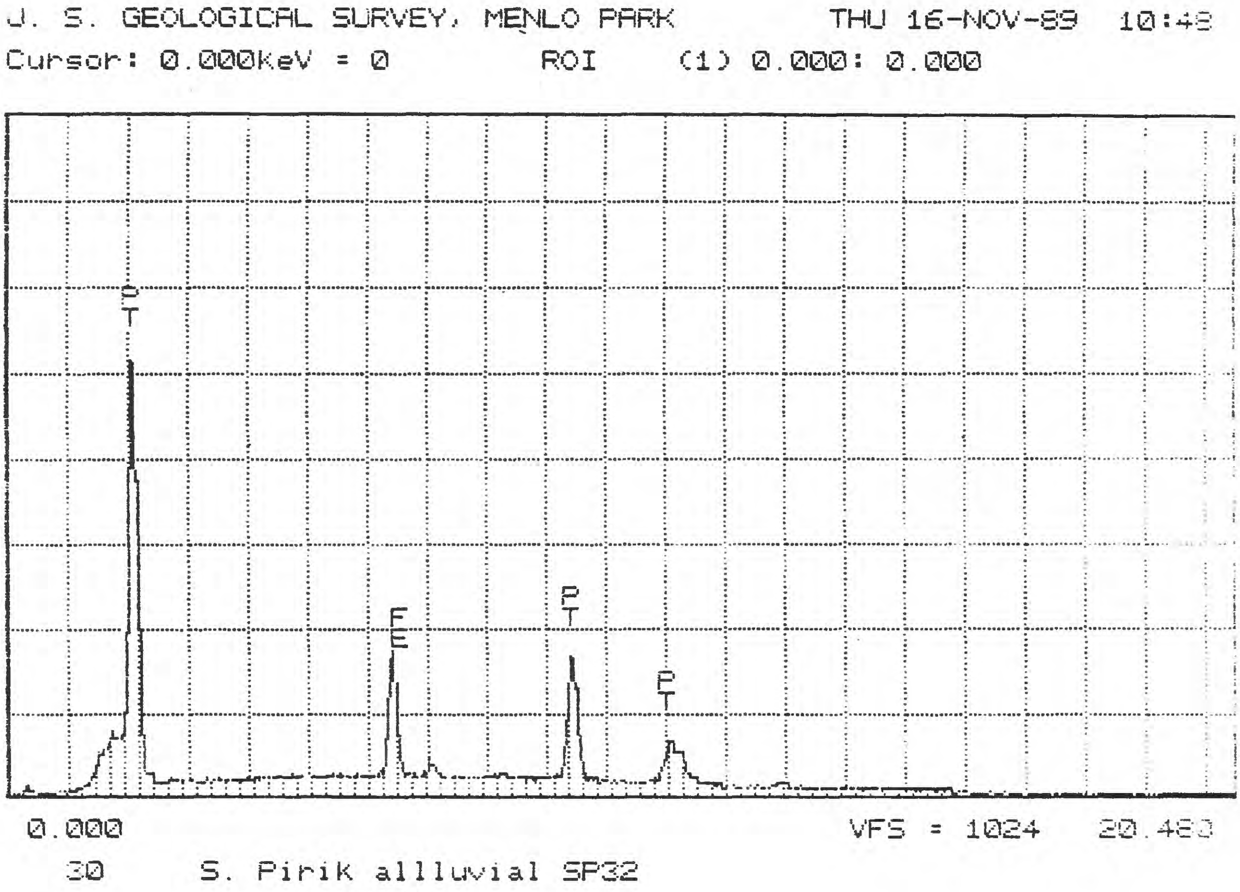
SP29





SP32

same as SP32



```
U. S. GEOLOGICAL SURVEY, MENLO PARK          THU 16-NOV-89  10:48
Cursor: 0.000KeV = 0          ROI     (1) 0.000: 0.000
```

```
 0.000                                        VFS = 1024    20.480
   30      S. Pirik allluvial SP32
```

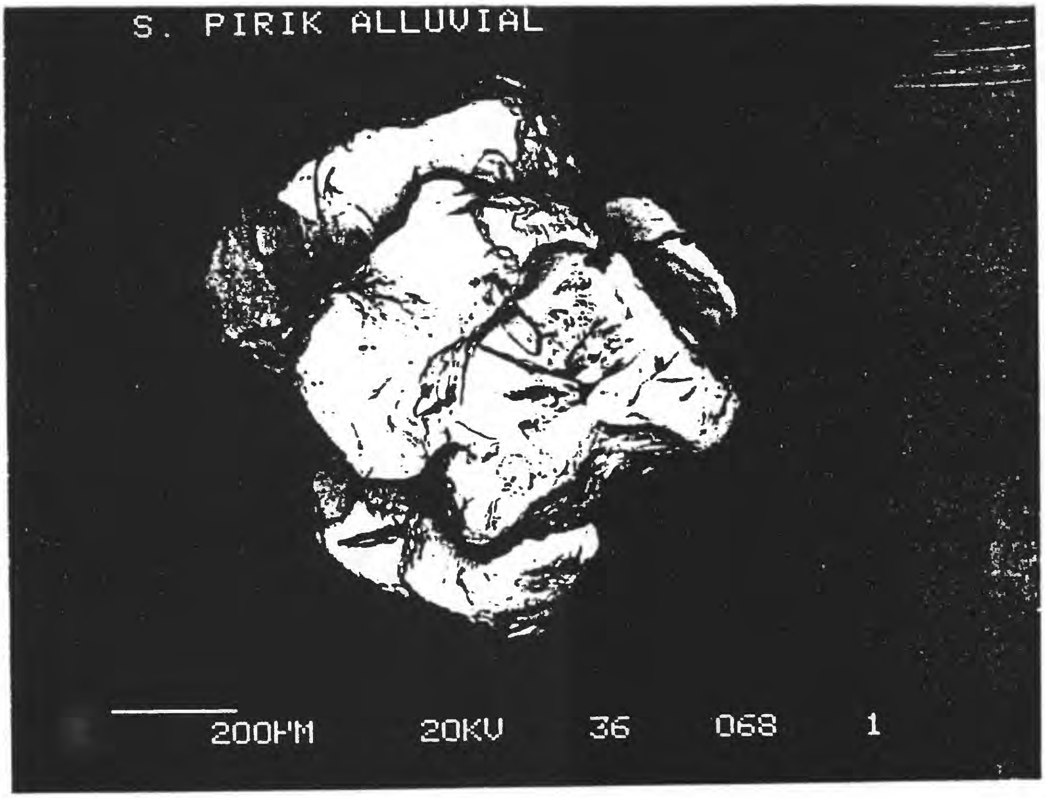
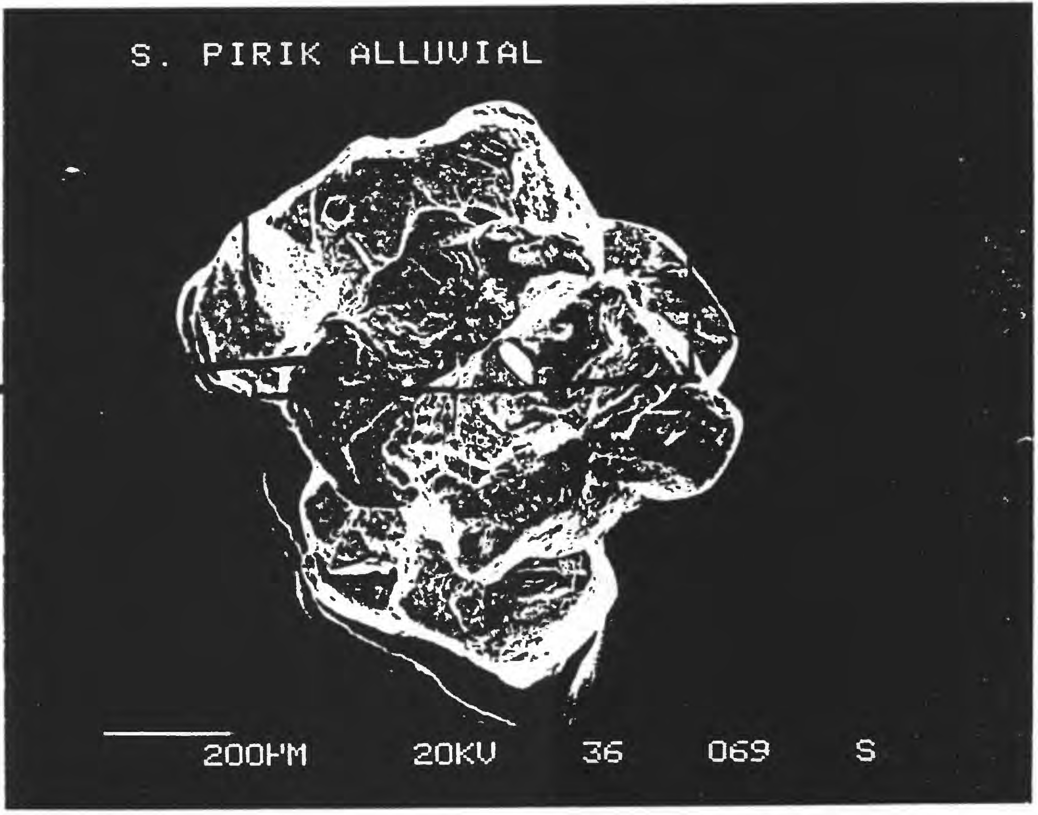
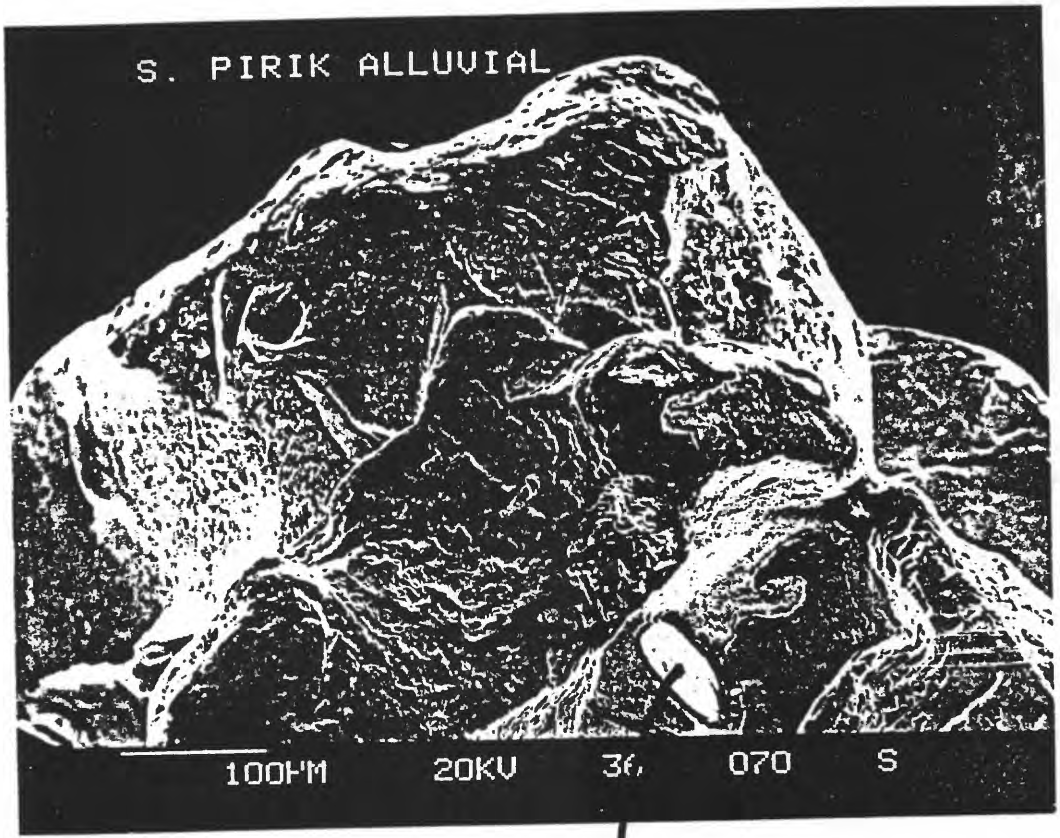


Photo.#070

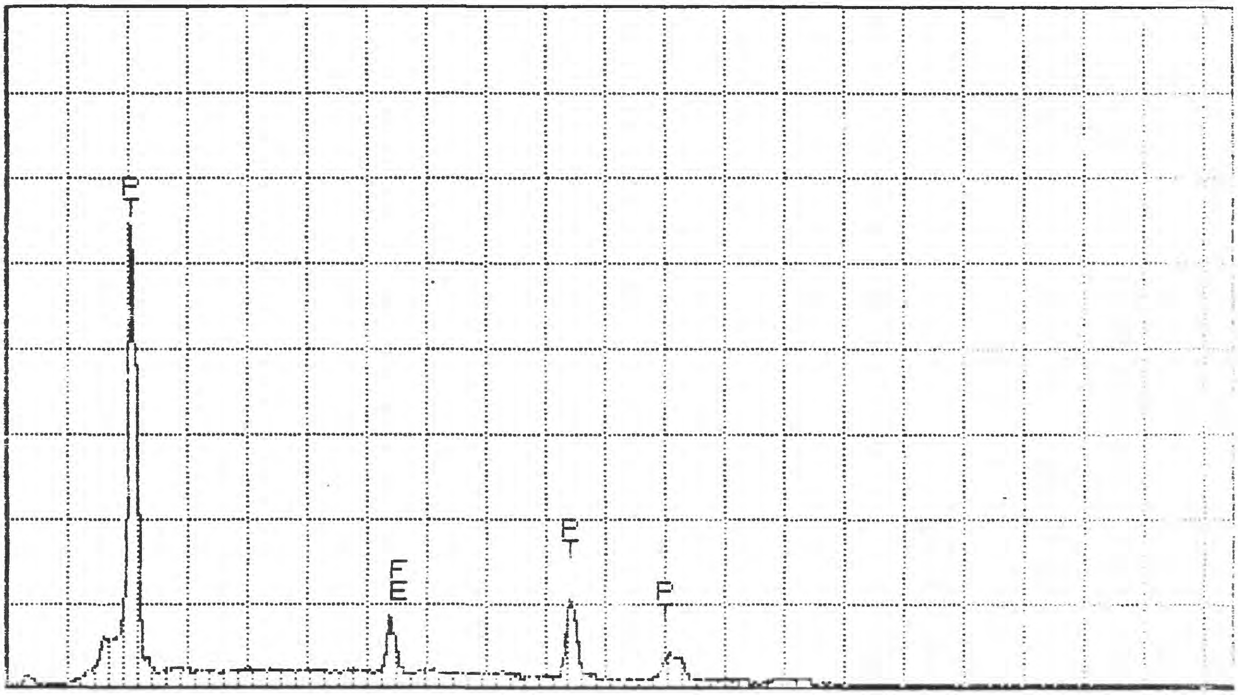


SP33

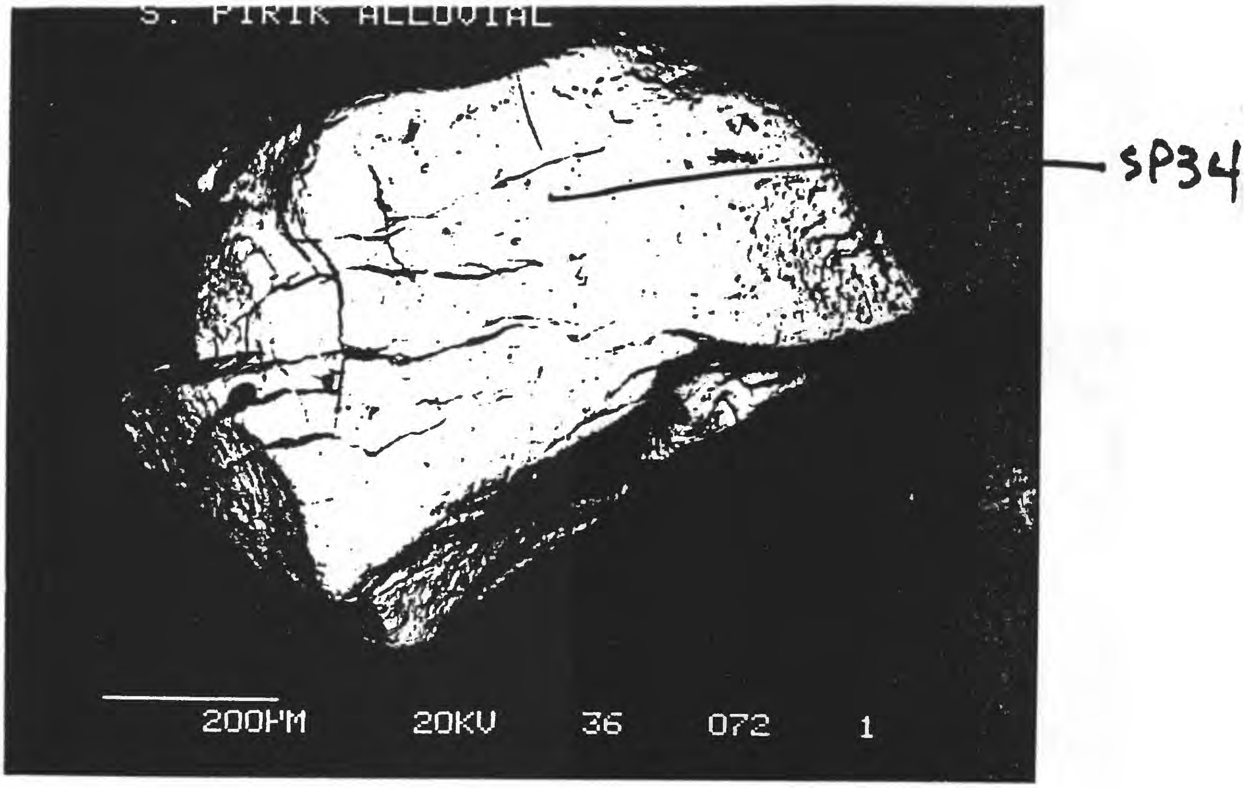


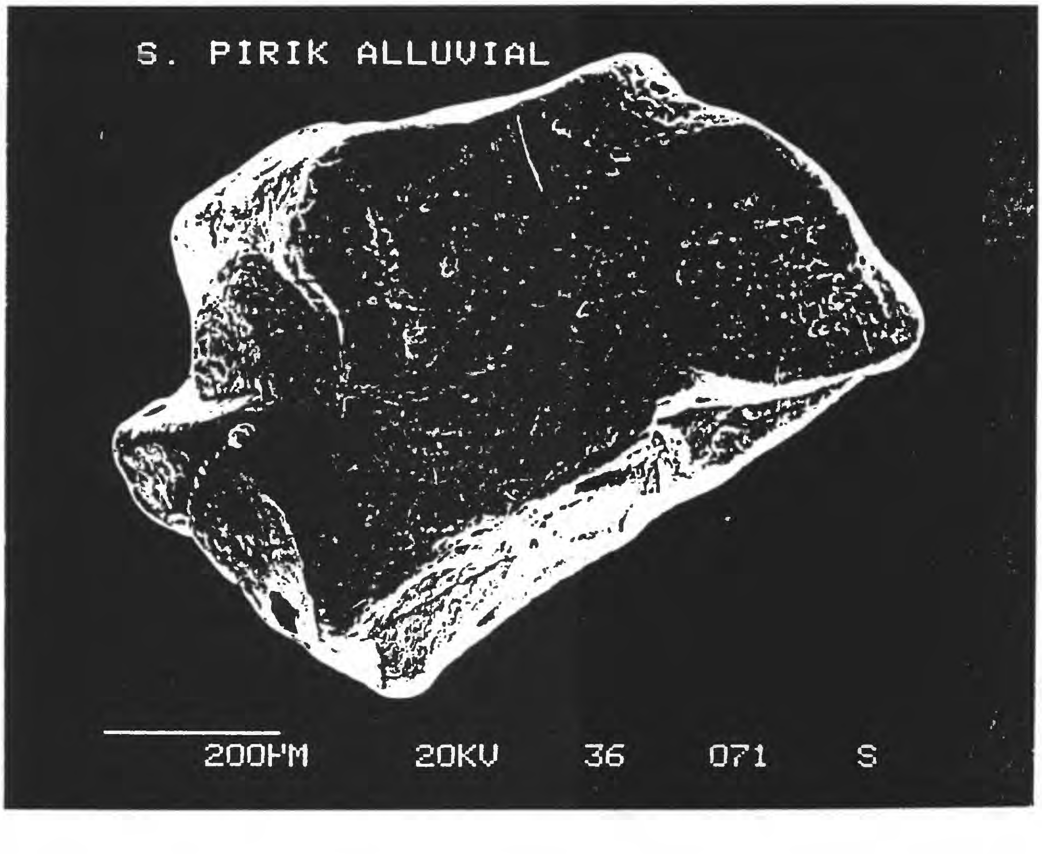
same as SP 33

```
U. S. GEOLOGICAL SURVEY, MENLO PARK          THU 16-NOV-89  11:10
Cursor: 0.000KeV = 0          ROI    (1) 0.000: 0.000
```



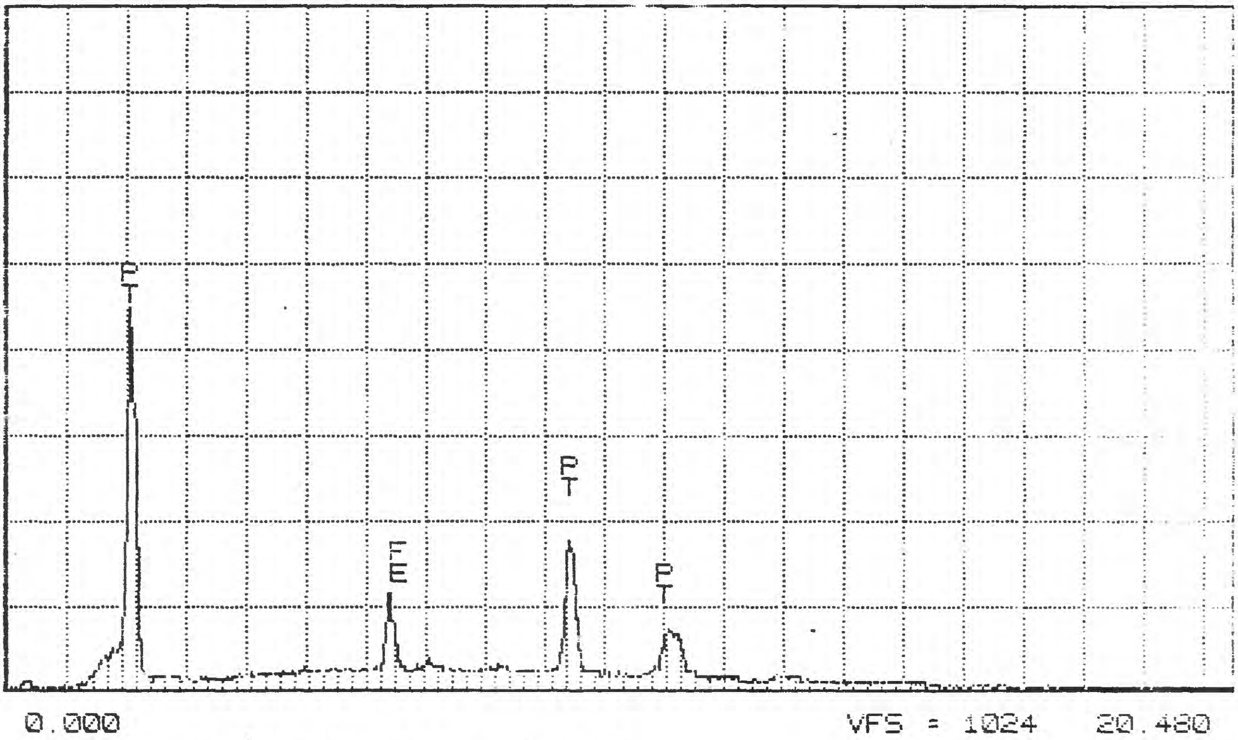
```
0.000                                      VFS = 2048    20.480
  30      S. Pirik allluvial SP33
```


S. PIRIK ALLUVIAL
SP34
200µM
20KV
36
072
1

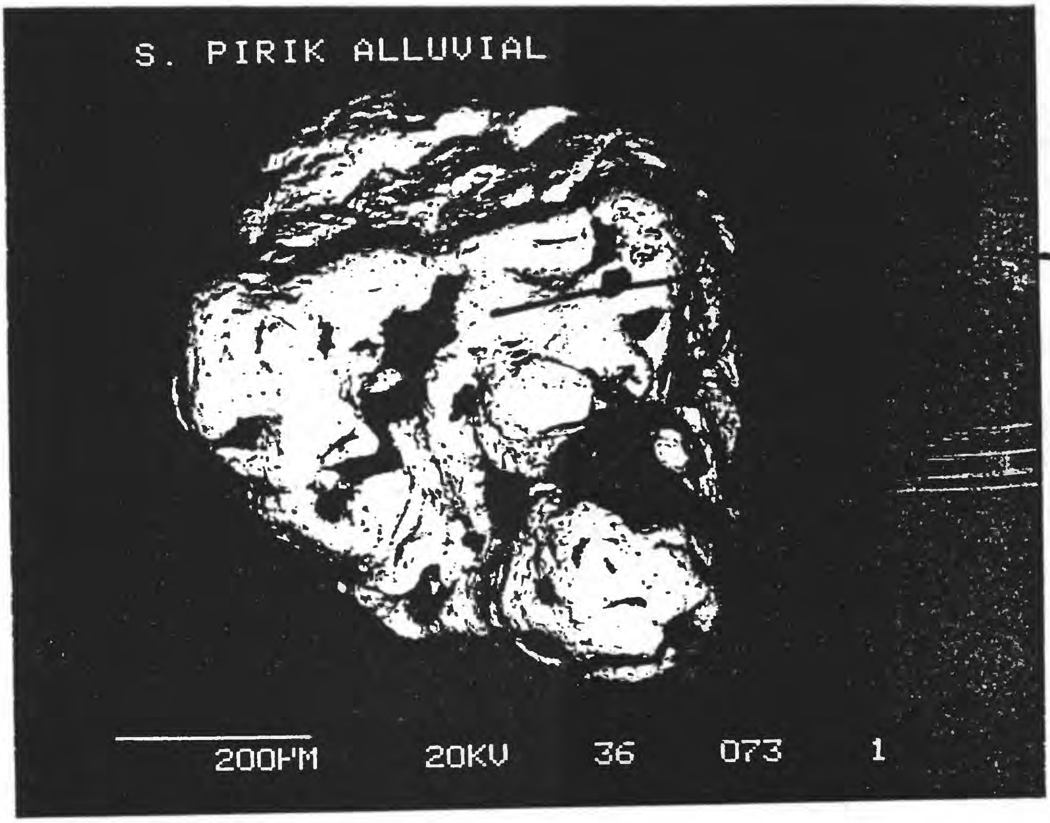

S. PIRIK ALLUVIAL
200µM
20KV
36
071
S

U. S. GEOLOGICAL SURVEY, MENLO PARK THU 16-NOV-89 11:26

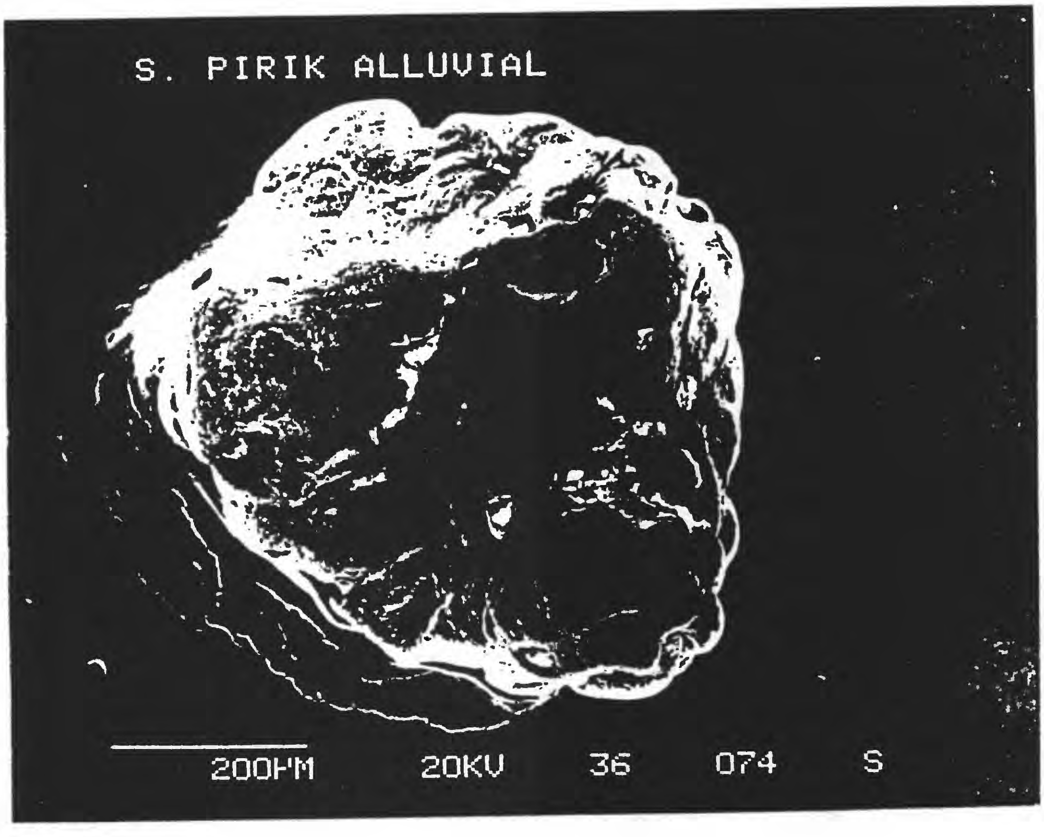
Cursor: 0.000keV = 0 ROI (1) 0.000: 0.000



30 S. Pirik allluvial SP34

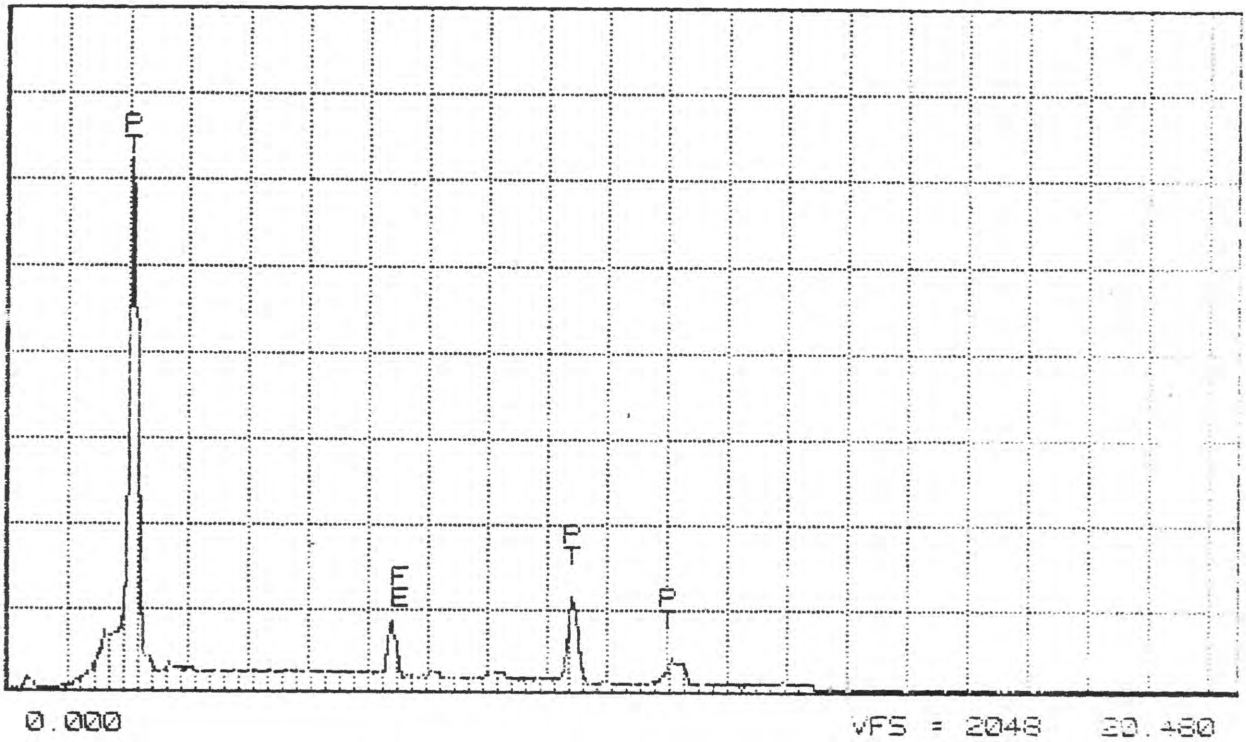

S. PIRIK ALLUVIAL
200µM 20KV 36 073 1

SP35


S. PIRIK ALLUVIAL
200µM 20KV 36 074 S

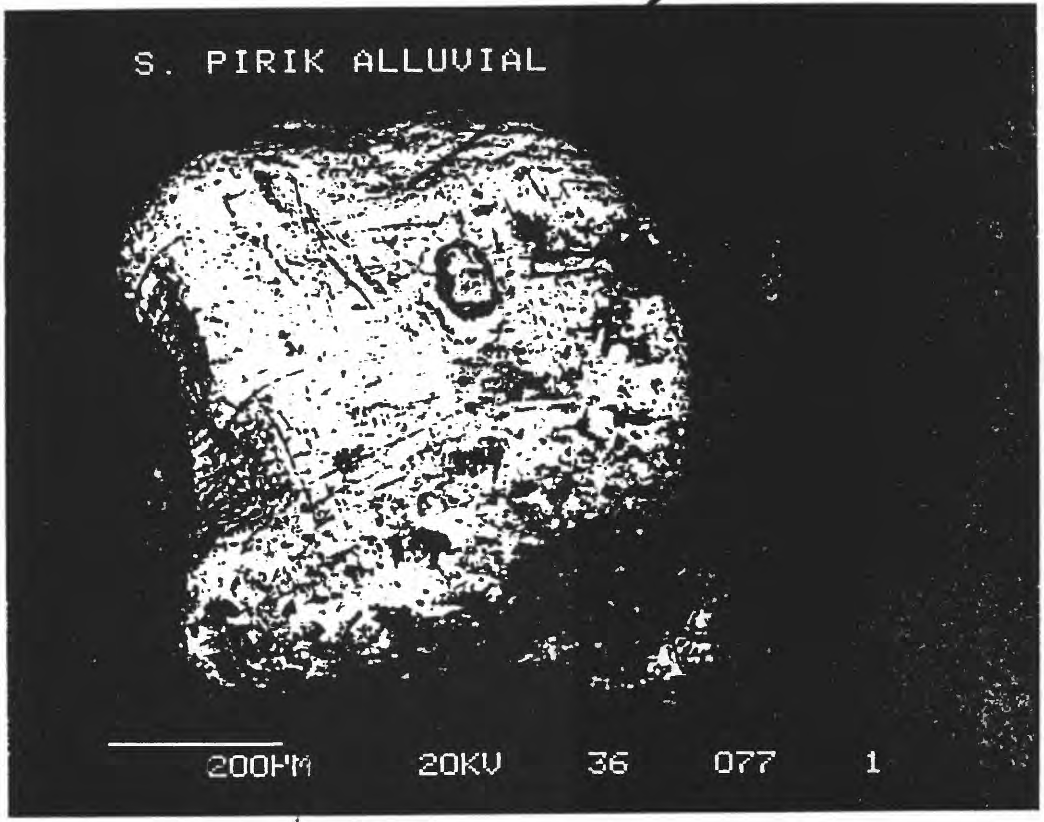
U. S. GEOLOGICAL SURVEY, MENLO PARK THU 16-NOV-89 11:37

Cursor: 0.000keV = 0 ROI (1) 0.000: 0.000

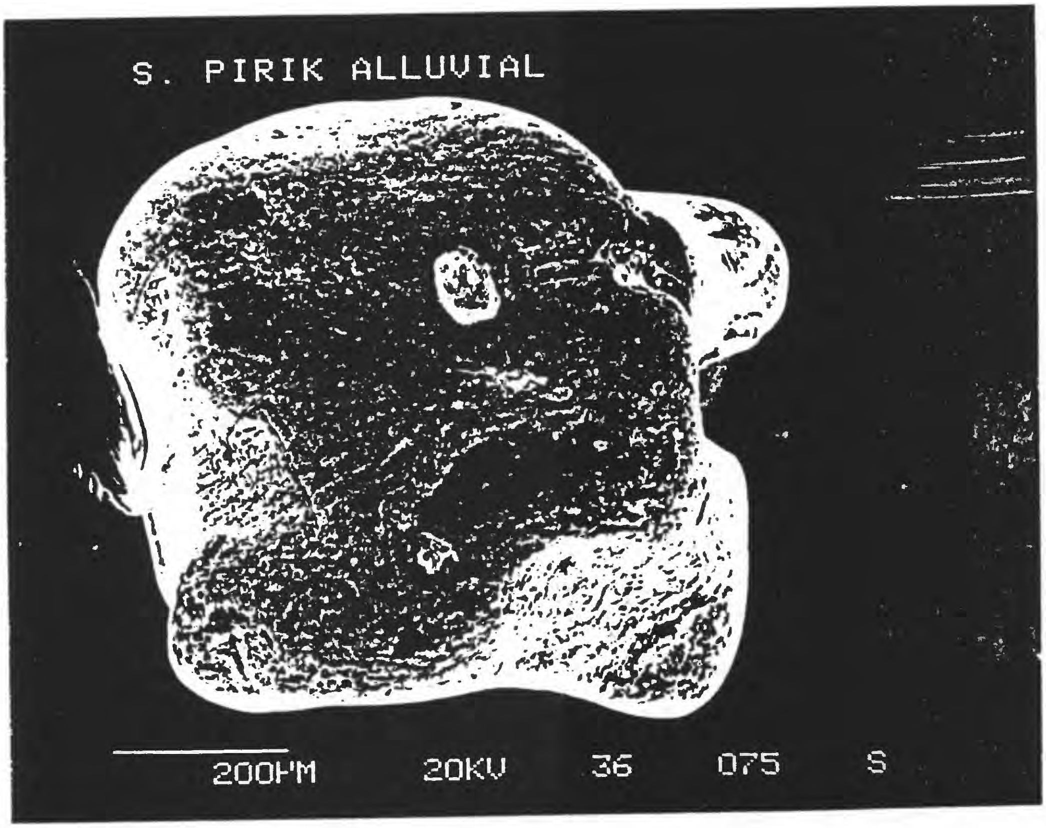


30 S. Pirik alllluvial SP35

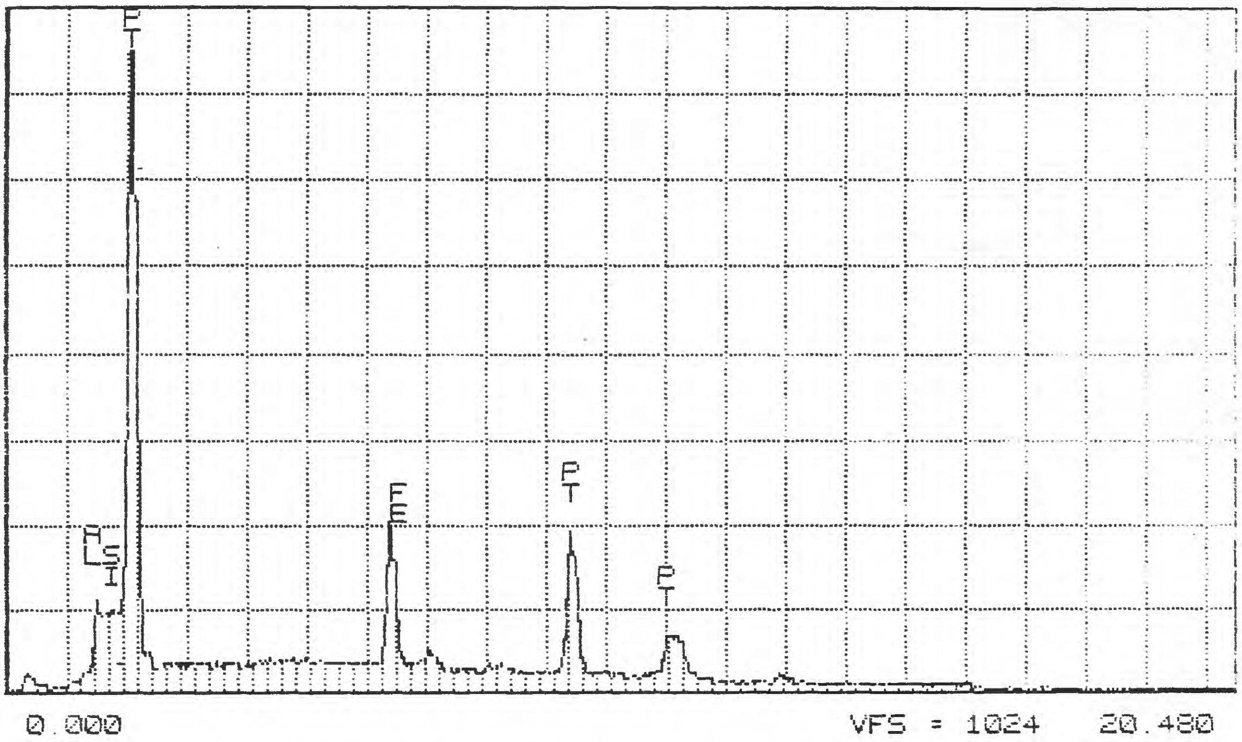
SP36



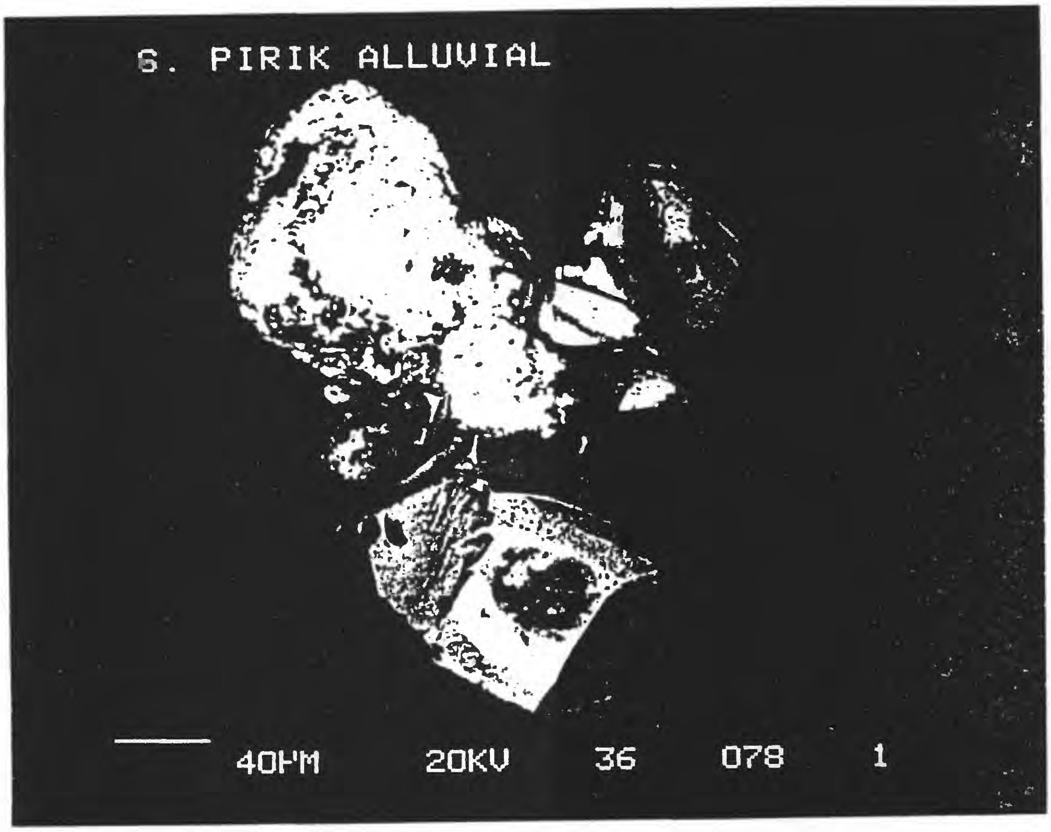
same as SP 36

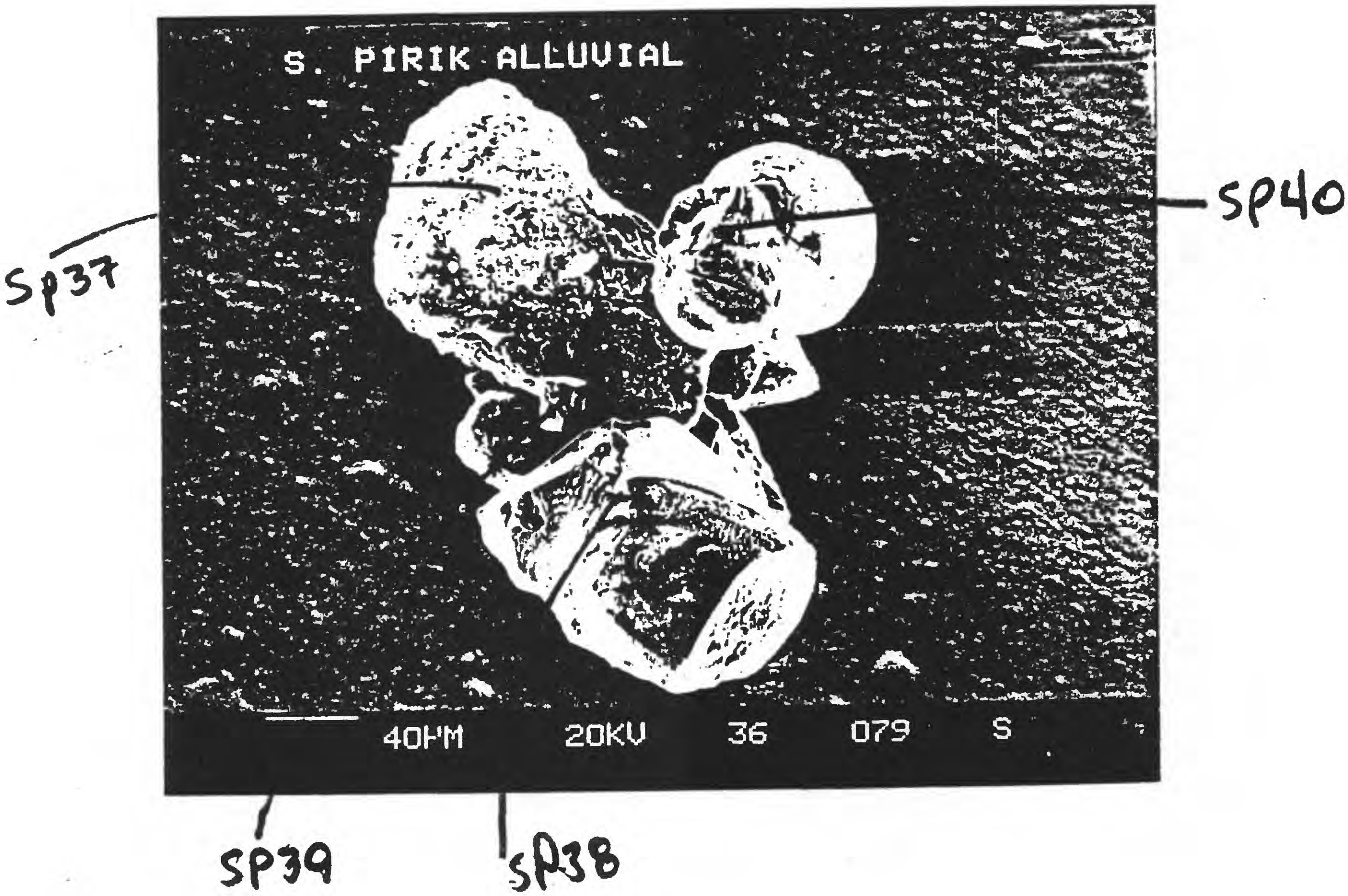


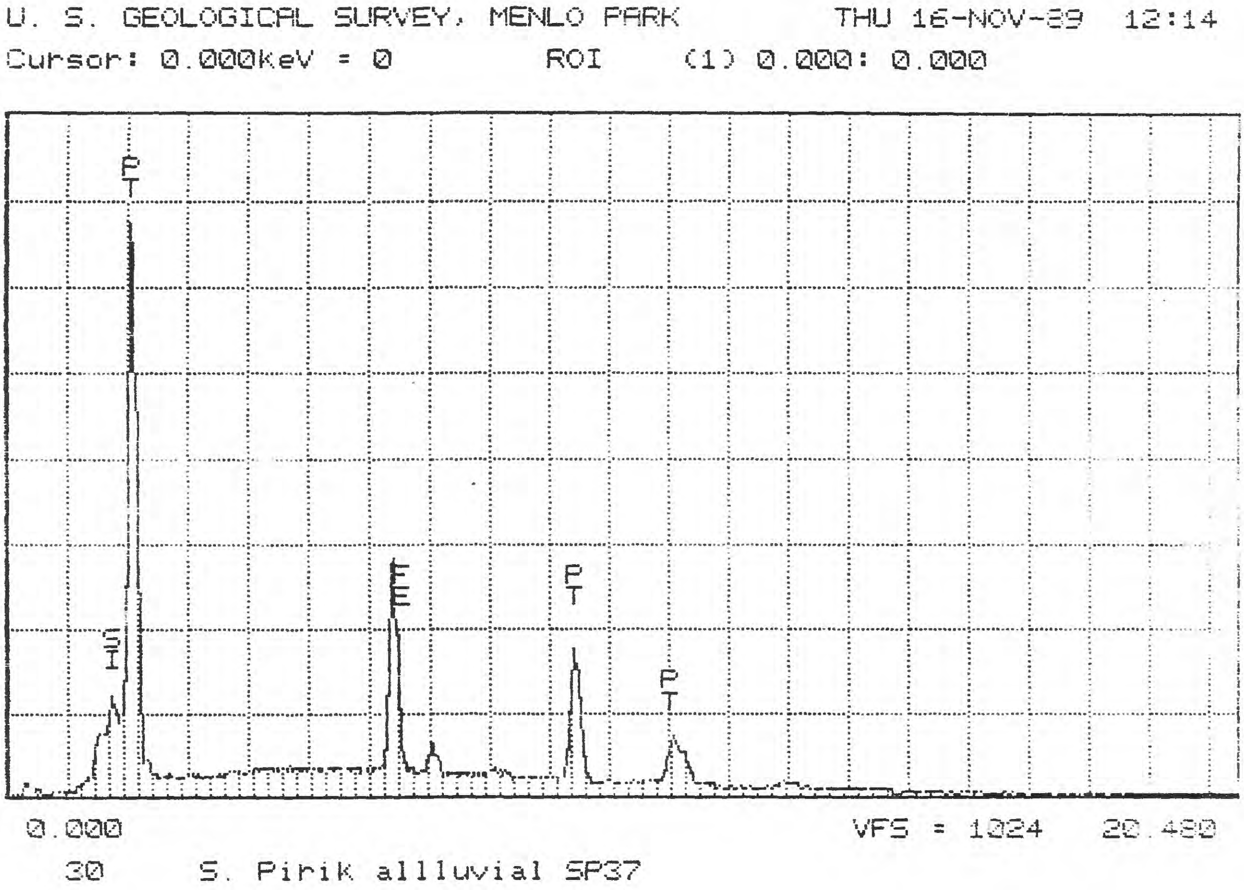
U. S. GEOLOGICAL SURVEY, MENLO PARK THU 16-NOV-89 11:50
Cursor: 0.000KeV = 0 ROI (1) 0.000: 0.000



30 S. Pirik alllluvial SP36


S. PIRIK ALLUVIAL
40µM
20KV
36
078
1


S. PIRIK ALLUVIAL
40µM
20KV
36
079
S
SP40
Sp37
SP39
SP38



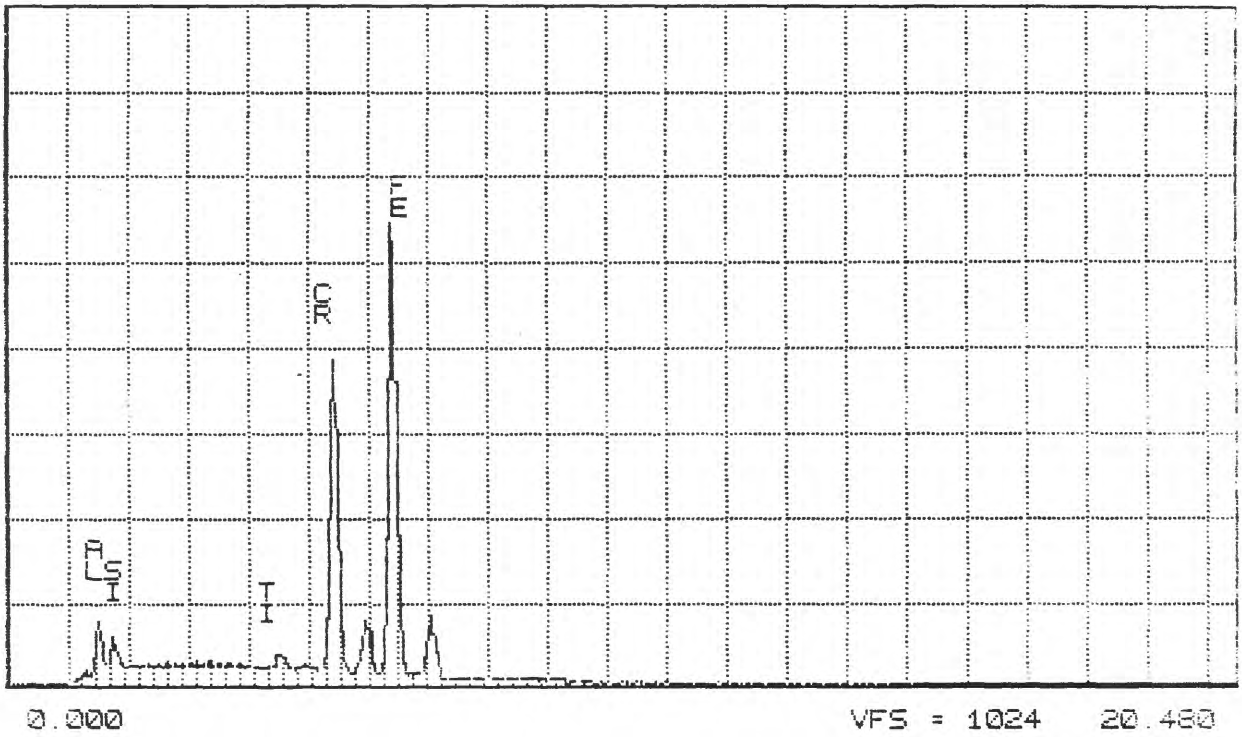
U. S. GEOLOGICAL SURVEY, MENLO PARK THU 16-NOV-89 12:14

Cursor: 0.000keV = 0 ROI (1) 0.000: 0.000

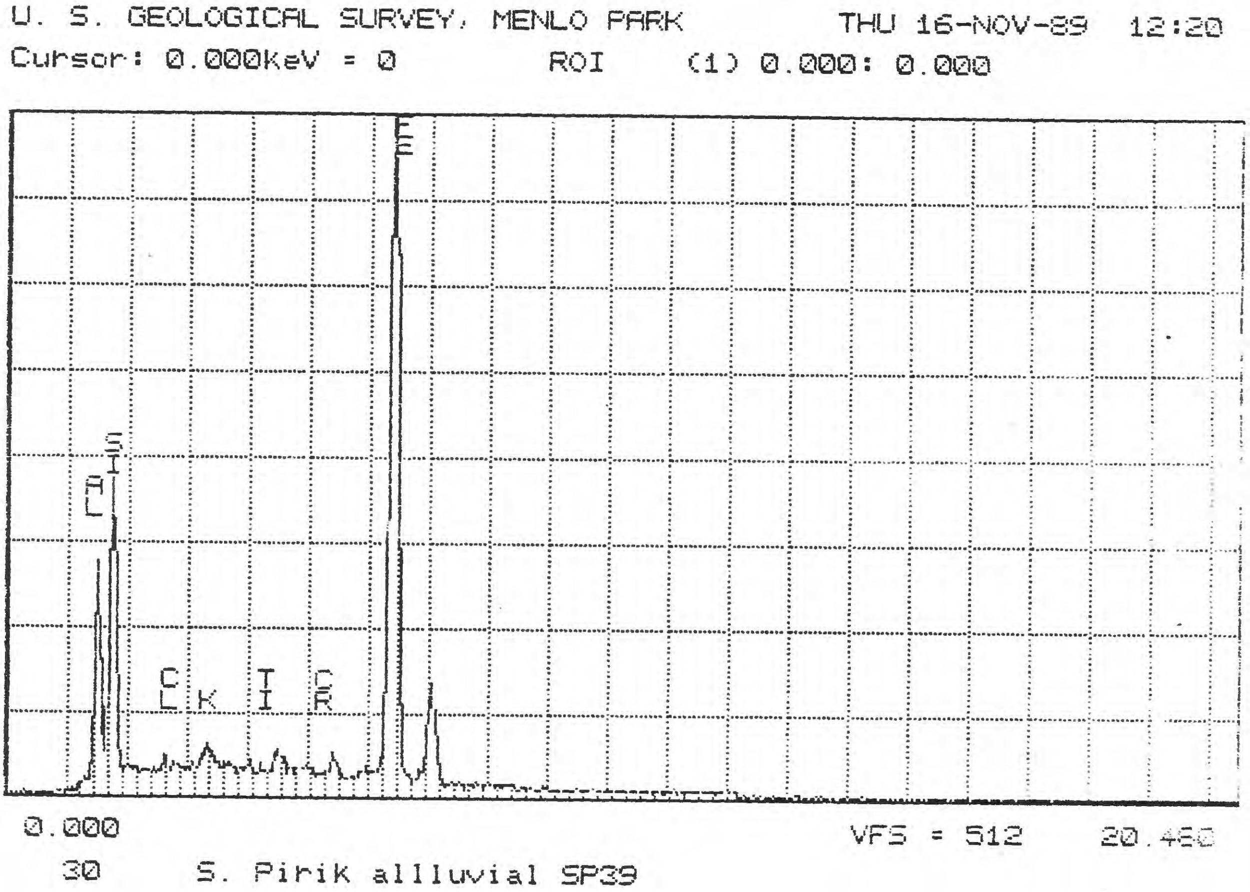
0.000 VFS = 1024 20.480

30 S. Pirik allluvial SP37

U. S. GEOLOGICAL SURVEY, MENLO PARK THU 16-NOV-89 12:18
Cursor: 0.000keV = 0 ROI (1) 0.000: 0.000



30 S. Pirik allluvial SP38



U. S. GEOLOGICAL SURVEY, MENLO PARK THU 16-NOV-89 12:20

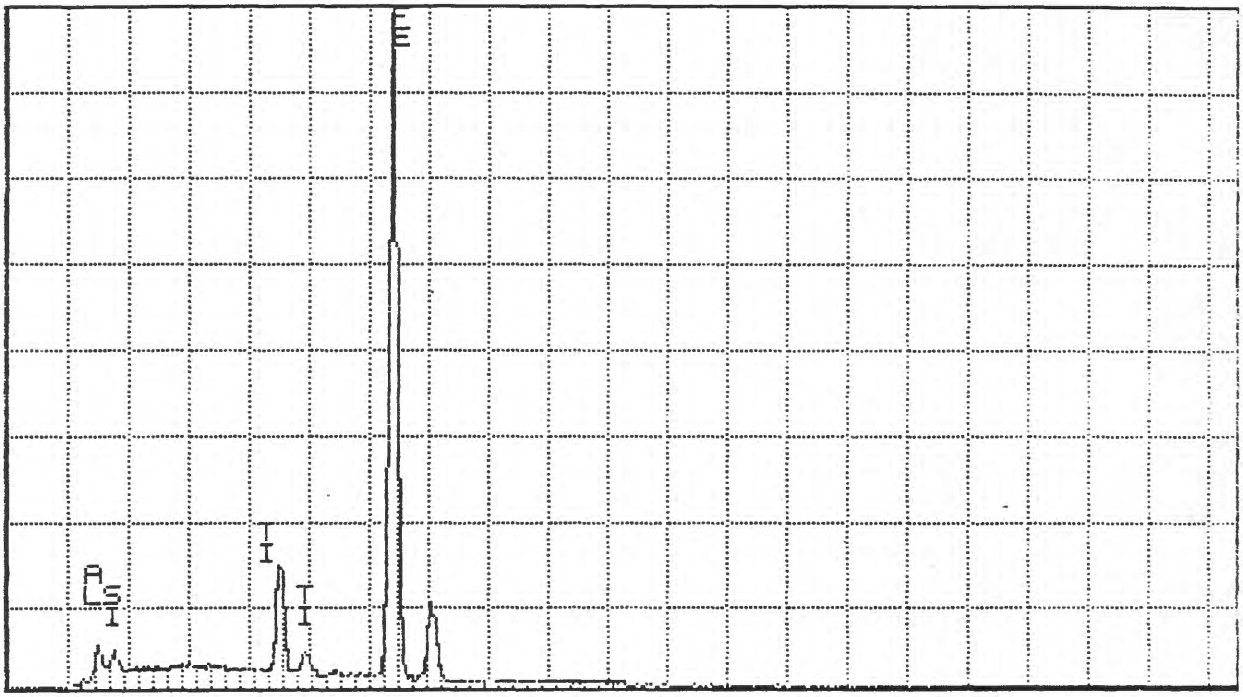
Cursor: 0.000KeV = 0 ROI (1) 0.000: 0.000

0.000 VFS = 512 20.480

30 S. Pirik allluvial SP39

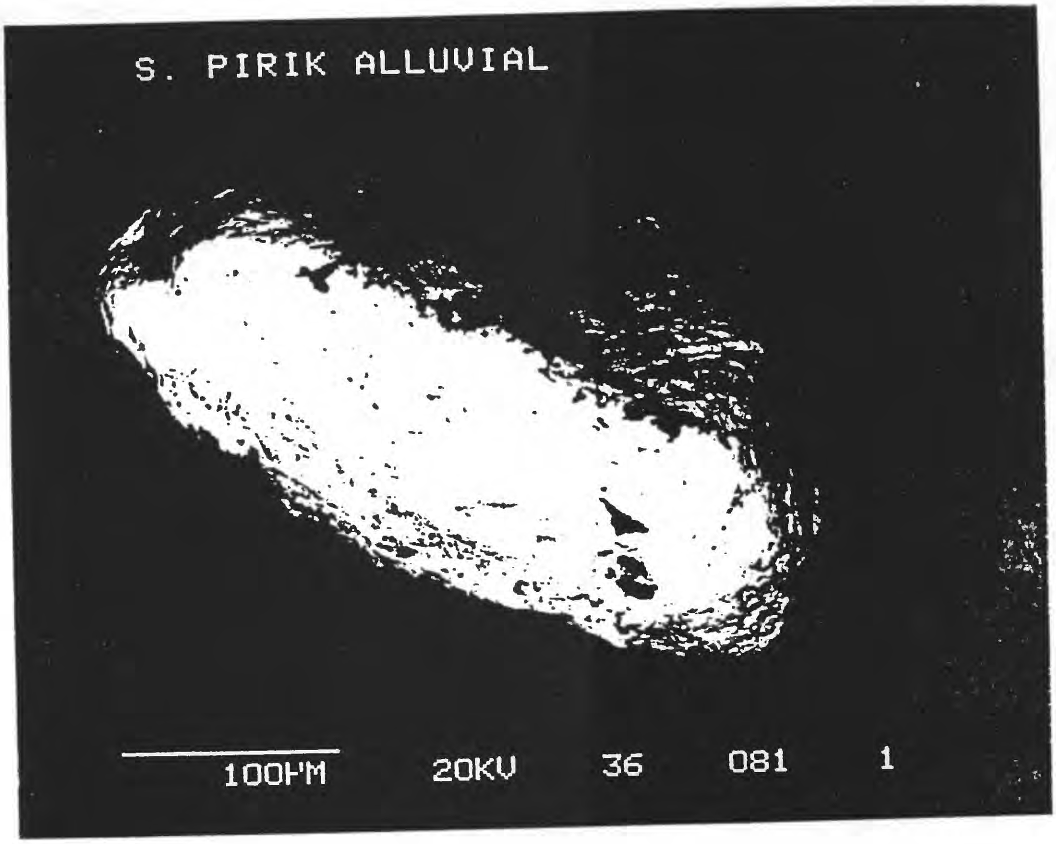
U. S. GEOLOGICAL SURVEY, MENLO PARK　　THU 16-NOV-89　12:22

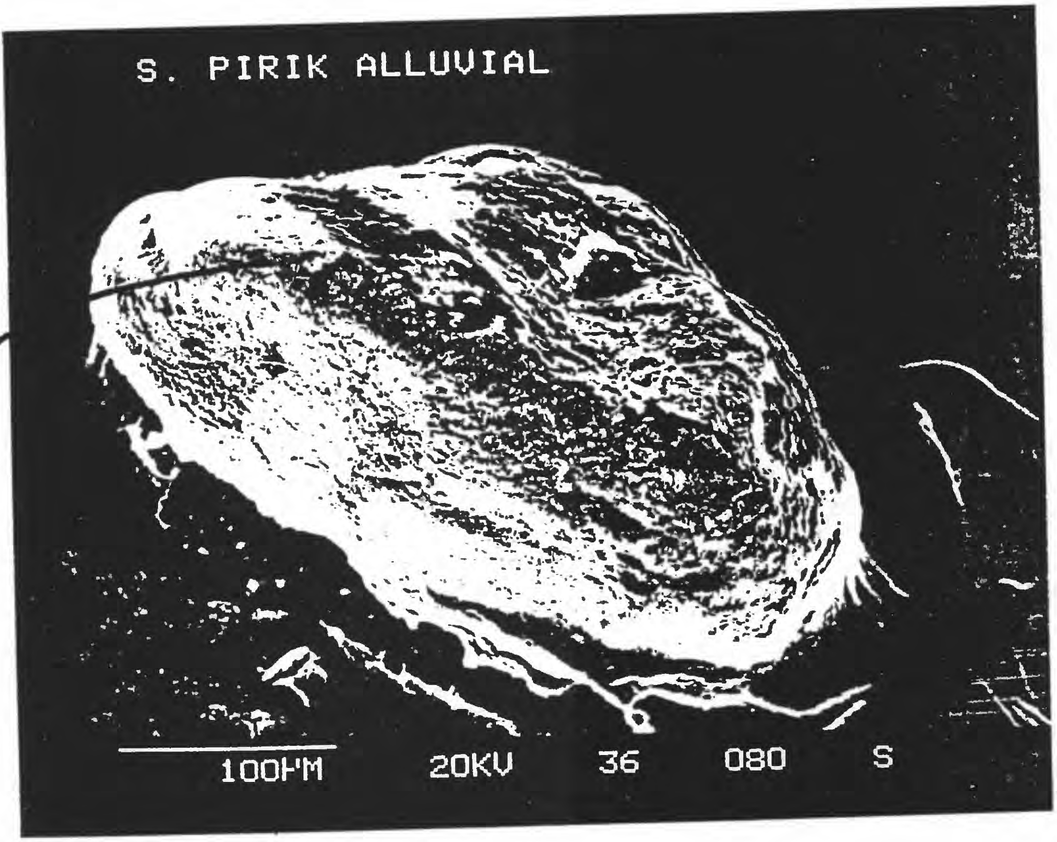
Cursor: 0.000keV = 0　　ROI　(1) 0.000: 0.000



0.000　　VFS = 1024　20.480

30　S. Pirik allluvial SP40

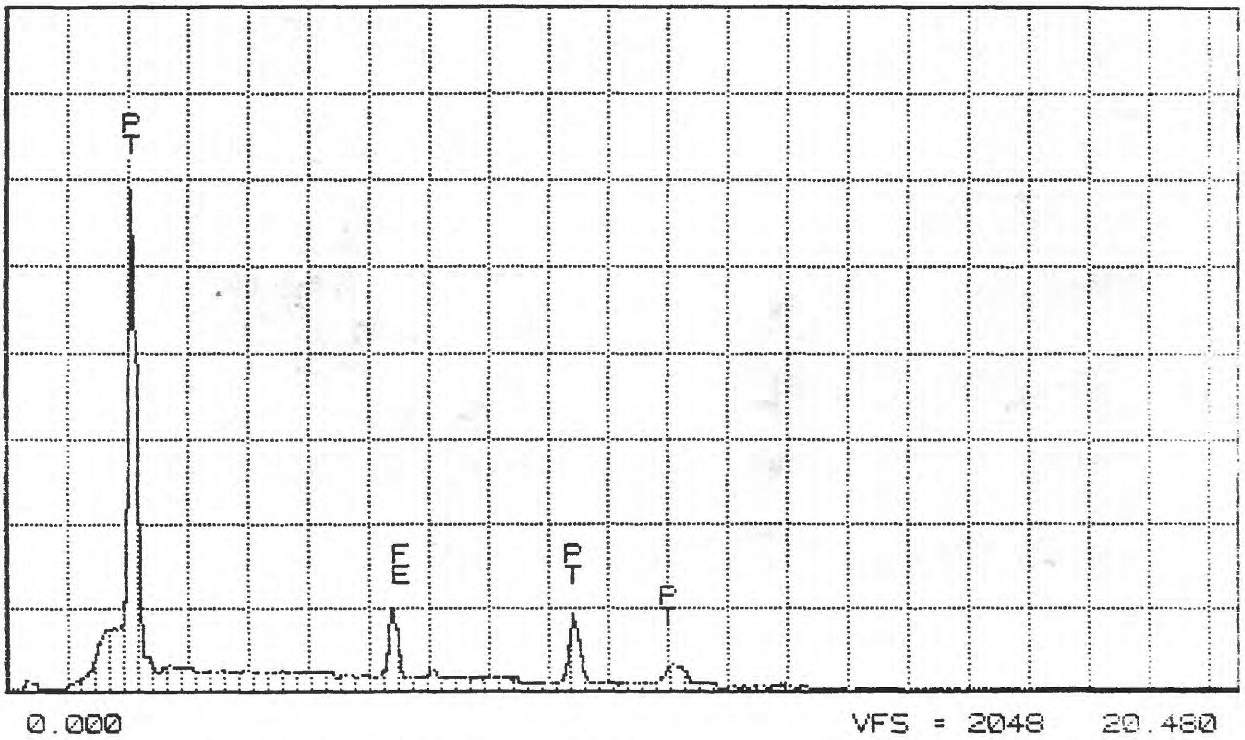

S. PIRIK ALLUVIAL
100µM
20KV
36
081
1


S. PIRIK ALLUVIAL
100µM
20KV
36
080
S

SP41

U. S. GEOLOGICAL SURVEY, MENLO PARK THU 16-NOV-89 12:31

Cursor: 0.000KeV = 0 ROI (1) 0.000: 0.000



30 S. Pirik alllluvial SP41