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INVESTIGACIÓN GEOQUÍMICA DE NIOBIO Y TÁNTALO EN LA PROVINCIA DE LA CORUÑA

J. M. López de Azcona *

RESUMEN

Se estudia una nueva técnica espectroquímica para la valoración cuantitativa aproximada de Nb y Ta en los minerales y una modificación de la misma para determinar con precisión la relación atómica Nb/Ta en los correspondientes pentaóxidos.

Se aplican estas técnicas al análisis de las arenas de playa de la costa de la provincia de La Coruña, con lo que se localizaron zonas interesantes desde el punto de vista de estos dos elementos.

Conocidas las zonas en grandes rasgos se procedió a un demuestre sobre el terreno y localización de los filones que pueden tener importancia desde el punto de vista industrial.

Se fija para la zona de Boiro (Coruña) la relación atómica Nb/Ta en 14,7 ± 0.3.

INTRODUCCIÓN

Para las investigaciones geoquímicas de niobio y tántalo, es necesario disponer de una técnica analítica, que al mismo tiempo de ser muy sensible no esté sometida a errores diferenciales del análisis. La sensibilidad grande se alcanza por las técnicas espectroquímicas con excitación por arco, pero en el caso presente tiene un inconveniente fundamental que es el punto elevado de fusión de ambos metales 1,950 y 3,027 grados, y las temperaturas de ebullición 2,900 y 4,000 grados respectivamente. Esto da lugar a una dificultad en conseguir la volatilización total, con una disminución de sensibilidad y caso de lograr sea total para el niobio, pueden producirse fenómenos de destilación fraccionada en el arco, que de en la interpretación un contenido aparente en tántalo, menor que el real.

Para resolver esta dificultad, se ideó una técnica consistente en la preparación de una mezcla deflagrante a terceras partes en peso de carbón pulverizado puro, cinc metálico y clorato potásico espectralmente puros. Preparada ésta se hace una mezcla íntima entre una parte de la muestra a analizar y tres de aquélla.

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Como excitación se emplea el arco de corriente continua a una tensión de 110 V y una intensidad de 15 A, pero con el objeto de que se establezcan automáticamente la excitación y perdure hasta la volatización total del Nb y del Ta, se conecta en paralelo con los correspondientes filtros de protección una corriente de alta frecuencia. A los electrodos se les da la forma y dimensiones adecuadas, así como una separación de 2.5 mm. El electrodo inferior es el positivo que precisamente alcanza mayor temperatura y facilita la deflagración. La cantidad de muestra empleada es de 0.0075 g. o sea de 0.030 g. después de unida a la mezcla deflagrante. La duración de la emisión es de 5 segundos, por lo cual se conecta la puesta en marcha del circuito de alta frecuencia con un obturador automático graduado para los 5 segundos.

LA INVESTIGACIÓN

En el año 1945 en colaboración con el Ingeniero Comba Sigüenza, Jefe de Investigaciones Mineras del Instituto Geológico, comenzamos un estudio sistemático de las playas de la provincia de La Coruña, operación que requirió dos años de trabajos de campo, ya que además de los demuestres de las correspondientes playas, se efectuaron los de cuantos aluviones cercanos a las mismas se consideraron fuesen de interés, habiéndose estudiado 111 parajes con un total de 600 muestras. En éstas se hizo una separación por densidades y dentro de cada grupo obtenido, una nueva separación por magnetismo, con lo que las muestras quedaron considerablemente aumentadas, al obtener estas fracciones.

Todas las fracciones se analizaron espectroquímicamente durante los años 1946 y 1947, y al dar cuenta de los resultados a la superioridad, ésta decidió pedir la reserva de las seis zonas de la provincia de La Coruña más interesantes.

En el año 1955 se estudió detenidamente la reserva de Boiro y en este año se está investigando la de Noya.

SITUACIÓN GEOLÓGICA

Se aprecia en general entre las Rías de Noya y Arosa, una corrida de rocas antiguas de norte a sur, interrumpidas por una serie de manifestaciones más modernas, con la particularidad de que los diques pegmatíticos mineralizados se encuentran en las rocas antiguas.

En el occidente de la provincia de La Coruña, puede recorrer el geólogo una faja de esquistos y gneises antiguos que la cortan, formando un pequeño arco de norte a sur con potencia en algunas ocasiones de hasta cuatro kilómetros, que comienza al norte de Malpica y terminan sus últimas manifestaciones al sur de la provincia en Abanqueiro, pasando por Noya, atraviesa la provincia de Pontevedra, cruza el Miño y penetra en Portugal hasta el Duero. Al oeste de esta faja, existen unos esquistos, en algunos casos biotíticos, con dirección N 10°, que cubren desde Lampón hasta el Barbanza, dentro de ellos se observan dos facies, una más compacta que la otra, en los diques pegmatíticos de esta segunda es donde se encuentra principalmente la mineralización del niobio y tántalo. Estas dos grandes fajas, comprenden de una tercera que va desde Lage hasta Boiro, consistente en un granito gneisificado de dos micas, que en algunos sitios, como en Cuadarnojo, da lugar a una variedad ligeramente profiroide, con orientación en el 75% de los porfiroblastos, los cuales tienen las caras delimitadas perfectamente.

Los mencionados gneises tienen en algunos parajes un marcado metamorfismo regional y así como en los esquistos, se encuentra considerable cantidad de enjambres de filones y diques de origen eruptivo, ya ácidos como aplitas, felsitas, etc., ya básicos como anfibolitas.

El granito orientado es de estructura ordenada, con proporción del mismo orden de biotita y moscovita, tamaño medio del grano, y orientación N 10° a N 20°, concordante con los macizos esquistosos y gneisicos. Este tiene la variedad de los feldespatos porfídicos. Zonas fluidales en el contacto con éste y con los esquistos. Tiene zonas con muchas pegmatitas (no mineralizadas) y diques de cuarzo. Este es como el del monte Neme, tan famoso por sus criaderos de volframio.

Los esquistos más occidentales de la zona considerada están limitados por un granito de dos micas no orientado de grano grueso, en general bastante homogéneo, salvo en su límite oriental cerca de los contactos con los esquistos y el granito gneisico de dos micas que cubre la parte más alta del Barbanza. Los gneises orientales, están interrumpidos por un afloramiento aproximadamente circular de 5 km de diámetro de granito de grano grueso de biotita que en algunos lugares tiene porfiroblastos de hasta 6 cm. Este granito se presenta de una forma bastante uniforme dentro de algunas pequeñas diferencias en el tamaño del grano, pero no hemos observado que alcanzase a manifestarse con grandes porfiroblastos, en ellos se aprecia en general su erosión en bloques redondeados.

Al sur de la reserva de Boiro, existe un granito discordante de grano grueso, que ocupa la zona de Cabo Cruz, con una serie de digitaciones entre Lampón y la Puebla del Caramiñal. En los contactos de este granito con las rocas orientadas, se han podido apreciar en la misma costa, manantiales de magnífica agua potable.

Entre los rasgos característicos que se han apreciado en la zona representada, hay varios que inmediatamente saltan a la vista. Uno de ellos es que el límite de los diversos terrenos no es neto, y quizá como más típico es el caso de Abanqueiro, donde la mancha representada como gneisica es en realidad una sucesión de 2 km de potentes corridas de granito gneisico y gneises, donde al oeste dominan los granitos orientados y en Portomuro los gneises. Esta mancha tiene un dique de aplitas granitíferas que va desde el suroeste de Abanqueiro hasta Belles de Abajo. En Brion hay un pequeño isleo de gneises en la faja norte-sur del granito gneisificado, lo que puede servir para consideración geocronológica. En el estrechamiento de Rebordelo-Tinanes, se aprecian en la costa unas manchas esquistosas de dirección dominante N 10° E, pero entre ambos lugares sólo se encuentra el granito gneisificado.

También se encuentran en el granito gnéisico, algunos enclaves de los esquistos del tipo de Montaño, como el de Teaño, pero carecen de diques pegmatíticos.

La zona de esquistos mineralizados está limitada al E por un dique felsítico que partiendo del mar termina, aparentemente al N en Pazos de Coroño.

El moderno granito de biotita de grano grueso, tiene enclaves de granito gnéisico como en el N de Aldea de Arriba y de esquistos como en Rosom.

ESTUDIO DE LAS PLAYAS DE LA MARGEN NOROCCIDENTAL DE LA RÍA DE AROSA

El estudio elemental de los arenales de las playas de la margen noroccidental de la Ría de Arosa, comienza por la de Reboreo y termina en la de Corrubedo, paraje este último que se puede considerar como no perteneciente a la mencionada Ría, pero sus arenales los hemos visto enriquecidos en determinadas ocasiones, por los arrastres marinos de dicha procedencia.

Fue de fácil identificación el niobio y tántalo en estos arenales, así como que el arrastre de las corrientes habían producido la aportación de estos dos elementos a la playa de Angueiro fuera de la zona de reserva por parecer, por todos los datos que hemos podido recopilar, ser debidos a un origen marino en lugar de continental. Ambos elementos fueron encontrados en menores cantidades en las playas de Aguiños, Coroso y Colorinos y en otras como la playa de Esteiro en ninguna de las ocasiones que la hemos reconocido pudimos identificar el Nb y Ta. Después de varias investigaciones llegamos a la conclusión de que todo el niobio y tántalo encontrado desde la punta Cabío hacia el mar, procedía de aportación marina, aunque su primitiva procedencia fuese en parte fluvial.

A partir de la punta de Ostreira en las inmediaciones de Jobre hacia el NE, la impresión que producen los arenales es diferente, se empiezan a encontrar cantidades aunque todavía pequeñas de ambos metales en la playa de Ría Sort, pero en la inmediata del Caramiñal, se encuentran en cantidades muy importantes, sin duda por la aportación del Río Barbanza, donde hemos logrado por concentración directa con una sencilla batea de las arenas de la playa llegar a leyes en pentaóxidos, superiores al 0.1%. Todavía son mayores las riquezas de la playa de Tarmuiña y de las zonas de aportes del Río Goyanes en las que por el mismo procedimiento la riqueza en pentaóxidos excedía del 1%, cantidad extraordinaria, lo que es indicio de las cercanías de los diques pegmatíticos con el mineral originario. Al seguir el recorrido por la Ría de Arosa y efectuar toma de muestras en playas tan inmediatas como las de Barrañá y Carrageiros, las leyes bajan considerablemente y en muchas ocasiones carecen de ambos metales.

Por estos reconocimientos se ve que hay tres ríos que son los que aportan mayores cantidades de mineral a la ría: el Barbanza con su afluente el Lérez y los de Lampón y Goyanes.

De estos estudios de arenas, se ha deducido la existencia de otros elementos de gran interés. Las monazitas son frecuentes en casi todas las playas desde Aguiños hasta Budión, en algunas ocasiones en cantidades tan grandes, que es suficiente, después de determinados temporales, el pasar una pala por los arenales recogiendo una capa superficial de 2 a 3 mm de espesor, la cual es renovada incluso varias veces al mes, donde los temporales hacen una función concentradora, en ellas por medición de su actividad se han deducido leyes equivalentes para el todo uno de 0.02% de torio para la playa de Barrañá y 0.08 para la de Budión. Las arenas de estas playas son completamente diferentes, mientras que la de la primera tiene mucha ilmenita y pocos granates, la segunda tiene como elemento dominante los granates. También hemos apreciado en otras ocasiones el interés que tienen las playas de Aguiños, Insuela, etc., desde el punto de vista del torio, pero ahora no las consideramos por estar dentro de la misma ría de Arosa, alejadas de la reserva.

Para el estudio del torio de estas dos playas, se lavó de cada una en la misma playa con batea, cuatro kilogramos de tierras, dando la de Budión 1,344 g de fracción pesada y la de Barrañá 56 g, índice de la gran diferencia de constitución de ambas.

La separación de la monazita, es sumamente fácil, alcanzando riquezas que la hacen de gran interés, como lo son las tres fracciones de menor magnetismo de cada playa; dentro de ellas la magnética a 4 amperios de Budión y las de 4 y 5 a. de Barrañá, que permiten clasificarlas entre las más ricas logradas por una separación tan simple, con la particularidad de dar un rendimiento elevado, dado que la primera representa el 53% de la monazita de Budión y las segundas el 55% de la Barbanza.

Del estudio con filtros, de la actividad de estas monazitas, se deduce que más del 80% corresponde al torio y el resto al uranio. Los valores dados en el cuadro se refieren al contenido en torio para dar una radiactividad equivalente a la de las muestras respectivas.

Además de las niobio-tantalitas y monazitas, algunas con marcada radiactividad, se han encontrado en estas playas varios elementos del grupo de las tierras raras, procedentes de las monazitas.

Un elemento interesante de estos arenales es el estaño; el cual ha dado cantidades verdaderamente extraordinarias en las zonas cercanas a la desembocadura del río Goyanes, donde concentrados superiores al 10% del metal los logra cualquier chiquillo lavando con una lata. Simultáneamente con estos minerales se encuentra el oro y en las playas donde la ley de los anteriores baja, es frecuente, como nos ha ocurrido en la de Barrañá, encontrar destacadas partículas de oro entre los productos pesados de la batea. En preparaciones microscópicas se han identificado partículas de oro en el dique felsítico de Goyanes y el aplítico de Budion.

En algunas playas de la provincia de La Coruña, no hemos podido identificar el circonio a pesar del interés puesto, pero en la Ría de Arosa, lo hemos encontrado a veces en los concentrados en proporciones de hasta el 0.1%.

El plomo nos fué fácil identificarlo en todas las playas, en algunas ocasiones con concentraciones de 0.01%, el cual, no lo consideramos de interés como los anteriores, para efectuar prospecciones geoquímicas, a causa de la gran sensibilidad que tienen nuestras técnicas para este elemento, lo localizamos en varios sitios en proporciones cercanas a la media de la constitución elemental cortical y además que por lo que hemos manifestado anteriormente, podríamos contestar fácilmente a la pregunta: ¿Es radiogénica una gran parte del plomo de la Ría de Arosa?

Hay muchas playas de Galicia que tienen una riqueza en litio superior a la normal y esto lo hemos encontrado en la ría a que nos referimos en algunas playas, entre los elementos ligeros de las fracciones no magnéticas, habiendo alcanzado valores de más de 0.1% de Li_2O en playas como la de Goyanes los elementos pesados. Este exceso de litio, hemos comprobado que procede de espodumenas litiníferas que hemos encontrado en las pagmatitas y una primera anomalía se encuentra, en que en la mayor parte de las obras que hablan de las espodumenas, suelen tratar de su gran alterabilidad con pérdida del litio y sustitución de éste por el sodio, lo que es mucho más fácil en el caso de la acción de las aguas marinas por su contenido elevado en sodio, pero hemos sacado la impresión de que en general estas espodumenas gallegas son más resistentes que lo esperado a los efectos del lavado superficial.

El cobre es un elemento encontrado en estas arenas en concentraciones de 0.001% á 0.0001% lo que es normal en cualquier punto de la costa, también se pueden considerar normales las de cobalto de 0.0001% y las de niquel de

0.01%, en cromo existen algunas diferencias habiendo llegado a valores del orden de 0.1% en algunos concentrados de la playa de Cerrageiros y en cuanto se refiere al molibdeno, el máximo obtenido en las arenas de este grupo pertenece a la de Castiñeiras con cerca del 1%.

Algunos elementos que parecía natural se encontrasen en las arenas, no se lograron identificar, los cuales quizá con concentraciones a partir de cantidades mayores de tierras, pues operábamos en general con unos 4 Kg, se hubiese conseguido reconocer sus líneas en los espectrogramas, tal ocurre con el berilio, dado que en estas pegmatitas y en muchos de los aluviones de los ríos hay considerables cantidades de berilos.

ESTUDIO DE LOS DIQUES DE PEGMATITAS Y DE LOS ALUVIONES

Para el estudio de la mineralización del niobio y tántalo, se comenzó por un recorrido en el terreno, con el fin de identificar la zona que podía ser apta geológicamente, apreciándose en seguida que los diques mineralizados están prácticamente limitados a los de pegmatitas encajadas en los esquistos metamórficos en su facies menos compacta y principalmente en las zonas marginales con el granito de dos micas no orientado, estando situada esta zona reducida al poniente del dique felsítico, que va de Pazos de Coroño a la desembocadura del río Coroño en Goyañes. Al E de este dique, las únicas manifestaciones interesantes son los aluviones del río y los arenales de la playa de Barrañá, que pierden riquezas conforme se alejan de la desembocadura del Río Coroño. Los límits norte y poniente quedan establecidos por el macizo de granito no orientado de dos micas de Barbana y el S por las digitaciones del granito de biotita de grano grueso prolongaciones del de Cabo Cruz.

Para darse una idea del rendimiento de estos filones, en uno de ellos que hemos denominado "Forestal" por estar en un camino forestal, en la concesión "Florita", se llevaron al laboratorio 20 Kg. de tierras, tal como salían del arranque, sin concentración previa alguna. Después de molida la muestra a 1 mm se sometió a una clasificación en tres densidades por medio de una mesa Wilfley. Los mixtos y estériles están constituidos principalmente de cuarzo, al que acompañan berilos y espodumenas. También se encuentran berilos y espodumenas pero en menor cantidad en la fracción más densa. La fracción densa está formada por magnetita, ilmenita, niobita, granates, turmalina y casiterita y de ella se obtienen subfracciones separadas magnéticamente con intensidades en las bobinas del electroimán del 1, 2, 3, 4 y 5 amperios. Las subfracciones más ricas en Nb y Ta son las menos magnéticas, o sea las de 3, 4 y 5 amperios, llegando esta última a tener una concentración en pentaóxidos del 15.6% con una recuperación en cada una de estas subfracciones de 7.4 — 40.6 y 52% del contenido total de las tierras. La porción no magnética dio 69.2% de estaño.

Con los análisis de estas diversas fracciones, se confirma la apreciación hecha sobre el terreno, de que las pegmatitas complejas con niobio y tántalo de la zona de Boiro además de tener en general una cantidad grande de casiterita, contienen cristales muy interesantes de berilo y de tamaño inferior de turmalina, principalmente negra y de espodumena, también se encuentran pero ya en contacto con los esquistos principalmente la magnetita, los granates y la ilmenita.

Los primitivos reconocimientos geoquímicos efectuados en la provincia de La Coruña, pusieron de manifiesto la importancia que tienen los aluviones, tanto para la minería de los metales clásicos como del estaño y del volframio, como para los modernos, entre ellos la del nobio y la del tántalo. Por esta razón, se efectuaron dos ensayos de aluviones, uno en propio Barbanza y otro en un cauce antiguo en el Balao.

El primer demuestre de aluviones, que es el denominado del Barbanza, corresponde a una zona de su cauce, a 1,700 m al noroeste de la Aldea de Piñeiro, en la cual se practicaron 30 pocillos, con profundidades máximas de 3.6 m y un total de 56 m. En los pocillos, se observaron tres procesos de sedimentación sucesivos siendo el único mineralizador el correspondiente a la formación inferior con espesor de unos decímetros, a la cual quizá puede haber pasado algo de su contenido rico de los dos procesos posteriores como consecuencia de su densidad mayor. La superficie reconocida es de unos 6,000 m^2 y en zona próxima a filones mineralizados, habiéndose limitado esta zona tanto en aguas abajo como arriba, por no haberse encontrado mineral en los cinco pocillos siguientes en uno y otro sentido. De estos pocillos sólo se concentraron con batea, las muestras de la formación inferior, lavándose 24 m^3 que dieron un concentrado de 55 Kg o sea algo más de 2 Km^3. El tratamiento posterior de estas tierras fue análogo al descrito para el filón "Forestal". La fracción densa dio una importante riqueza en estaño, pero en pentaóxidos sólo se llegó a alcanzar un 3.9% en la subfracción a 4 amperios que es la más rica. El valor de los dos pentaóxidos en el concentrado obtenido con batea es de 0.1 g/kg lo que corresponde en las tierras de la formación inferior a una riqueza de 0.0001 g/kg.

El segundo demuestre de aluviones, es el denominado de Xeniña, en una zona perteneciente a las aguas del Arroyo Balao, a 600 m al suroeste de la Aldea de Escobias. Se hicieron 30 pozos distribuidos en una superficie de 22,000 m^2, en los cuales también se identificaron los tres procesos de sedimentación, y la mineralización en el inferior. Los pocillos tuvieron una profundidad máxima de 2.7 con un total de 32 m. Las tierras obtenidas de la formación inferior fueron 26 m^3, que dieron un concentrado en batea de 53 Kg. De este concentrado en batea se obtuvo en la mesa una fracción densa de casi el 2%, en la que la parte no magnética contiene 69.2% de estaño y la magnética a 5 amperios 15.6% de la suma de ambos pentaóxidos de Nb y Ta. En el concentrado de batea se ha determinado una ley de 0.25 g/kg que corresponde al todo uno de la formación inferior de los pocillos de 0.00025 g/kg.

En la zona reconocida de Barbanza, teniendo en cuenta que el espesor de la formación inferior es de 0.3 m como término medio la reserva se puede suponer de 360 Kg de pentaóxidos, y la correspondiente a la zona de Xeniña de 3,400 Kg; no obstante la explotación puede ser interesante si se orienta hacia el estaño y se considera la de estos dos elementos como un subproducto. Según cálculos que hemos efectuado de los diversos aluviones mineralizados en toda la zona reservada por el Estado, la cantidad de suma de pentaóxidos de niobio y tántalo puede llegar a ser del orden de 20,000 Kg.

En las playas se efectuaron estudios de posibles reservas, las cuales son inferiores a las de los aluviones.

CONSIDERACIONES GEOQUÍMICAS DE LAS NIOBITAS

Un punto que consideramos de interés geoquímico, es la determinación precisa de la relación atómica Nb/Ta. Para ello es necesario una técnica que detecte cuantitativamente ambos elementos con facilidad y hemos comprobado que la que mejor resultado nos dio, ha consistido en la separación conjunta de ambos pentaóxidos y la valoración de la relación entre ambos por técnica espectroquímica deflagrante en arco, con la cual hemos podido efectuar valoraciones de pentaóxidos con precisiones del orden del 1%, se ha recurrido a las líneas 3116,365 A° de Nb y 3115,857 A° de Ta que tienen la misma densidad de ennegrecimiento cuando ambos pentaóxidos están en relación de 37/13 en peso.

De las 101 valoraciones de pentaóxidos se ha sacado a la medida aritmética, de la relación del número de átomos de dichos elementos, y hemos llegado a que en la formación de Boiro están en la de 14.7 ± 0.3. En el cuadro, con los valores de los investigadores más acreditados en esta rama de la geoquímica, se puede apreciar que este valor es concordante con el primitivo de Goldsmidt y con el publicado recientemente por Suess y Urey.

Atomos Si $= 10^6$

Autor	Año	Nb	Ta	Relación atómica $\frac{Nb}{Ta}$
Goldsmidt	1937	6.9	0.40	17.2
Brown	1949	0.9	0.31	2.9
Urey	1954	0.8	0.32	2.5
Suess y Urey	1956	1.00	0.065	15.4
L. de Azcona	1955	—	—	14.7

Se efectuaron varias valoraciones de uranio, en los concentrados más ricos y en los ejemplares seleccionados de niobitas puras, en los primeros el contenido medio en uranio es de 0.06%, y en los segundos 0.09%. Con el fin de situar este uranio, se hicieron preparaciones nucleares, para obtener las correspondientes impresiones fotográficas y se ha comprobado que menos de la octava parte del uranio está formando concentraciones y el resto de los átomos forman parte de las celdillas elementales de las niobitas.

CONCLUSIONES

1a.—Se ha comprobado por técnicas de prospección geoquímica la existencia en la zona de Boiro, de una cantidad importante de niobitas, tanto en los arenales de las playas, como en los aluviones y los diques pegmatíticos, éstos con irregularidades grandes en la mineralización.

2a.—En sitios no citados anteriormente, se ha evidenciado que los diques pegmáticos complejos tienen buenos ejemplares de berilos y espodumenas.

3a.—La relación en átomos del niobio a los del tántalo, en la zona de Boiro, es de 14.7 ± 0.3.

4a.—La riqueza en uranio de estas niobitas, es como término medio de 0.08%.

COMPARISON OF SOIL ANALYSIS WITH OTHER PROSPECTING METHODS AT A SMALL HIGH-GRADE COPPER LODE *

L. C. HUFF **

ABSTRACT

At the Malachite mine, in Jefferson County, Colorado, the two ore bodies are concentrations of pyrrhotite and chalcopyrite in a mineralized fracture zone which parallels the banding of gneiss and schist country rock. Limonite, gossan, and some rock fragments coated with malachite guided early prospectors to one ore body which was mined over 40 years ago. In 1940, geophysical studies lead to the discovery of another ore body in places less than 60 feet beneath the land surface.

Recent geologic work shows the scarcity of surface indications of the new ore body. Surface indications are obscured by gossan and soil derived from a branch of the fracture zone exposed farther uphill. The copper content of the soil above the new ore body and in three other places along the fracture zone exceeds 1,000 parts per million. Abnormal concentrations of copper in the soil are detectable for 2,600 feet along the fracture zone and locally as much as 900 feet down hill. In this area soil analysis seems to be of particular value in identifying broad areas of mineralization, and the geophysical methods of particular value in closely outlining smaller prospecting targets. A combination of geologic, geophysical, and geochemical methods should be advantageous in the search for similar deposits.

INTRODUCTION

Purpose of investigation. There is a growing need for comparisons of prospecting methods. Geochemical and other prospecting techniques have been developed and greatly improved within the past several years. Of necessity, many of the new prospecting techniques are complicated and require highly specialized training to interpret their results. Because of these complications the advantages and disadvantages of alternative prospecting techniques are becoming more and more difficult to evaluate. Some comparison of the new prospecting techniques can be obtained by analysing the "case histories" of ore discoveries and by testing several techniques on a single ore body. The

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"case history" of an ore body discovered by geophysical methods at the Malachite mine in Jefferson County, Colorado, is summarized and the geophysical data is compared here with new geologic and geochemical prospecting data.

THE MALACHITE MINE

The Malachite mine is in sec. 30, T. 4 S., R. 70 W., in the Front Range of the Rocky Mountains about 12 miles west of Denver, Colorado. As shown by the Denver Mountain Parks topographic quadrangle the mine is on the north side of Bear Creek Canyon near the town of Idledale, at an altitude of 7,500 feet. Exposures of bed rock are numerous near the mine but most of the land surface is covered with a thin rocky soil. Some of the area is grassland but most of it is covered by widely spaced pine trees and brushy thickets.

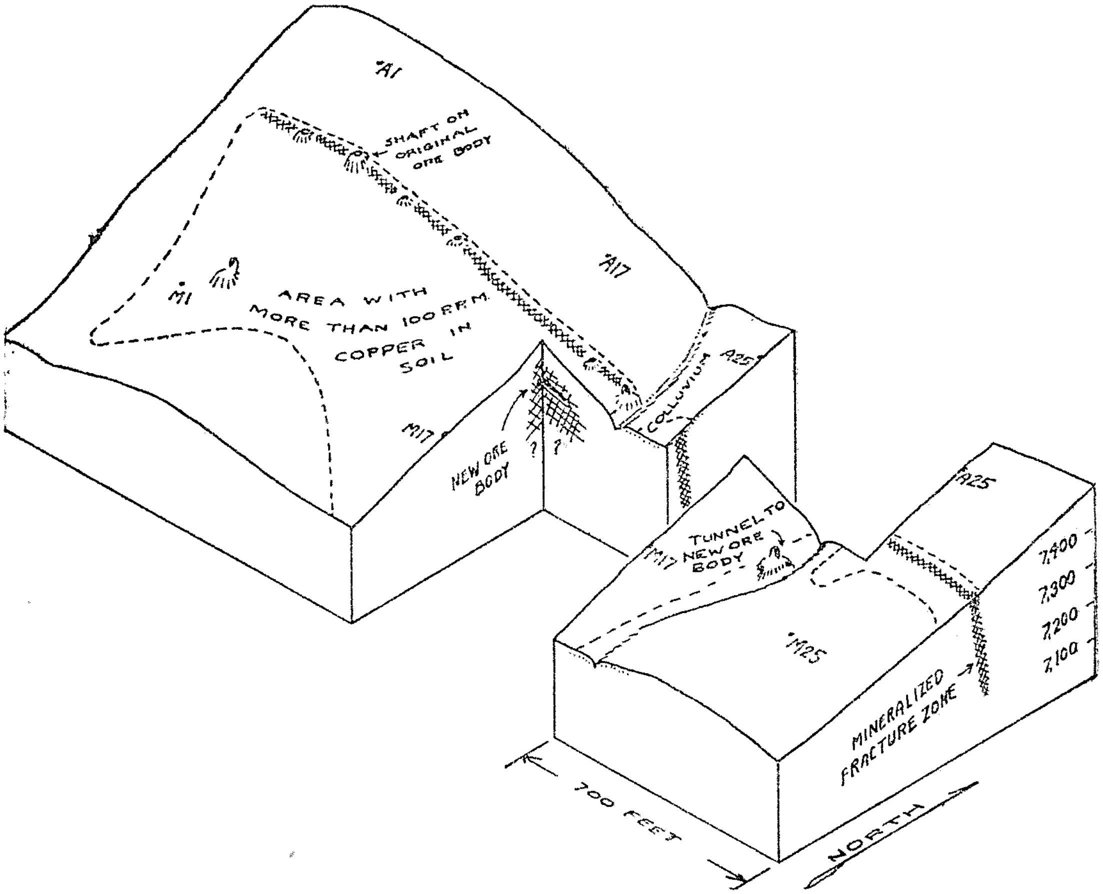

Fig. 1. Block diagram showing general relations of ore bodies and the mineralized zone in the Malachite mine area, and the location of cross sections.

The mine has produced ore valued at more than $ 79,000. The original or west ore body (Fig. 1) was discovered about 1866 (Morehouse, 1950, p. 20), probably by tracing float of oxidized copper ore to its source at the outcrop.

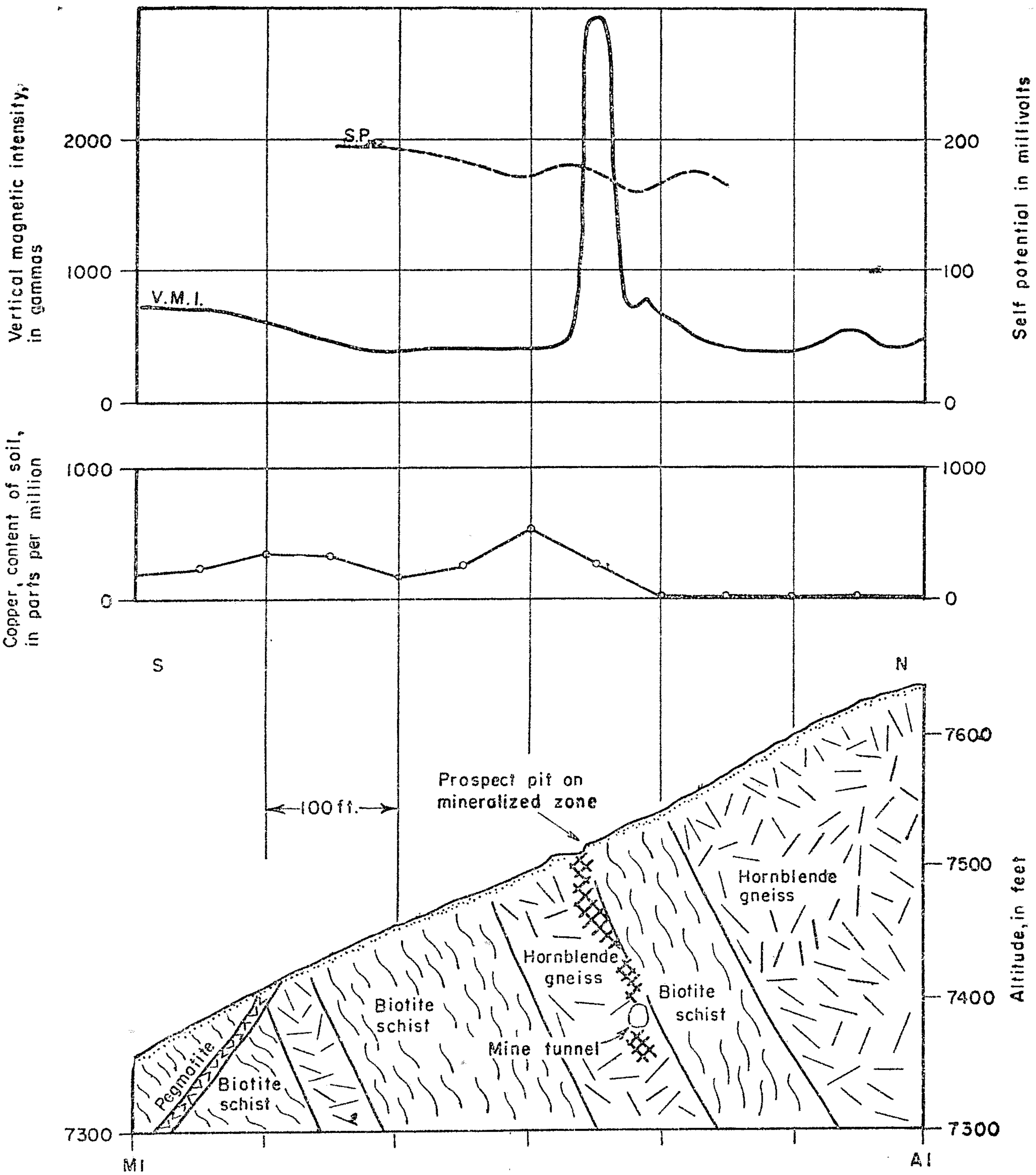

Fig. 2. Comparison of geologic, geochemical, and geophysical data along section A1-M1 near the western ore body.

Lindgren (1908) states that partly oxidized copper ore valued at $ 35,000 was mined from a shaft in this west ore body.

The east ore body was discovered by geophysical methods. Self-potential surveys, made by a student class of the Colorado School of Mines in 1938 and 1939, revealed a prominent anomaly east of known ore and encouraged the mine owner to drive a short tunnel which penetrated a new ore body in 1940. Ore shipped from this ore body from September 1940 to March 1941, contained $ 44,000 worth of copper, gold, and silver (Heiland, Tripp, and Wantland, 1945).

Geophysical studies have revealed marked vertical magnetic, resistivity, equipotential-line and self-potential anomalies near the new ore body. Thus, several geophysical techniques are capable of detecting this ore body, which is close to the land surface but which has no obvious indication of its presence.

Geophysical investigations made in the Malachite area by the Colorado School of Mines have been described (Heiland, Tripp, and Wantland, 1945). The geological and geochemical data given here compliment the geophysical data available and permit a comparison of prospecting techniques as guides to this new ore body. A brief description of the geologic setting of the mine is essential to evaluating the prospecting guides.

GEOLOGIC SETTING

The famous Central City mining district is about 15 miles west of the Malachite mine but there are no other mines or prospects in the immediate vicinity. Precambrian metamorphic rocks are the country rocks of the mine area. Sedimentary rocks of Paleozoic and Mesozoic form the foot hills of the Front Range about 3 miles east of the mine and late Precambrian granitic intrusions are located to the west and north.

Bedrock.—Quartz-biotite schist and hornblende gneiss constitute the bedrock at the mine. Alternating layers of these rocks from 50 to several hundred feet in thickness have an east-west strike and a dip to the south of from 60° to 90°. The banding and foliation of these rocks parallels the layering. The quartz-biotite Schist probably is metamorphosed sandstone and the hornblende gneiss may be metamorphosed quartz diorite of flows or sills (Lovering and Goddard, 1950, p. 20). The schist and gneiss are cut by numerous pegmatite dikes which trend in a northeasterly direction. The hornblende gneiss and the pegmatite are particularly resistant to erosion and form most of the outcrops near the mine.

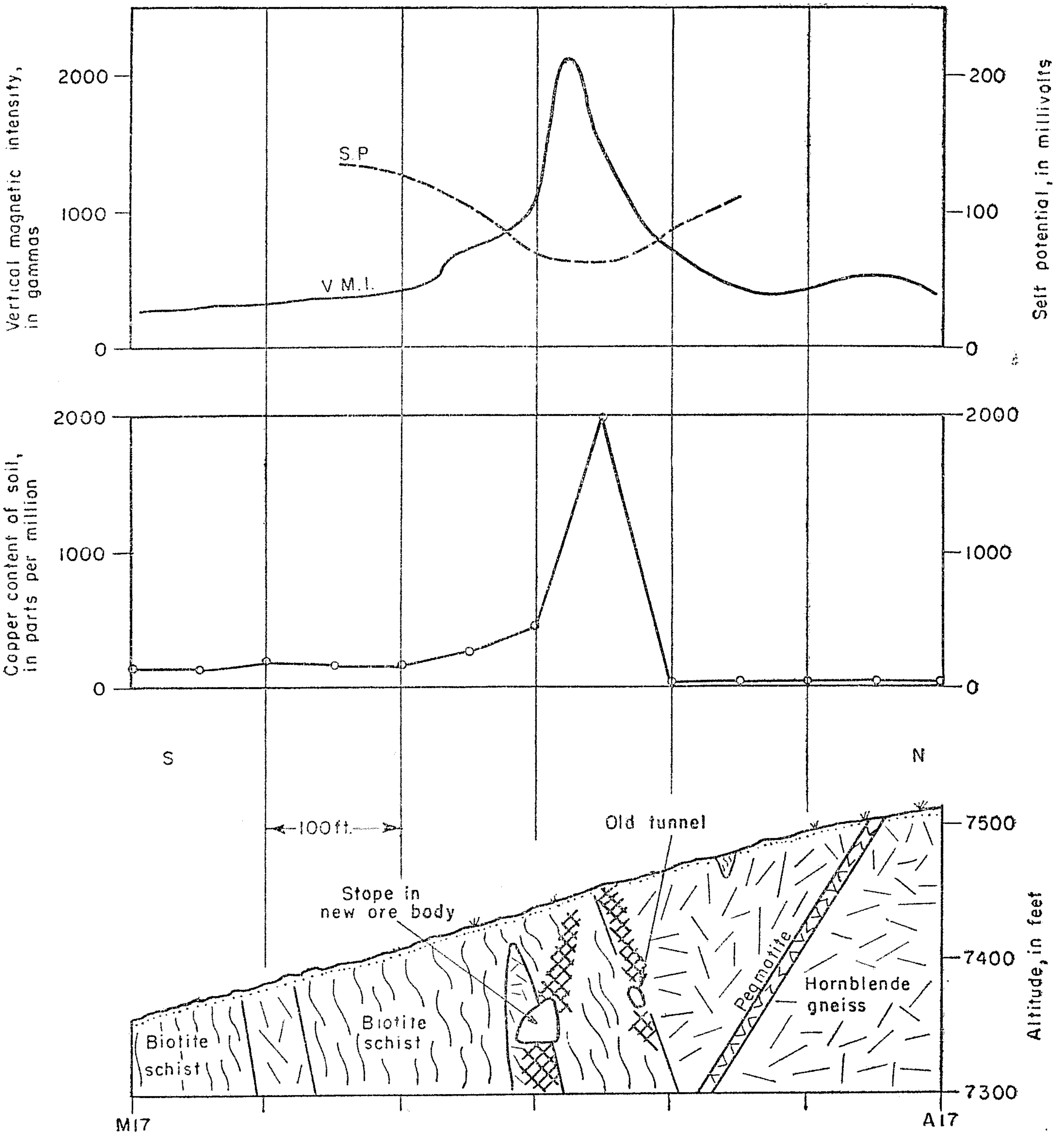

Fig. 3. Comparison of geologic, geochemical, and geophysical data along section A17-M17 through ore body discovered in 1940.

Surficial materials.—The surficial materials near the mine include colluvium and soil. The colluvium, which is a mixture of silt, sand, and gravel, borders several small creeks near the mine. It has a maximum thickness of about 20 feet. The soil is much more extensive and covers most of the land surface in the area mapped. The soil is thin and rocky with recognizable but poorly defined soil horizons. The soil horizons consist of a dark-brown to black "A" horizon with abundant organic material, and a light-brown "B" horizon containing less organic material but with more silt and clay. The "C" horizon, or weathered and softened bedrock, is at a depth of only 2 to 3 feet.

The soil properties are closely related to the local bedrock. In the "B" horizon the rock fragments are similar in composition to the bedrock immediately underneath and have apparently been transported only a few feet. In the "A" horizon or surface soil the pebbles are hard, subrounded fragments chiefly of pegmatite or hornblende gneiss. Fragments of these rocks become more numerous when traced uphill toward their outcrop. The relationships show that the soil is in part truly residual and in part derived from the hillside above. The local origin of the soil is of importance in interpreting both geologic and geochemical guides to ore.

Geologic structure.—The mine is in a mineralized fracture zone 50 to 100 feet wide that has been traced about 2,600 feet by means of outcrops, float, and scattered prospect pits (Fig. 1). Where exposures are lacking, the north margin of the fracture zone was mapped as the uphill limit of iron-stained fragments and gossan. The south, or downhill, margin could be mapped only approximately because of slope wash. Near the west ore body the fracture zone is slightly irregular (Fig. 2) but it does not branch or split. Elsewhere there is some local branching or splitting of the fracture zone. The east ore body is in a branch of the zone which thins and pinches upward (Fig. 3). The only surface indications of mineralization along this section are on a separate branch of the fracture zone. Several hundred feet east of the east ore body (Fig. 4) the northern branch crops out but there is no evidence of the southern branch. Thus, the branch in which the new ore body is located pinches out both upward and eastward.

Ore bodies.—The west ore body was an irregular pipelike body which cropped out at the surface (Fig. 2). The east ore body was about 350 feet long from east to west, and averaged about 60 feet in width. It was highly irregular, particularly in the plane of the ore zone. Pipelike projections of ore extended as much as 60 feet above the tunnel level and within 60 feet of the land surface.

The mineralogy of the two principal ore bodies is similar (Morehouse, 1950). Chalcopyrite and pyrrhotite are abundant, but galena and dark-brown

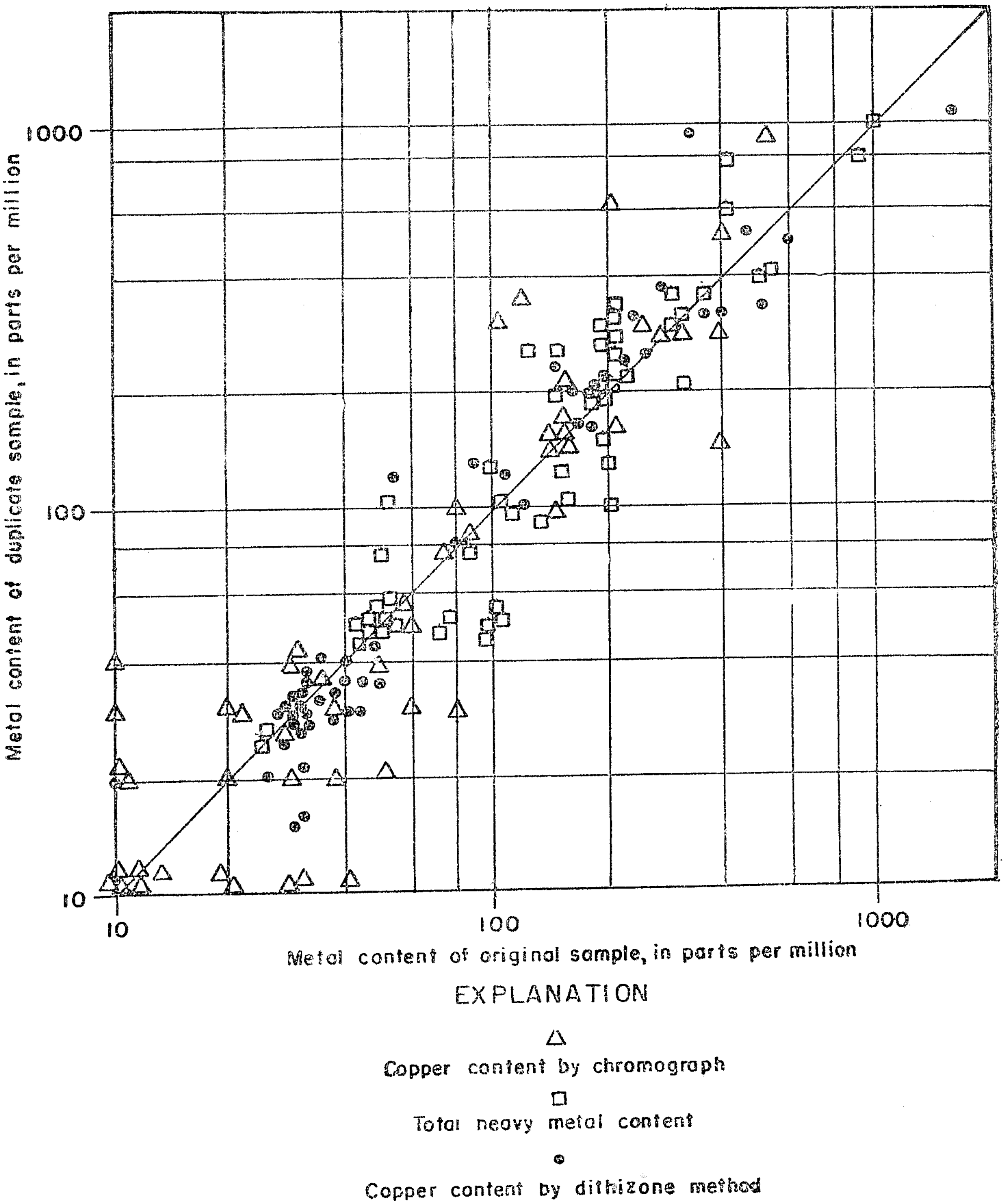

Fig. 5. Scatter diagram showing reproducability of soil sampling and analysis.

sphalerite are also present. The ore contains some gold and silver. No cobalt or nickel minerals have been identified and there is very little vein quartz. Although in some places the ore and rock minerals are intergrown in a manner suggesting simultaneous crystallization, in most places the ore minerals fill fractures and interstices between fragments of the country rock.

The ore deposits may be magmatic (Lindgren, 1908; Boyd, 1934) or they may be hydrothermal (Morehouse, 1950) in origin. They are probably Precambrian in age (Lindgren, 1908; Boyd, 1934; Lovering and Goddard, 1950), but may be Tertiary (Morehouse, 1950). Geologic mapping showed no close relationship to the hornblende gneiss, the probable parent magma of magmatic ore, but did disclose fracture control of the ore deposition. This fracture control, plus the association of copper with lead and zinc rather than with cobalt and nickel, lead the writer to consider the ore hydrothermal.

GEOCHEMICAL PROSPECTING

The geochemical study of the Malachite mine area by the U. S. Geological Survey started in 1948. Encouraged bv this work several students of the Colorado School of Mines made geochemical studies of the area. Horino (1950)

TABLE 1

RANGE OF ORE-METAL CONTENT OF SAMPLES OF PLANTS, WATER, SEDIMENT, AND SOIL COLLECTED AT VARIOUS DISTANCES FROM ORE

(Analyst Harold Bloom, U. S. Geological Survey)

Material	No. of samples	Type of analysis	Range (ppm)	Ratio *
Plants	14	Copper	8 to 21	3
Water	10	Total heavy metal	0.01 to 0.30	30
Sediment	10	Total heavy metal	75 to 250	3
Soil, shallow; "A" horizon	12	Copper	50 to 5,300	106
Soil, one-half to 1 foot deep; "B" horizon	12	Copper	60 to 6,500	108
Weathered rock, 1 to 2 feet deep; "C" horizon	12	Copper	50 to 15,000	300

* Highest value/lowest value.

demonstrated by spectrographic analysis the presence in the mineralized rock of trace amount of nickel and cobalt which had not previously been identified. Pierce and Dias (1950) measured the total heavy-metal content of soil samples from along three traverses across the mineralized zone and found marked anomalies above the new ore body. Some of the U. S. Geological Survey results, demonstrating a marked copper anomaly in soil above the ore, have been reported previously (Huff, 1952).

Choice of methods.—Preliminary geochemical studies were used to try several geochemical techniques. The preliminary studies were directed chiefly towards finding what kinds of samples and analysis yielded the widest range of metal content. Samples of water, alluvium, plants, rock, and soil were collected both near ore and, to indicate background, at a considerable distance from ore. The range in heavy-metal content of alluvial sediment and of pine needles and twigs proved to be comparatively small (Table 1). Water sampling was found unsuitable because of scarcity of water in the mine area. Weathered rock, although yielding the greatest range in heavy-metal content, was found impracticable for prospecting because of difficulties of collecting numerous samples.

TABLE 2

RANGE OF METAL CONTENT IN SUITE OF SOIL SAMPLES COLLECTED ALONG ONE TRAVERSE CROSSING THE ORE ZONE

(Analysts Harold Bloom, Victor Kling, A. P. Marranzino and J. P. Schuch; U. S. Geological Survey)

Metal	Type of analysis	Range (ppm)	Ratio *
Total heavy metal	Field	50 to 2,000	40
Copper	Laboratory	50 to 5,300	106
Copper	*Field*	35 to 5,500	157
Zinc	Laboratory	80 to 500	62
Lead	Laboratory	25 to 70	28
Cobalt	Field	10 to 20	2
Nickel	Field	0	—
Silver	Field	0.4 to 12	30

* Highest value/lowest value.

The use of soil for geochemical prospecting in the Malachite area has several advantages. Soil samples are easy to collect. The soil exhibits a particularly high range in metal content (Table 1). Soil near ore contains less than 50 ppm, a total range of over 100 fold. Shallow soil yields a wider anomaly than the deeper soil or the weathered rock (Huff, 1952). Additional studies (Table 2) show that copper has a greater tota range than any other ore metal in the soil.

Analyses of various size fractions of a soil sample collected downhill from the ore zone (Table 3) indicate that copper from the ore tends to concentrate in the finest particles of the soil. These preliminary studies indicated that copper analysis of a fine fraction of the surface soil could provide data for a geochemical map of the Malachite area.

TABLE 3

COPPER CONTENT OF VARIOUS SIZE FRACTIONS OF A SOIL SAMPLE COLLECTED 150 FEET DOWNHILL FROM ORE ZONE

(Analyst J. H. McCarthy, U. S. Geological Survey)

Mesh no.	Percent by weight	Copper (ppm)
5–10	7	160
10–18	7	170
18–35	12	175
35–60	26	245
60–120	24	365
120–520		
less than 250	8	430

Several analytical methods are available for measuring the copper content of soil which were devised especially for geochemical prospecting. The total-heavy-metal method (Huff, 1951), the chromograph method for copper (Lakin, Almond, and Ward, 1952, p. 16) and the dithizone test for copper (Lakin, Almond, and Ward, 1952, p. 25) are all field-type methods simplified to expedite the analysis of large numbers of samples commonly used in a geochemical prospecting study. Comparison with laboratory analyses (Huff, 1952) shows that all three of these field-type methods will detect most of the copper present in typical soil samples from the Malachite mine area.

Published comparisons give little information concerning ability to repeat results. To provide such information an additional study was made based upon 50 samples collected in duplicate. For this study samples were collected at 50-feet intervals along four traverses across the ore zone. The original sample and its duplicate were not taken from exactly the same place but were separated by several feet to simulate conditions corresponding to actual repetition of the surveying and sampling process. All of the samples were analyzed by the three different methods mentioned and the above results are given as a scatter diagram (Fig. 5).

The scatter diagram indicates that significant differences exist in reproducability of the three methods. Because all the results are subject to the same sampling error it is believed that these differences result chiefly from differences in analytical precision for the three methods. The results obtained with the dithizone test for copper show the least scatter and, therefore, the highest reproducability. For this reason the dithizone method was used in preparing the maps and profiles showing copper concentration in the soil that will be described next.

Distribution of copper-rich soil.—The distribution of soil containing abnormal amounts of copper was determined from samples collected on a grid pattern. Approximately 600 soil samples were collected at 50 —or 100— feet intervals on a rectangular grid. Then the copper content of the minus 80-mesh fraction of the soil was determined in the U. S. Geological Survey laboratory by the dithizone method. The analyses were plotted on the topographic map and contoured. The 100-ppm-copper contour is indicated on the accompanying block diagram (Fig. 1). Soil uphill and distant from the ore zone has a copper content of from 20 to 50 ppm. The soil richest in copper, which contains 1,000 ppm copper or more, occurs near the mineralized zone and particularly near prospect pits and mine workings.

The distribution of copper in the soil gives some indication of its manner of dispersion. Dispersion of copper north of the fracture zone may result either from primary dispersion of copper in the wall rock or from secondary dispersion uphill by soil formation or other secondary processes. Apparently neither of these processes were significant. because the copper content of the soil decreases abruptly uphill from the fracture zone. Downhill from the fracture zone the distribution of copper-rich soil is much more extensive and the copper contours outline lobate areas extending far downhill towards the local drainage routes. Between the east and west ore bodies the copper anomaly attains its maximum breadth and the copper content of the soil is over 100 ppm for about 900 feet downhill from the mineralized zone. It is evident that most of the dispersion of the copper during weathering and erosion is caused by soil creep and other processes which transport the copper downhill.

The close relationship between copper-rich soil and the ore bodies is of significance in prospecting. Both of the ore bodies are in areas where the copper content of the soil exceeds 1,000 ppm. Moreover both of the ore bodies are loci from which abnormal concentrations of copper diminish gradually several hundred feet downhill. These relations show that the copper content of soil can be used for prospecting in much the same manner as the distribution of iron-stained float. Some copper concentrations can be located simply by tracing copper in soil uphill to its bedrock source.

COMPARISON OF PROSPECTING TECHNIQUES

Unbiased comparisons of geologic, geophysical, and geochemical prospecting techniques are not easily attained. At some risk of over simplification, geologic, geophysical, and geochemical data are compared here on cross sections. These are given for the west ore body (Fig. 2), for the new or east ore body (Fig. 3), and for a traverse several hundred feet east of known ore (Fig. 4).

Both the known ore bodies and all of the mineralized rock lie within the fracture zone. Assuming a hydrothermal origin, this relationship simply indicates that the fractured rock formed a permeable zone favorable for the passage of hydrothermal solutions. Because of this association, the preparation of geologic maps and sections showing the fracture zone may be considered a geologic prospecting technique.

Near the west ore body (Fig. 2) all evidence would have encouraged exploration. Malachite-stained fragments of gossan are abundant and provide an obvious geologic guide to ore. The geochemical anomaly is large and the narrow, sharp, magnetic anomaly suggests a shallow ore body, which is exactly what was found and mined out years ago.

Along section A25-M25 east of the new ore body, a thin layer of colluvium and soil covers the mineralized zone (Fig. 4). There is no gossan or other visible evidence for ore. Both geophysical and geochemical data yield anomalies over the mineralogic zone. The magnetic anomaly 150 feet north of the mineralized zone bears no relationship to known copper mineralization and probably is caused by a local accumulation of magnetite in the gneiss. Here geologic and geochemical data advantageously supplement the geophysical data.

Near the east or new ore body (Fig. 3) there are two branches of the fracture zone. On the surface the location of the northern or uphill branch is easily identified by the distribution of gossan and malachite stains. There is no surface evidence of the southern branch. If the southern branch contributes any gossan to the mantle, it is completely obscured by gossan float from the mineralized zone uphill. The structural setting of the east ore body gives some indication that the exact locations of ore bodies are related to pinch outs of the fractured zone. A geologist with accurate subsurface data has some chance of predicting where within the fracture zone ore bodies may be found. However, the southern branch of the ore zone would not be apparent to a geologist lacking subsurface data.

The copper content of soil is anomalous in an area extending over the new ore body. The critical question concerning the soil data is whether the anomaly can be attributed solely to the mineralized outcrop. In other words, if this geochemical data had been available before 1940, would the geochemist have suspected the existence of a second mineralized zone? There is much room for difference of opinion here. The geochemical data would certainly favor exploration in this area; however, the ore underlies only a relatively small part of the area of copper-rich soil which presumably might be considered favorable for exploration from the geochemical data. This relation sharply illustrates one limitation of geochemical prospecting by soil analysis. A geochemical anomaly for one ore body may be obscured by the occurrence of other ore higher on the hillside.

The vertical magnetic data yield a wide, high anomaly (fig. 3). Such data certainly indicates the presence of a large magnetic body at depth and should encourage exploration, as it did in 1940.

Geologic, geophysical, and geochemical prospecting techniques yield markedly different results. Chemical methods give the most direct evidence of the presence of the ore metal. Yet, as has been shown, chemical anomalies may be complex and misleading. None of the methods will prove the presence of mineable ore or will give a complete picture by themselves. It seems evident that the best results may be obtained by the use of these prospecting techniques in combination.

At the Malachite mine the geochemical anomalies are considerably wider than the geophysical anomalies. Under such conditions soil sampling at 100-foot intervals near mines and prospects could be combined advantageously with preliminary geologic reconnaissance to eliminate broad areas of favorable ground. Then detailed geologic and geophysical investigations of the favorable area could be used to closely outline targets for drilling. Investigations made in this sequence may be the best and quickest method of prospecting for such ore deposits.

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GEOCHEMICAL PROSPECTING IN THE KHOH-DARIBA COPPER AREA, ALWAR DISTRICT, RAJASTHAN, INDIA

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and P. G. ADYALKAR * * *

ABSTRACT

The copper deposits of the Khoh-Dariba area, Rajasthan State, India, are of Precambrian age and have a hypothermal mineral association. Mineralization is controlled by high angle faults and the principal deposits are localized mainly in phyllites and subordinately in quartzites of the middle Precambrian Alwar series.

Geochemical prospecting was undertaken in conjunction with detailed geologic mapping and geophysical prospecting of the area and was started over known mineralized zones and then extended to unknown ground on geologically guided extensions from known deposits.

Samples of thin residual soils over known deposits showed significant geochemical highs, far above background values, of copper. Cobalt values proved erratic and in general low, and to bear no apparent direct relation to copper values.

Extensive sampling across extensions of faults controlling known copper mineralization disclosed interesting copper anomalies which at one point coincided with a distinct cobalt high. Exploration of this zone has been recommended.

In all cases highs of copper were found to overlap self-potential geophysical anomalies.

Work done to date warrants the statement that geologically guided geochemical prospecting should be continued in the Khoh-Dariba area.

INTRODUCTION

India has many deposits that have been sources of copper in the past but only one area is a current source of copper, supplying about 15 percent of the country's requirements of this metal. Many of these abandoned deposits, last worked one or more centuries ago, are in the state of Rajasthan, in northwestern India, and the more promising deposits are being intensively investigated by the Geological Survey of India. As a part of this programme geophysical prospecting was carried out, and more recently, geochemical prospecting has been

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started with the hope of extending known zones of mineralization and of finding new deposits.

The first copper district in which the geochemical method of prospecting was investigated was the Khoh-Dariba area in Rajasthan State, where the work was coordinated with the progress and results of geological mapping and geophysical prospecting. This work began in 1953 and is still in progress. Investigations in geochemical prospecting were started in February, 1954, when soil samples were taken over known deposits in order to determine the nature and magnitude of geochemical anomalies. With confirmation of the existance of significant geochemical highs over these known deposits soil sampling was extended across extensions of premineral faults and favourable rocks away from known deposits, and reconnaissance, sampling was done across possible mineralized faults in new areas. This paper presents the results of the geochemical investigation so far carried out.

The Khoh-Dariba copper area is in Alwar District, northwestern Rajasthan, about 125 miles south-southwest of Delhi, and about 40 miles south of the city of Alwar (Fig. 1). The most important copper deposits of this area are near the abandoned mine village of Dariba, about 2 miles south of Khoh village. The topography is characterized by steep sided hills and ridges which rise to several hundred feet above bordering flat valleys, the floors of which are about 1,200 feet above sea level. Uniform summit levels of the highest hills and ridges, at an altitude of about 2,000 feet, apparently are remnants of an old extensive erosion surface whose age is not certain. The climate is semi-arid, with an average annual rainfall of 22 inches, nearly all of which falls between the months of June and September. The rainfall occurs mainly in the form of torrential downpours of short duration; consequently, runoff is very rapid and stream beds are dry throughout most of the year. Minimum winter temperatures occasionally fall to 35 degrees Fahrenheit, and maximum temperatures of about 115 degrees are recorded during the pre-monsoon hot season of April and May, while the diurnal temperature fluctuation is as much as 40 degrees.

The copper deposits probably have long been known but the discovery and early history of mining is obscure. The presence of numerous shafts, pits, underground workings, dumps of waste rocks and slag, and the ruins of a mine village testify to a flourishing mining and smelting industry that must have extended over a period of many years. It is generally believed that mining ceased early in the 19th century, though for what reasons it is not known. There were subsequent efforts to re-open the mines, the latest during a period of three years from 1943 to 1946, but all of these apparently failed. To judge by the amount of copper slag present, estimated to be between 5,000 and 6,000

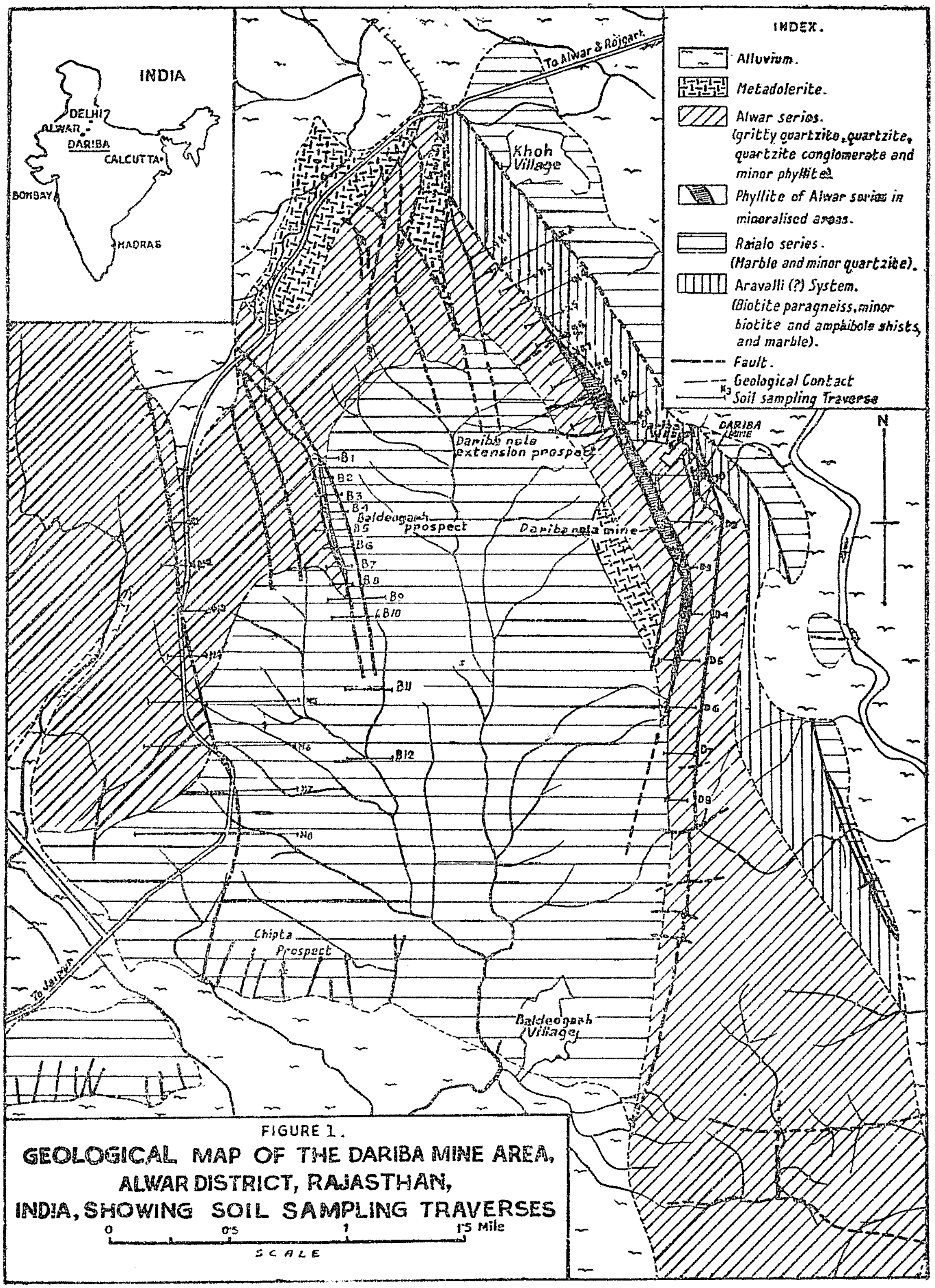


FIGURE 1.

GEOLOGICAL MAP OF THE DARIBA MINE AREA, ALWAR DISTRICT, RAJASTHAN, INDIA, SHOWING SOIL SAMPLING TRAVERSES tons, and by the number and size of the old mine working, past production could not have been great.

ACKNOWLEDGEMENTS

Analyses of soil samples collected by the writers were done by P. D. Malhotra, A. N. Chowdhury, and S. C. Chakravarty, chemists. The initial work was done under the supervision of F. N. Ward, chemist, United States Geological Survey, whom the writers thank for his many valuable suggestions in the collection and handling of soil samples.

The geology of the area was mapped by B. Srikantan, P. G. Adyalkar and C. J. R. Varaprasada Rao, under the supervision of John A. Straczek. We deeply appreciate the personal cooperation and keen interest in the project given by Dr. M. S. Krishnan, former Director, and Mr. V. P. Sondhi, Director, Geological Survey of India.

GENERAL GEOLOGY

Precambrian metamorphosed sedimentary rocks and very minor metamorphosed igneous rocks underlie the whole of the Khoh-Dariba area. These rocks have been classified into three major groups, as shown in the following geological column:

Recent and subrecent		— Alluvium
Precambrian		— Metadolerite
Delhi system — — —	Alwar series	— Quartzite, gritty and arkosic quartzite, phyllite and quartzite conglomerate.
	— — — Unconformity — — —	
Aravalli (?) system (Precambrian)	Raialo series	— Dolomite marble with subordinate intercalated quartzites and phyllites.
	— — Unconformity — — —	
	Older Aravalli group — —	— Biotite gneiss, biotite schist, marble, biotite-talc schist, and amphibole schist.

The oldest rocks, the Older Aravalli group, are mainly biotite gneiss, probably a paragneiss, which flanks some of the ridges of the area or occur in the valleys. The rocks of the Raialo series, principally dolomite marble, occupy the broad valleys, and the resistant rocks of the Alwar series form the highest ridges and hills.

The rocks have undergone strong deformation which has produced overturned isoclinal folds, followed by complex faulting which localizes the copper mineralization. The regional structural trend is northerly and the rocks have a general westerly dip at moderate to steep angles. The ridge forming Alwar rocks apparently form isoclinal synclines on the older rocks of the Aravalli system, but most of these folds have been disrupted by major, steeply dipping, northerly trending faults.

ROCK WEATHERING, SOILS AND ALLUVIUM

Rock weathering in this part of India is not intensive. In general, soils are thin and immature, and alluvium is thickly developed only near the major stream courses. Both soils and alluvium overlie comparatively fresh rock, and the residual and alluvial soils that flank ridges contain numerous angular fragments of relatively unweathered rock. The soils are low in organic matter and are not conspicuously zoned.

COPPER DEPOSITS

There are four copper mines and prospects in the Khoh-Dariba area, each of which is marked by old workings. These are the Dariba, and the nearby Dariba nala mines, which were evidently the chief producers of copper in the past, and the Baldeogarh and Chipta prospects from which only small amounts of ore appears to have been mined (Fig. 1). All of these deposits, with the exception of the Chipta prospect, are localized along northerly trending fault zones in rocks of the Alwar series, of which phyllite seems to be the most favored host. The Chipta deposit is in the marbles and intercalated quartzites and phyllites of the Raialo series and is the only deposit in which copper mineralization is associated with a quartz vein.

The only accessible workings are those of the Dariba mine where primary mineralization is seen to consist of small, irregular and discontinuous veins and stringers of sulphides in phyllite, and of disseminations of sulphides in quartzites with which the phyllites are intercalated. Mineralization is controlled by steep pre-mineral faults which offset moderately dipping phyllites and quartzites.

Minerals in the Dariba deposit include chalcopyrite with associated cubanite, pyrrhotite, and pyrite. Very minor quartz is the only introduced gangue mineral. The wall rocks in the mineralized zone are locally altered to a peculiar porphyroblastic biotite rock containing roundish porphyroblasts of microline. The most intense alternation appears to be localized along the ore shoot outlined by an old stope.

The Dariba ore body has an axial length of about 600 feet, a height of about 150 feet and a width ranging up 35 feet. The ore shoot, which has an apparent southward plunge of about 20 degrees, apparently does not reach the surface, which is an interesting consideration from the standpoint of geochemical prospecting. The mineralized zones of the other deposits range in length from 150 feet to about 1,000 feet, as outlined by surface workings.

METAL CONTENT OF ORE AND ALTERATION ROCK

The semiquantitative content of copper, nickel, cobalt, and arsenic in unoxidized ore and "spotted" biotite alteration rock from the underground workings of the Dariba mine was determined (Table 1).

TABLE 1

METAL CONTENT OF ORE AND ALTERATION ROCK

Sample number		Description	Metal content (ppm)			
			Cu	Ni	Co	As
Gd	A	Ore, with visible chalcopyrite, pyrrhotie and pyrite.	>4,000	600	500	25
	B	Ore, with much chalcopyrite, and little pyrrhotite.	>4,000	75	75	25
	C	"Spotted" biotite Alteration rock; visible chalcopyrite.	2,500	50	20	25

Nickel and cobalt in ore and alteration rock appear to be related to the amount of pyrrhotite present, and not to the copper content. Arsenic minerals apparently are not present. In addition to the above elements traces of lead and zinc were found to be present in the ore. Copper, and perhaps nickel and cobalt, appear therefore to be the only metallic elements of practical interest from the standpoint of sampling and analysis of soils and surface rocks in geochemical prospecting.

OXIDATION AND ENRICHMENT

Oxidation evidently extends as much as 40 feet below the surface but there is no evidence of the development of ore bodies of secondary enrichment. The oxidation products consist mainly of very minor green copper carbonate and of red to reddish-brown limonite.

GEOCHEMICAL PROSPECTING

INTRODUCTION

Investigation of the technique of geochemical prospecting in an old and abandoned mineral district such as the Khoh-Dariba area has the disadvantage that few zones of mineralization are readily accessible and scanty data on the grade, nature and extent of primary mineralization are available. Even more important is the fact that the surface in the vicinity of such deposits is generally strewn with mineralized waste rock and soils tend to be contamined. Such a condition is apparent in parts of the Khoh-Dariba area. Yet, the nature and range of geochemical anomalies over known zones of mineralization should be determined, if possible, in order that anomalies over new zones be appraised with greater confidence. This is particularly true in India where geochemical prospecting is a relatively new field of study.

To avoid the effects of possible contamination about mines and prospects surface rocks can be sampled instead of soil, as was done by Straczek in the Zawar zinc-lead area of Rajasthan. However, in the Khoh-Dariba area rock sampling was not feasible because outcrops are not always sufficiently closely spaced, and it was not practicable to dig sample pits down to bedrock. Consequently, for the preliminary sampling, it was decided to take samples at various depths across known mineralized zones in order to assess the effects of surface contamination; and to compare these results with those obtained by sampling of soils across extensions of lacalizing fault zones away from the old mines, workings and dumps.

SAMPLING PROCEDURE

Soil samples were collected from arbitrarily determined regular intervals along lines oriented across the strike of known or inferred mineralized zones, as established by geological mapping. The earlier lines followed those located with transit and tape by the geophysical prospecting party. Lines outside the area covered by the geophysical party were surveyed with Brunton compass and tape. All the lines were located on areal photographs, and those in the Dariba and Dariba nala mine area were plotted on a large scale geologic and topographic map.

Several ounces of soil were collected from each station at a depth of about 6 inches, and where the possibility of surface contamination from mine debris was suspected and a check was desired, samples were taken from a greater depth. At first picks were tried for the digging of the samples. These were soon replaced by pointed steel bars about four feet in length which were found much more satisfactory in the hard-packed rock-strewn soils.

The samples were screened through a 5 mesh, followed by a 20-mesh product was placed in new aluminium screw-top containers. These containers proved unsatisfactory as they were easily dented and the lids often jammed. Now all soil samples are placed in alkathene plastic bags, which are either heat-sealed in the field or securely tied with a string.

For each sample the color of the soil, the type of rock fragments in the soil, and the distance to the nearest exposure of bedrock and to mine dumps and mine workings was recorded.

A part of the soil samples on the first sample line in the Dariba mine area were spaced as closely as 10 feet but subsequent samples were spaced 25 feet apart, and still others at 50 feet.

ANALYTICAL METHODS

The proven analytical methods in current use by the United States Geological Survey where adopted and no research on the limits or limitations of these and other methods for conditions in India have yet been made. Such research in planned for the near future when the geochemical laboratory is expanded and better equipped.

In the laboratory the soil samples were screened through an 80-mesh stainless steel wire screen and a fraction selected for analysis. For the determination of copper the nitric acid extraction method described by Bloom and Crowe (1953), an aqueous colorimetric technique utilizing dithizone as the analytical reagent, was used. The method has the advantage of being relatively simple and rapid and although only readily soluble copper is extracted apparently gives adequate results for the purpose of geochemical prospecting. However, no great significance, can be attached to the absolute values of individual samples as the results are only semiquantitative.

For cobalt the method described by Almond (1953) was used. Nickel was determined by the standard laboratory colorimeter method. Arsenic was estimated by a modified Gutzeit method given by Almond (1953).

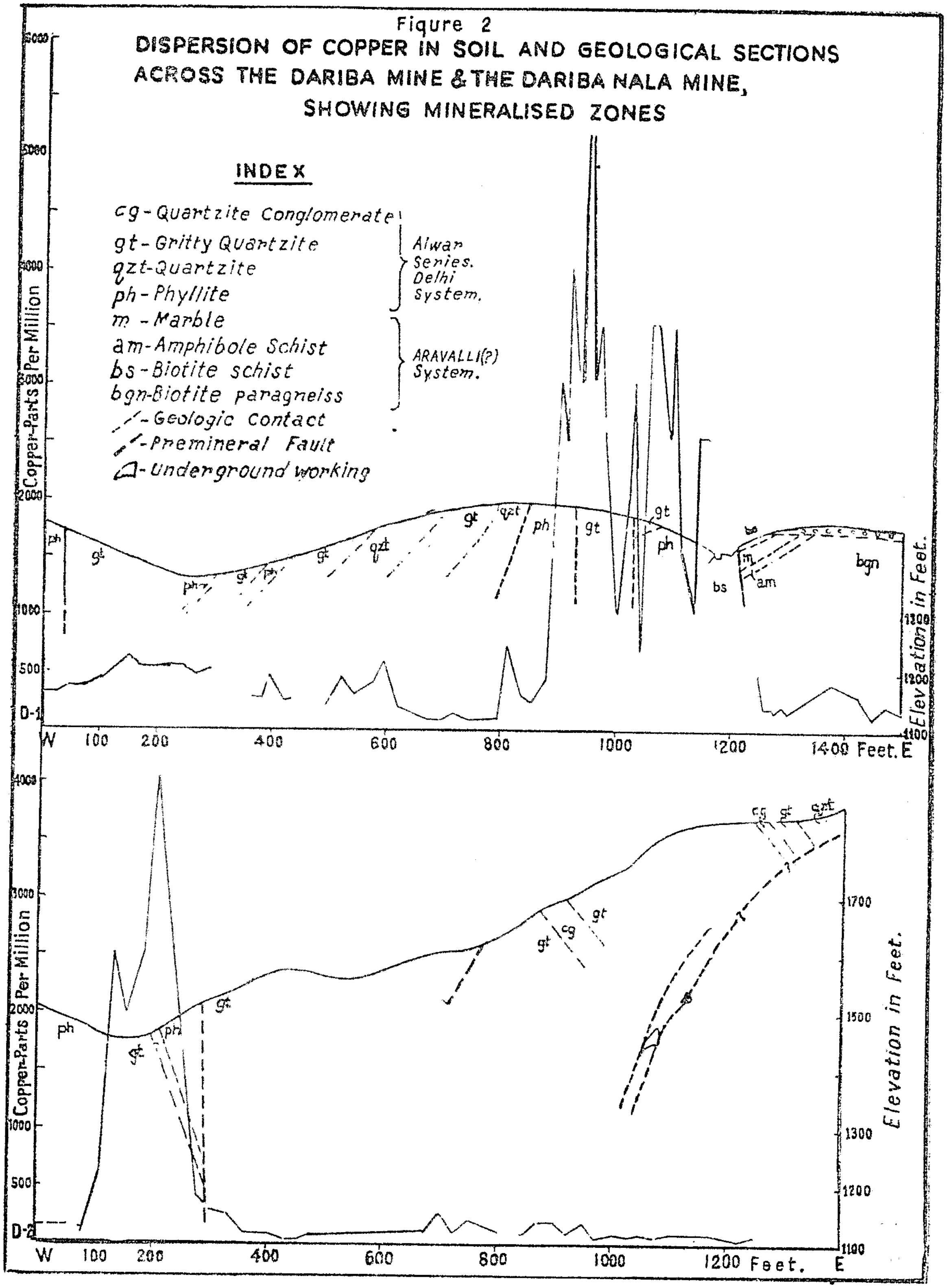


Figure 2

DISPERSION OF COPPER IN SOIL AND GEOLOGICAL SECTIONS ACROSS THE DARIBA MINE & THE DARIBA NALA MINE, SHOWING MINERALISED ZONES

RESULTS

Because the soil cover in the vicinity of the known deposits is thin it was thought that geochemical anomalies might reflect rather closely the relatively narrow mineralized zones. This condition actually determined the selected spacing of the early sampling, whereas the trend of the deposits under study determined the orientation of the sample lines. Most of the known mineralized zones are localized by faults that parallel the principal ridges of the area or follow faults in small valleys that are transverse to these ridges. Most lines of samples therefore trend across the slope of the ground and across valley bottoms. The ends of the sample lines were generally determined by exposures of quartzite or quartzite conglomerate which form excellent and extensive outcrops and hold up the upper parts of the ridges. In places these resistant beds, which are not known to be mineralized anywhere in the area, crop out well down the ridge flanks. It was assumed that any mineralization in these rocks would be picked up in the soil samples on the slopes below.

BACKGROUND LEVELS

Background lewels of copper were determined in soil samples collected at three points away from known copper deposits. All three samples — one from a point one-fourth of a mile west of the Tehla village, which is about 4 miles north of Khoh village (Fig. 1); the second 1.5 miles west of Tehla; and the third about one mile south of Tehla— gave 25 ppm of copper. Local background values, that is, those in the vicinity of known deposits, appear to be of the order of 10 ppm; only one sample out of 250 first collected gave a value as low as 25 ppm.

DARIBA AND DARIBA NALA MINE AREAS

Figure 2 shows graphically the results of copper analyses of soil samples taken along two lines (D-1 and D-2), across the Dariba and Dariba nala mineralized zones, superposed on geologic sections along the same lines. A very high copper anomaly, with maximum values of over 7,000 ppm, was encountered over the north extensions of the faults that are seen to control mineralization in the Dariba underground workings. However, it is not known whether ore actually extends under the line of samples; the old stopes do not extend this far north, and the possibility that the anomaly zone may be due in part to contamination from old mine dumps lying on the hill slope above the sample line was seriously considered. Thinly scattered mine debris was locally evident along the line of samples but there was no direct evidence that any of this debris had been incorporated in the soils or that the soils had been disturbed. To check the possible effects of contamination, soil samples were taken at different depths through part of this anomaly zone. The results are tabulated in Table 2, in which the samples are listed in order from east to west, the west point being at 1,300 feet, and the east point at 360 feet on line D-1 (Fig. 2).

TABLE 2

VARIATION IN DEPTH OF COPPER IN SOIL, LINE D-1, DARIBA MINE

Field sample number		Depth below surface, in inches	Copper in parts per million
53	a	6	200
	b	12	100
52	a	6	150
	b	12	100
51	a	6	200
	b	12	100
50	a	6	200
	b	12	200
47	a	6	2,500
	b	12	3,000
46	a	6	1,500
	b	12	1 000
43	a	6	2,500
	b	12	3,500
42	a	6	3,000
	b	12	2,500
41	a	6	3,500
	b	12	3,500
40	a	6	3,500
	b	12	3,500
39	a	6	2,000
	b	12	2,000
1	a	4	700
	b	8	500
	c	12	600
2	a	8	3,000
	b	12	2,500
3	a	6	2,000
	b	16	2,000
4	a	6	1,000
	b	12	3,000
5	a	6	2,000

TABLE 2 (contd.)

VARIATION IN DEPTH OF COPPER IN SOIL, LINE D-1, DARIBA MINE

Field sample number	Depth below surface, in inches	Copper in parts per million
b	12	1,500
6 a	8	2,500
b	12	3,500
7 a	6	3,500
b	12	5,000
8 a	6	3,000
b	12	>7,000
9 a	6	6,000
b	12	5,000
10 a	6	3,000
b	12	4,000
11 a	6	3,000
b	12	3,000
12 a	6	4,000
b	12	4,000
13 a	6	2,500
b	12	3,000
14 a	6	3,000
b	12	2,500
15 a	8	2,000
b	14	2,500
17 a	6	250
b	12	200
18 a	6	300
b	12	200
19 a	6	500
b	12	400
21 a	6	300
b	12	100
23 a	6	100
b	12	100
37 a	6	300
b	12	500

The results shown in Table 2 are believed to suggest that contamination could not have been a major factor in producing the high copper values on line D-1. If contamination had been significant a much more erratic distribution of copper values should have resulted, and there should have been no marked coincidence of the anomaly represented by the deeper samples with that of the shallower samples. The question whether the copper values come from the underlying bedrock near the sample line or where derived from the known mineralized zone on the hill slope above cannot be satisfactorily answered. Some of the deeper samples were actually taken on bedrock, outcrops of which are seen near the line; this shows that the soils are very thin and suggests that the bedrock here may be mineralized. Several bedrock samples taken in the area of the anomaly of line D-1 (Table 3) shows that copper values in bedrock are lower than those in the soils, but are well above the local background level in rock which is of the order of 25 to 50 ppm. Primary sulfide mineralization, either chalcopyrite — cubanite or pyrrhotite, is indicated by the presence of indigenous limonite in sample Gd-G (Table 3).

TABLE 3

COPPER CONTENT OF SURFACE ROCK, DARIBA MINE

Sample number		Rock description	Copper in ppm
GD	C	Phyllite, showing some malachite stains; from prospect pit, 5 feet below surface.	300
	D	Phyllite from prospect pit, taken 5 feet below the surface; contains minor limonite.	300
	E	Phyllite from near soil sample station 47, line D-1; much limonite staining.	700
	F	As above; from near soil sample station 45.	600
	G	Phyllite; relatively fresh rock from near soil sample station 48 on line D-1; contains irregular pockets of bright red and pinkish limonite, apparently residual after sulphides.	500

Some of the soil samples in the high copper anomaly zone of line D-1 were also analyzed for arsenic and cobalt. Table 4 shows that arsenic values which range from less than 50 to 100 ppm, have no consistant correlation with those of copper, in fact show no convincing anomalies. Cobalt values range up to 75 ppm, and like arsenic appear to have no direct relation to copper values.

TABLE 4

ARSENIC AND COBALT CONTENT, AND RELATION TO COPPER CONTENT OF SOILS IN THE DARIBA MINE AREA

Sample number	Metal content (ppm)		
	Copper	Arsenic	Cobalt
Gd 50 a	200	—	20
41 b	3,500	—	20
39 a	2,000	—	20
1 b	500	50	20
2 b	2,500	50	20
7 b	5,000	50	50
8 b	>7,000	100	30
12 b	4,000	75	75
15 b	2,500	40	50
17 b	200	50	20
21 b	150	—	20

The Dariba mine mineralized zone was not picked up in line D-2 of soil samples. There are two possible explanations for the negative results: 1, that the apparent surface trace of the premineral fault zone which localizes mineralization was not crossed; and 2, there may be only traces of mineralization along the upper extension of the faults.

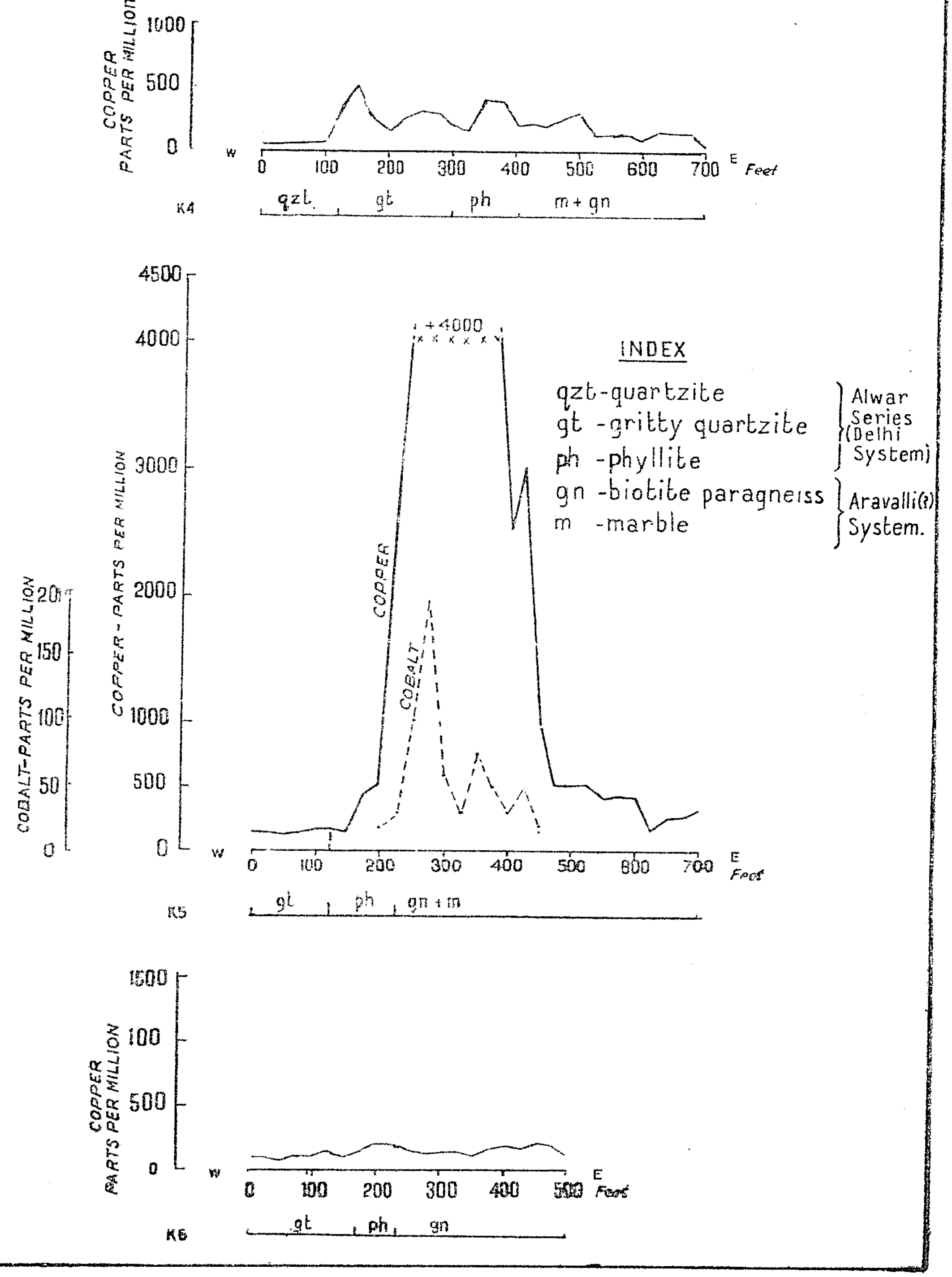
Abnormally high values of copper were obtained over the north end of the Dariba nala mineralized zone, just below the old workings and mine dumps, but the anomaly coincides with the bottom of the valley which follows the trace of the known mineralized zone. The possible effects of contamination from nearby mine dumps have not been evaluated. However, the extension of the Dariba nala mineralized zone across line D-1, as marked by the phyllite-quartzite fault contact, is well above the valley bottom and no prospect pits or mine dumps are present in the vicinity. Some of the samples from the hill slope just below the phyllite contact contain up to 600 ppm of copper which apparently reflects primary mineralization along the contact, as supported by the presence of small irregular pockets of indigenous limonite in the phyllite.

DARIBA NALA SOUTH EXTENSION

The results of soil sampling across the Dariba and Dariba nala mine zones were encouraging and soil samples were then taken across the south extension of the phyllite and fault zone of the Dariba nala mine. Lines were spaced at intervals of 1,000 feet and covered a strike distance of about 1 mile (figure 1). No significant anomalies were found in this region, although values of copper were found to range up to 150 ppm.

Figure 3

DISPERSION OF COPPER AND COBALT IN SOIL ACROSS DARIBA NALA MINE EXTENSION PROSPECT, SHOWING RELATION TO GEOLOGIC CONTACTS



Dariba nala north extension

The northerly extension of the phyllite and fault zone from the Dariba nala in a few small prospect pits in the phyllite in this area (Dariba nala extension mine is traceable for a distance of about one mile. Mineralization is evident prospect (Fig. 1), which in places contains minor irregular pockets of indigenous limonite; there are also fragments of limonite (gossan ?) in the overlying soils that are most numerous where the soil also contains fragments of phyllite. Values of copper above normal background levels were found on all of the 12 lines of samples shown in figure 1, but only three lines gave values high values were found to be over the extension of the Dariba nala phyllite and fault system or on the hill slope just below. Migration of copper cannot be great, if mineralization is in fact localized along one or the other of the faulted contacts of the phyllite. The asymetric shape of the anomalies is in accord with mechanical dispersion of copper as the soils crept slowly down the hill slope under the influence of gravity. The highest copper values, 4,000 ppm, were obtained along line K 5, as shown in figure 3. On this line the highest values begin just over the eastern side of the phyllite zone, which here is approximately 100 feet wide. A part of the samples across the copper anomaly were analyzed for cobalt, which also gave significantly high values, one sample reaching 200 ppm. Mineralization along the east fault contact of the phyllite is here indicated.

Chipta prospect

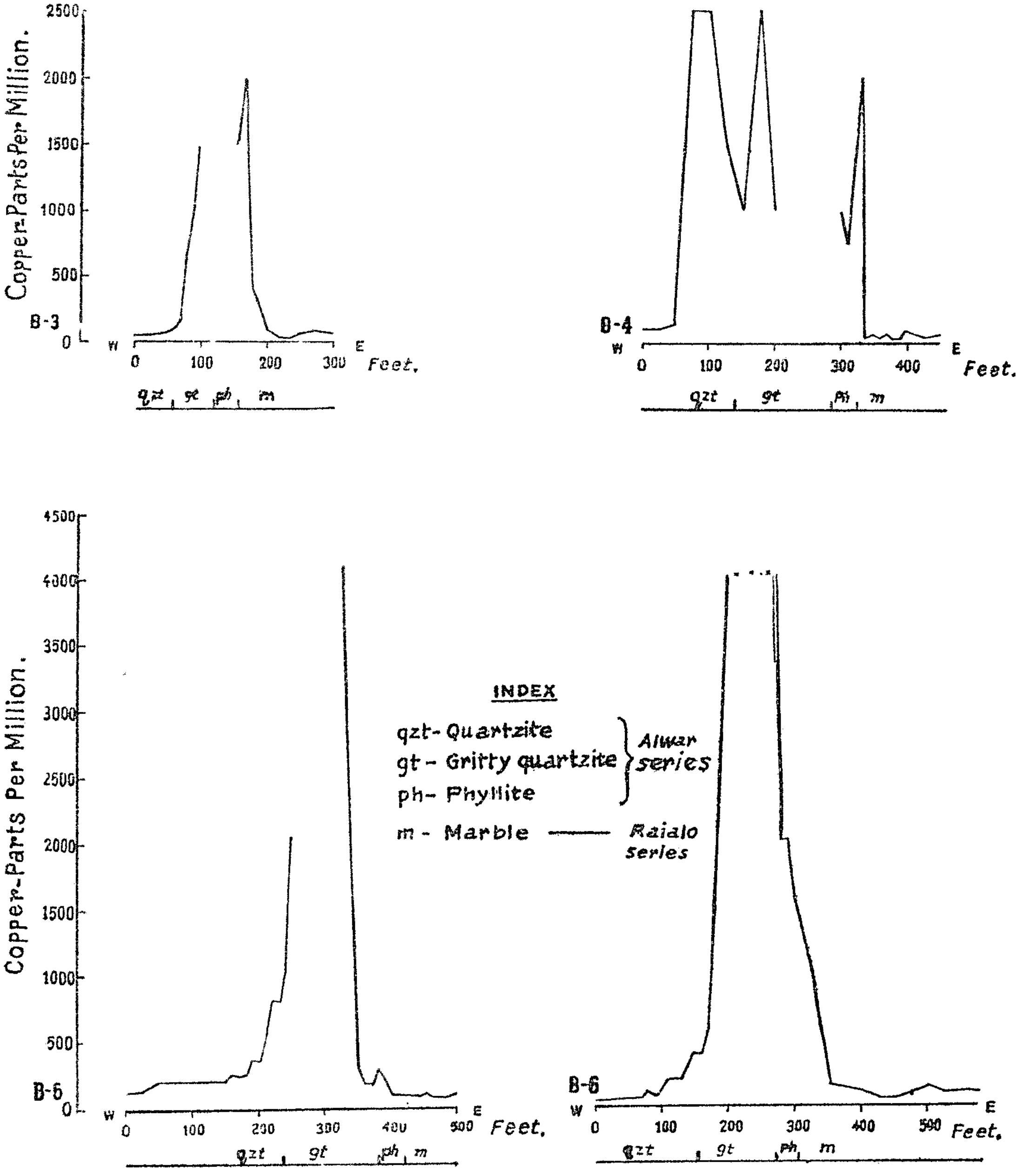
Nearly 100 samples were collected along three lines spaced about 200 feet apart across the Chipta quartz vein and across the projected continuation of the mineralized zone. The soils here are very thin and copper anomalies proved in general to be low reaching maximum values of 250 ppm.

Baldeogarh prospect

In old working at the Baldeogarh prospect mineralization is evident along a thin phyllite bed where it contacts Alwar quartzites on the west and Raialo marble on the east. The phyllite extends along the bottom of a narrow valley. Lines of soil samples were taken at intervals of 400 feet across the zone. The samples showed abnormally high values of copper, ranging to plus 4,000 ppm, over a strike distance of 1,300 feet. Results of analyses along four of these lines are shown in figure 4, in which the copper anomalies are shown in their relation to approximately located geologic contacts. Interestingly enough, the anomalies appear mainly to be due to mineralization along the north trending fault between quartzite on the west and gritty arkosic quartzite on the east (Fig. 1), on the hill slope west of phyllite bed. This poorly exposed contact

Figure 4.

DISPERSION OF COPPER IN SOIL ACROSS BALDEOGARH PROSPECT, SHOWING RELATION TO GEOLOGIC CONTACTS.



is not prospected by surface workings and therefore there is no reason to suspect soil contamination here. Values of copper fall off markedly on the north and south extensions of the Baldeogarh zone. The two southernmost lines of samples, B-11 and B-12 (Fig. 1), in Raialo dolomite show only background levels of copper. Exploration of the anomaly zones in the Baldeogarh mine by surface trenching down to bedrock is planned.

FAULT ZONE WEST OF BALDEOGARH PROSPECT

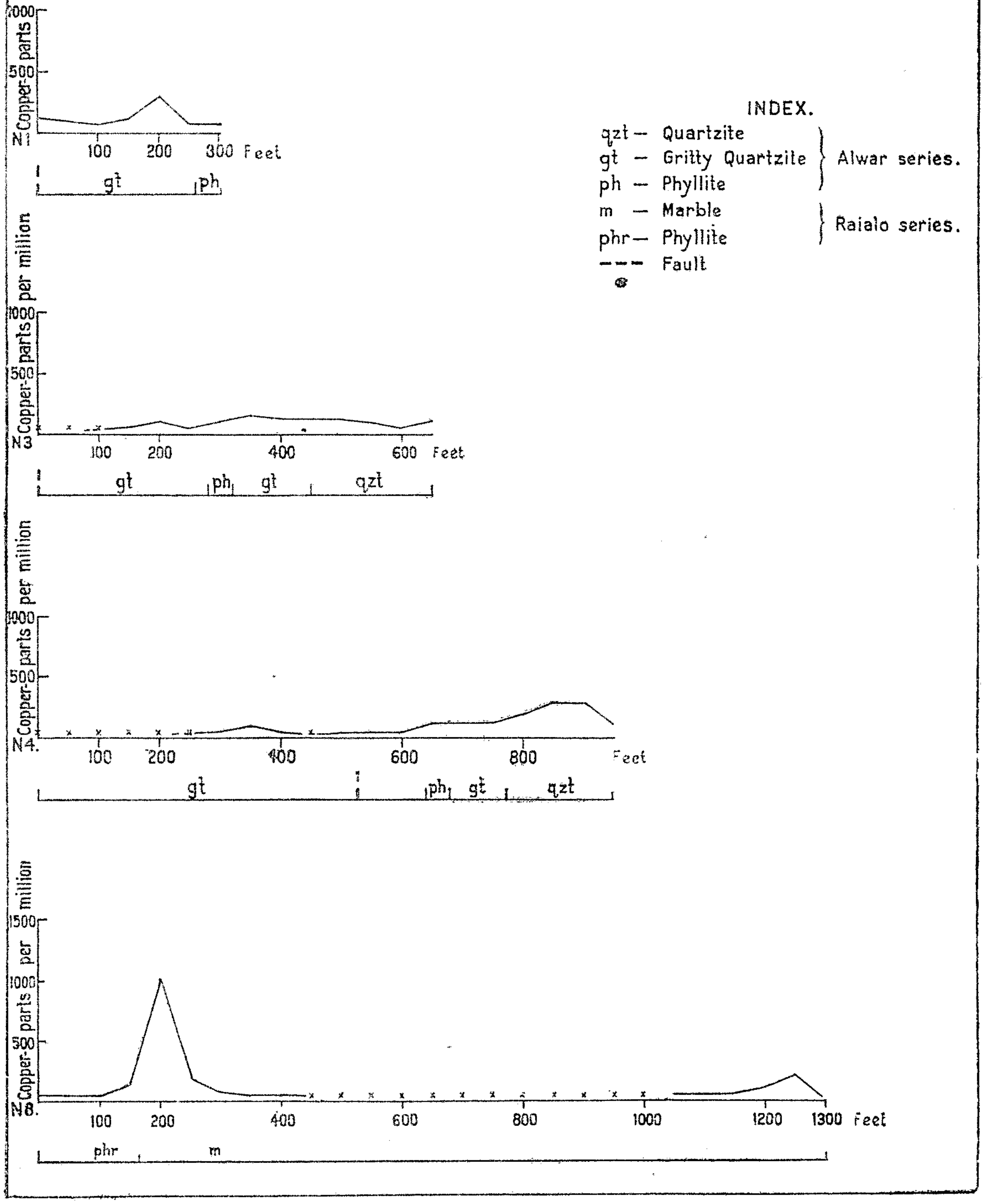
The encouraging results obtained by soil sampling over known mineralized zones and their extensions led to an extension of soil sampling into a new area where geological conditions appeared to be similar to those that control mineralization in the known deposits. Inspection of the areal geologic map, somewhat generalized in figure 1, indicated that the northerly trending fault in the valley, about 0.7 of a mile west of the Baldeogarh prospect would be worth prospecting, particularly as there are poorly exposed thin phyllite beds along or near the fault. Samples of soil across this zone gave copper values well above normal background levels (Fig. 5), suggesting that copper mineralization is present. However, along most lines the values proved to be low. The highest anomaly, a very narrow one that resulted from one sample which contained 1,000 ppm of copper, appears to be localized over a thin phyllite bed in marble at the west end of line N-8 (Fig. 1). Further sampling is necessary here to determine the nature and extent of this anomaly.

GEOPHYSICAL PROSPECTING

Geophysical prospecting in the Khoh-Dariba area by the Geophysical Section of the Geological Survey of India covered much of the ground subsequently prospected by soil sampling. Magnetic and selfpotential methods were utilized. Numerous magnetic anomalies were found which appeared to reflect bodies of meta-dolerite or amphibolite and to have no apparent relation to known zones of copper mineralization. Rather weak self-potential anomalies were, however, recorded over the Dariba and Dariba nala mines, over a small area on the north extension of the Dariba nala zone, and over the Baldeogarh deposit (Matthew 1954; Rao 1955). The anomalies of copper were found to coincide closely, although not in detail, with those indicated by the self-potential survey. However, no self-potential high was recorded over the high copper anomaly on line K-5, although a high was obtained on the next line to the north (K-4) which shows only a low copper anomaly (figure 3). The reason for this is not certain. Ground conditions were possibly so dry in the vicinity of line K-5 that electrochemical activity was low, while on line K-4 the weak activity present may be due not to oxidation of copper minerals but to oxidation of pyrrhotite or some other sulphide.

Figure 5.

DISPERSION OF COPPER IN SOIL ACROSS FAULT ZONE WEST OF BALDEOGARH PROSPECT SHOWING RELATION TO GEOLOGIC CONTACTS.



CONCLUSIONS

It is believed that the work so far done on the application of the technique of geochemical prospecting in the Khoh Dariba area indicates strongly that known zones of copper mineralization can be traced by the method, and that new mineralized zones can be found. Under the conditions of weathering and soil development in the Khoh-Dariba area, the bedrock source that gives rise to high values of copper in the soils apparently can be located within adequate limits to guide exploration in determining the presence or absence of ore, particularly if the known geological controls are used as additional guides. Although copper alone appears to give adequate anomalies cobalt, which is apparently less widely dispersed, may prove useful in places to locate source zones of mineralization more closely. A sample interval of 50 feet appears to be adequate to pick up any significant copper anomaly, and spacing of 100 feet is probably adequate for most reconnaissance sampling. Soil samples need not be taken at a depth greater than 4 to 6 inches.

As a preliminary to further exploration, should results warrant, surface trenching and sampling of the bedrock across some of the higher anomalies of copper have been recommended. Once the bedrock-trace of the mineralized zone has been accurately located, a prospect pit or shaft can be sunk to the base of the zone of oxidation to determine the grade and width of primary copper mineralization.

Copper mineralization may underlie a cover of soil and alluvium in many other places in the Khoh-Dariba and surrounding area, and the results thus far obtained indicates that geologically guided geochemical prospecting should be continued.

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GEOCHEMICAL PROSPECTING IN THE SINGHBHUM COPPER BELT, BIHAR, INDIA

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N. V. R. Subrahmanyam, * * S. K. Bose * * and P. K. Banerjee

ABSTRACT

The 90-mile long copper belt of the Singhbhum district, Southern Bihar State, India, is the site of the only producing copper mines in India and is believed to be one of the most promising copper areas in this country. The deposits are in Pre-Cambrian chlorite-amphibole and chlorite, biotite schists, quartzites, quartz schists and conglomerates of the Iron-ore series, into which granite plutons have been emplaced. Mineralization is localised along moderately dipping strike shear zones. The primary deposits contain chalcopyrite, pyrrhotite, pyrite, pentlandite, millerite and violarite.

Geochemical prospecting for copper was carried out over a 10-mile long, half-mile wide belt along which there are old mine workings. Nearly continuous anomalies of copper were found in this belt and low anomalies of cobalt were also found. The geochemical highs coincide with known zones of copper mineralization, but many highs occur over zones previously unknown. Most lines show two or more peaks indicating parallel zones of mineralization.

Prospecting by drilling of the zones of highest copper anomalies is recommended.

INTRODUCTION

The application of geochemical methods of prospecting for minerals, especially for metallic minerals, is a comparatively recent development. As a result of surveys carried out in other countries, particularly in U.S.S.R. and U.S.A. it is considered that geochemical prospecting is an useful tool in geological exploration. It helps in extending the area of economic importance around a known mineral outcrop and thereby shortening the lag or gap between the discovery and production. It is claimed that with the application of this technique, old deposits have been rediscovered and have been shown to extend over a larger area than was previously realized. The workers in this field, however, realize that more basic information regarding size and nature of anoma-

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lies of the known mineralized zones needs to be collected before the significance of this technique of ore-finding is fully appreciated.

Geochemical prospecting has recently been introduced in some of the important mineralized zones in India with the co-operation of the U. S. Geological Survey. This paper presents the results of this prospecting in progress in the Singhbhum copper belt, Bihar, which is considered to be one of the most promising copper areas of the country. Apart from being the only copper mining centre of the country, the potentiality of the belt is reflected, among other considerations, in its very extent which is some 90 miles in length.

EARLIER EXPLORATION

The history of mining in this belt falls under two distinct phases: ancient and modern. The ancient mining, which probably dates as far back as 2,000 B.C., appears to have continued intermittently till the end of the 6th century. The skill of the ancient prospectors, miners and metallurgists is indicated by the extensive workings and innumerable slag heaps scattered throughout the belt.

The earlier history of modern mining in the belt which began in 1857 shows successive failures due either to the poor character of the deposits prospected or unwise expenditure of limited capital on expensive projects before the deposits were proved. The costliest failure was that of the Cape Copper Company at Rakha Mines where, in spite of the large reserves of ore proved, the active development could be continued only for a brief period of 9 years owing to financial difficulties. During this operation the Company produced 180,095 tons of ore having an average assay value of 3.8 percent copper and valued at £ 224,702 from which 3,550 tons of copper, worth £ 319,381 were extracted at the Company's smelter. The prospecting at Mosabani and its neighbouring localities carried out at about the same period ultimately resulted in a good producing mine under the management of the Indian Copper Corporation. Two roughly parallel lodes have been developed at Mosabani for a total distance of three miles and to a vertical depth of 2,250 feet. The nieghbouring mines of the same concern at Badia and Dhobani have been closed down owing to lack of profitable ore but the deposits at Pathargghara and Surda, which are being developed at present may ultimately compensate the loss. Between 1925 and 1954, 8,062,314 tons of ore valued at £ 13,725,000 approximately were raised and treated at the Company's plant at Moubhandar to produce 149,741 tons of refined copper.

Besides the prospecting carried out by the private enterprise, the Geological Survey of India conducted investigations from time to time since the very early days of modern mining. Among the notable works carried out by its officers, mention may be made of the drilling campaign during 1906-08 which renewed the attention to the belt and subsequent work by J. A. Dunn, which comprised regional mapping and investigation of minerals of economic importance in south Bihar, including the copper belt. The work of Dunn, published in the Geological Survey of India's Memoir No. LXIX, Vol. 1, is the first serious attempt to study the economic aspect of the deposits and potentiality of the belt. Systematic geophysical surveys using Self-Potential and Magnetic methods, were commenced by the Geological Survey of India in 1950 with promising results over certain lengths of the belt necessitating further investigation before a fresh drilling campaign is launched. The geochemical prospecting is a part of the present programme of detailed mapping in the copper belt which is in progress since 1954.

REGIONAL GEOLOGIC SETTING

Based on the evidence collected by Dunn and the earlier workers the geological succession in this part of Bihar may be summarised as follows:

9. Alluvium,
8. Laterite,
7. ? Tertiary grits,
6. Newer Dolerite,
5. Kolhan series,
4. Singhbhum granite, soda granite & granophyre (may be pre-Dhanjori),
3. ? Ultrabasic igneous rocks,
2. Dalma and Dhanjori lavas and sediments,
1. Iron-ore series — { Iron-ore-stage. Chaibasa stage.

The Iron-ore series constituting the most widespread group of the region includes all the important rock units of the copper belt, other than the granites. It essentially comprises a series of sediments grading upwards into a series of lava flows.

No final conclusion has yet been arrived at regarding the geologic history of the Archaean terrain in Singhbhum, and the succession of events as depicted through the geological sequence above is a tentative one. The highly metamorphosed rocks of the Chaibasa stage are clearly the oldest in this region and the base of this group is yet unknown. The less metamorphosed phyllites of the Iron-ore stage overlying the Chaibasa stage in the northern side of the geo-anticline form a normal sequence. A long period of time had elapsed before the volcanism of the Dalma and Dhanjori periods manifested itself in spreading a thick mantle of basic lavas over the meta-sediments, to be followed shortly by large scale folding and thrusting in which all the rock units were involved. During the waning stages of this deformation, granitic invasions of batholithic dimensions came in. After a considerable interval of comparative quiescense, sedimentation again ensued in local basins in which shales, sandstones and limestones of the Kolhan period were deposited. The last intrusive activity, represented by a suite of dolerite dykes of regional extent, is considered by some to be post-Archaean in age. The status of the ultrabasic intrusives is yet undetermined and they may even be earlier than the granitic invasions. Since the Archaean time the area remained a land mass till the late Tertiary times and was subjected to prolonged erosion resulting in a widespread peneplanation. The grits and gravels which form a belt overlying the Archaeans in the eastern margin of the area represent the western edge of the late Tertiary coastal deposits.

The shear zone, which bisects the rocks of the Iron-ore series, forms a broad arc, convex towards the north and swinging from east-northeast on the western side to northwest on the eastern side. The tectonic history is important, for the resulting structures were responsible for controlling the localization of the later ore fluids. The great mountain building movement, directed toward the south, culminated in a great zone of overthrust along the overfolded southern limb of a geo-anticline which had formed the axis of the Archaean range. Highly metamorphosed rocks to the north were thrust bodily against the less altered rocks to the south and along the overthrust, the rocks were completely sheared. Soda granite and granophyre invaded along the thrust zone and being caught up in the movements, still operative, were sheared as completely as the enclosing schists and in places entirely mylonitised.

In the copper belt, mineralization was almost entirely confined to the zone of overthrust. Copper veins of payable size and concentration have been formed only in certain places where the mechanical effects of rock movements have been sufficiently favourable. The richest section lies where the overthrust movements piled up against resistant metavolcanics and became concentrated into a narrow zone as compared with the wider zones of shear elsewhere where copper minerals are too widely disseminated to reward exploitation. As a general rule, the harder country rocks, e.g., granite, epidiorite and quartzite, acted as more favourable host rocks because of the cleaner fractures in them in comparison with the softer mica schits.

TOPOGRAPHIC AND GEOLOGIC FEATURES OF THE AREA PROSPECTED.

The portion of the copper belt over which the geochemical study was carried out falls at the northern edge of a thickly wooded range which rises about 450 feet from a flat country drained by the main river system of the region, the Subarnarekha and its tributaries. In the mineralized shear zone, the range is broken up into a set of craggy linear ridges formed of resistant units like quartzite, quartz-kyanite, granuline, etc., with intervening valley portions occupied by the predominantly schistose rocks. The ridges have a general northwest-southeast trend, in conformity with the strike of the country rocks.

In the Rakha Mines area the main mineralized zone runs along a ravine between two prominent ridges of which the southern one is higher with its peak, the Sideshar, attaining an altitude of 1,460 feet above the mean sea level. Proceeding eastwards these ridges converge together and form a single wider ridge in which the mineralized zone occupies either its crest or the northern flank.

A number of streams rise from the hills and flow in an easterly direction for two or three miles to join the Subarnarekha. Numerous gullies run along the slopes of the ridges and sometimes cut deeply into the hill sides forming a very rugged topography.

The slopes of the hills are generally steep and debris of fresh rock fragments, sometimes thickly covering the underlying rocks, are common. In the topographic depressions along the main stream courses the soil cover is, however, deep and amenable to cultivation.

The portion of the copper belt covering the area of geochemical study was recently re-surveyed by the authors on aerial photographs of scale 2 inches = 1 mile. Some of the critical portions have also been mapped by planetable with telescopic alidade on a scale of 100 feet = 1 inch.

Due to the structural complexity of the area geologically mapped, it is possible only to give a generalised succession of the rock types, which is detailed below. The rock formations have been grouped into different units under practical limits set by the scale of the aerial photo sheets. Where large scale geological mapping by plane table was carried out, it has been possible to delineate further traceable horizons within these groups.

ARCHAEAN

North of the shear zone

1—Tertiary gravels and laterite,

2—Mica schist (with garnet and kyanite), lenses of hornblende schist and ultrabasic sills,

3—Kyanite-quartz schist with andalusite, dumortierite and tourmaline.

Shear zone

1—Quartz-chlorite schist,

2—Albite-biotite-quartz schist with lenses of tourmaline-magnetite rock,

3—Tourmaline-chlorite-quartz rock (occasionally conglomeratic) with copper lodes.

South of the shear zone

1—Chlorite and biotite schists.

2—Quartzite.

3—Talc and chlorite schists

4—Quartzite.

5—Chlorite schist with biotite and talc.

6—Quartzite (locally developed in the western sector).

7—Meta-volcanics (biotite-chlorite schist, epidiorite and chlorite- actinolite schist) and altered ultrabasic rocks.

A brief description of the important rock formations and their structural features is given below.

The kyanite-quartz rock, forming the scarp face of the outermost ridge of this belt, is a highly variable unit and grades frequently into sericite-rich bands. Microscopically, it is composed of variable proportions of hypautoblastic to xenoblastic deformed kyanite and quartz; late-kinematic sericite; and rare phlogopite, andalusite and tourmaline. Inmmediately south of it is a persistent zone of biotite-chlorite schist, consisting of chlorite (penninite) and brown and green biotite with abundant deformed quartz and occasional iron ore.

The shear zone to the south of the kyanite-quartz rock is fairly persistent except to the south of Kendadih. In Rakha Mines area it is characterised by the chlorite-quartz rock with thin bands of conglomerate on the hanging wall side; whereas in the Purnapani-Surda area, the shear zone can only be identified by the presence of tourmaline-chlorite-quartz rock. The shear zone is further marked by ancient and recent workings for copper ore in the form of pits, adits and inclines. Associated with the shear zone and the hanging wall side is a persistent zone of albite-quartz schist, composed of deformed quartz grains, chloritised biotite, late albite with rare chlorite, tourmaline and iron-ore. From south-southwest of Netra to south of Kendadih, the rocks of the shear zone are missing and only a wide zone of muscovite-kyanite-quartz schist is exposed.

South of the shear zone, the two bands of massive quartzite are underlain in the footwall side by ultrabasics and meta-volcanics. The ultrabasics are more dominant between Purnapani and Surda and are composed mainly of talc-tremolite schist. The meta-volcanics show a wide range of variation, from slightly altered epidiorite and vesicular chlorite schists to chlorite-actinolite schist and biotite-chlorite schist.

STRUCTURAL FEATURES:

Structurally, the area is very complicated due to the very intense folding and shearing all along the thrust zone. The general northwesterly strike in the Rakha Mines area gradually swerves to north-northwest beyond Kendadih, and near Surda the strike is approximately north-south. All the rock formations dip uniformly toward the north-east and east at 43° on an average. The structural pattern of the area is mainly controlled by a series of isoclinal folds with an axial depression between Rakha Mines and Kendadih. Axial plane cleavage, developed during this folding movement, later served as shear surfaces.

A number of transverse faults trending north-northwest and north-northeast run across the area. These faults are later than the copper mineralization, unlike the few strike faults, (*e.g.*, to the south of Matigara) which merge into the zone of mineralization leaving the mutual relationship obscure.

The foliation is marked by colour and compositional banding in the quartzitic formations and by layering of micaceous minerals in the incompetent horizons. Bedding is almost always obliterated beyond recognition, and even the colour banding in some quartzites is found to be an axial plane foliation, cutting across the noses of the plunging folds. A vertically dipping fracture cleavage cutting across the axes of the concertina folds is found to be developed in the incompetent horizons near Kendadih, where the shear zone takes a turn towards south. This restricted development might be due to the localization of stress in this area, as revealed also by the pattern of the antithetic wrench faults.

A statistical analysis of the axial plane foliations of the area suggest that near Rakha Mines, the regional fold axis of the isoclinal folds plunges at low angle toward the southeast whereas near Kendadih and Surda, the fold axis has a gentle north-northwesterly plunge. Plane table work in some of the critical areas reveals minor undulations in the regional fold axis. A later system of stress gave rise to another fold pattern, diagonal to the regional fold axis. The intensity of this system appears to be much less than the preceding one, as the folds are in the nature of open anticlines and synclines and are not very widespread in development.

The lineation patterns of the area cannot be easily correlated with the direction of maximum tectonic transport, as they make an angle of 0° to 30° with it. Some minor folds and intersection lines of flow and fracture cleavage are visibly parallel to the major fold axis, but statistical analyses of the majority of lineations, both in the competent and the incompetent formations, reveal that they are sub-parallel to 'a'.

Cross and oblique joints, sometimes with quartz vein fillings, are ubiquitous, their development being more intense in the competent rock formations.

SULPHIDE MINERALIZATION:

The sequence of deposition of the sulphides in this belt, as shown in Fig. 1, has been established from the field evidence as well as from the microscopic studies of the ores, mainly collected from the Mosaboni Mines. One of the principal features which becomes apparent from the study of the sequence of mineralization is that there are at least two distinct periods of ore deposition: an earlier apatite-magnetite phase separated from the later sulphide phase by a prolonged period of biotisation and chloritisation. Apatite-magnetite veins are much more severely crushed than the copper lodes. Pyrite has been extensively replaced by later sulphides. Pyrrhotite and pentlandite were probably deposited simultaneously. Pyrrhotite has been replaced by millerite and pentlandite by violarite. Chalcopyrite was the last of the sulphides to be deposited.

MINING HISTORY:

The previous mining attempts in this portion of the belt met with repeated failures but left some valuable information on the future prospects of this area. At Rakha Mines three lodes were opened up out of which the main Rakha lode with an average assay value of 3.8% Cu. was developed down to 900 feet, and an equally rich lode, about six furlongs to the south-east, was followed up to a depth of 300 feet. It is reported that in the Chapri area, one of the deep-holes passed through six copper bearing zones, the lowest of which averaged 4.5% copper over 8 feet. The lode, marked by small old workings southwest of Kendadih, was prospected from two shafts and an adit and though most irregular, proved at one place to be 42 inches wide, carrying up to 5.7% copper. The ridge northwest of Surda is remarkable for the number of old workings that honeycomb its top for a length of over 2,000 feet the pattern of which suggests the presence of at least 4 veins. The lodes found in the crosscuts and adits assayed 2 to 5% copper.

GEOCHEMICAL INVESTIGATION

The area selected for geochemical prospecting covers the most promising portion of the belt beyond the leased area of the Indian Copper Corporation, which is being actively developed at present.

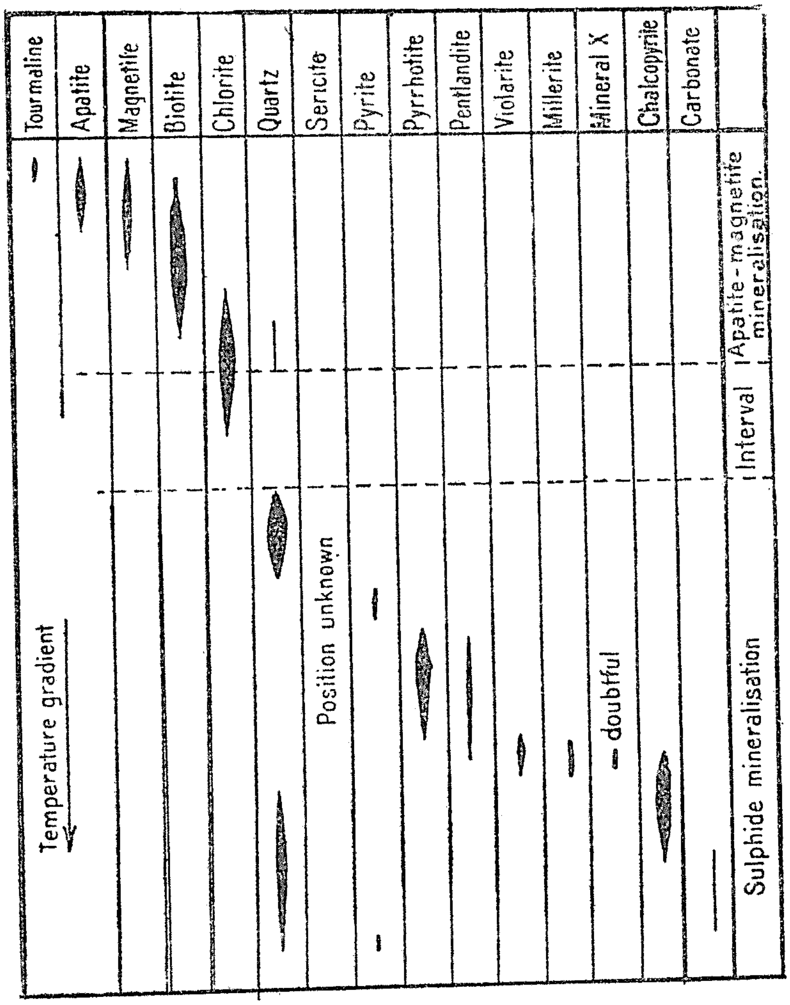


FIG. 1 —Diagram of deposition sequence.
(After Dunn)

The method of geochemical investigation adopted so far in the area is being confined to soil studies alone and is but a partial application of geochemical prospecting. Besides the study of the pattern of the anomalies based on supergene dispersal of metals, geochemical prospecting should also include a study of the primary dispersion which is determinable by systematic sampling of the bed rocks. The anomalies obtained from the soil samples, although indicative of mineralization in the vicinity, may not give reliable clues in fixing the exact position of the lodes or determine their extent and richness because of the influence of topography, nature of the soil, effects of leaching etc. on the ultimate concentration of the trace-metals. Moreover, the effects of contamination of the soil are inescapable in a mining district, particularly in areas like Singhbhum copper belt where mine dumps and ancient workings are numerous. The main reason which guided us in collecting only soil samples for study is the rapidity of work and the frequent presence of fairly thick residual soil cover along the traverse lines. In spite of the limitations of the method followed in this area, the results achieved so far and set forth in the following pages are sufficiently encouraging for its wider adoption along the whole length of the belt.

SAMPLING PROCEDURE

In all, 50 traverses varying in length from 800 feet to 4,000 feet were laid across the strike of the mineralized zone. The distance between the successive traverses was kept at about 1,000 feet as far as possible. As some of the lines ended in high peaks it was considered necessary to run a few longer additional traverses to cover the entire spread of the anomalous zones and to pick up other possible zones of high metal content further to be south. For a rapid progress of the work the lay-out of the lines was done by Brunton compass and steel tape. As far as practicable the geochemical traverse lines were laid in conformity with the geophysical traverses made earlier in this area.

Along each traverse, samples were collected at every 25 ft., but occasionally the sample interval was narrowed down to 10 ft. Samples were collected from immediately below the humus zone which hardly exceeds 6" to 9" from the surface. About 10 grams of the sieved sample were collected from each point and sealed in alkathene bags and submitted for analysis. Since the sampling was carried out during the dry season, there was no need to dry the samples before packing in the bags. No sample was collected from points where contamination was suspected due to the vicinity of old workings, mine dumps, slag heaps, stream courses etc.

SAMPLE ANALYSIS

Owing to the lack of facilities for field analysis, all the samples were sent to the Chemical Laboratory of the Geological Survey of India where a small section was set up for rapid analysis by colorimetric methods.

Initially, analyses were made only to determine the copper content of the soil sample. After the copper values of the soil samples were known, certain samples showing high copper values were selected and anlysed for cobalt. A few were also analysed for arsenic and nickel.

The analytical technique consisted of sieving the sample as received from the field through a 80-mesh sieve. A known amount of the sample was treated to bring the metal component into solution and mixed with a suitable organic reagent that produces a characteristic colouration, the intensity and quality of the colour depending upon the amount of the metal present. The colour produced by the sample was compared with those of standard solutions prepared with known amounts of the particular metal. For copper, the sample was digested with 1 : 3 nitric acid, and the test reagent was a solution of dithizone in carbon tetrachloride. For cobalt, the sample was first fused in potassium pyrosulphate and extracted with a solution of nitrozo-naphthanate in carbon tetrachloride. Arsenic was estimated by the modified Gutzeit method.

The results of the analyses are expressed in parts per million. The minimum concentration of copper in this area was 50 parts per million and the maximum, 4,000 parts and above per million as shown in the following analytical data (Tables I, II and III):

TABLE I

DETAILS OF THE GEOCHEMICAL TRAVERSES BETWEEN CHAPRI AND PURNAPANI

Traverse No.	Sample interval (in ft.)	Length of traverse (in ft.)	Peak anomaly (Cu, ppm) Distance from N. E. end (in ft.)	Anomaly spread (in ft.)
1	2	3	4	5
1—	25′	2675′		No anomaly.
2—	25′	1350′		No anomaly.
3—	25′	1800′	1500/950	— 1000 50
4—	25′	2750′	2000/1500	— 1600 100
			2000/2000	— 2175 175
			3000/2300	— 2400 100
5—	25′	1600′–3000′	3000/1200	— 1300 100
		1400′	>4000/1325	— 1450 125
			2500/2375	— 2575 300
6—	25′	1425′	2500/225	— 150 75
			3000/175	— 50 125
			3000/250	— 350 100
			>4000/475	— 550 75
			3000/575	— 725 150

Traverse No.	Sample interval (in ft.)	Length of traverse (in ft.)	Peak anomaly (Cu, ppm) Distance from N. E. end (in ft.)	Anomaly spread (in ft.)
1	2	3	4	5
7—	25′	2500′	3000/450	— 300 125
			3500/200	— 250 50
			>4000/275	— 400 125
8—	25′	1175′	>4000/225	— 150 75
			3000/200	— 325 75
			>4000/550	— 675 125
9—	25′	1225′	2000/0	— 550 550
10—	25′	1100′	3000-3500/225	— 125 100
			>4000/100	— 50 50
			1750/300	— 550 250
11—	25′	1200′	3000/125	— 175 50
			2500/200	— 250 50
			3000/300	— 350 50
			3000/525	— 600 75
			>4000/1100	— 1175 75
12—	25′	1300′	>4000/0	— 150 150
			2500/575	— 650 75
			>4000/825	— 1000 175
			>4000/1075	— 1150 75
			4000/1175	— 1225 50
13—	25′	900′	>4000/0	— 100 100
			>4000/225	— 300 75
			>4000/500	— 575 75
			4000/675	— 750 75
14—	25′	825′	4000/0	— 50 50
			4000/350	— 475 125
			2000/750	— 825 75
15—	25′	1175′	4000/950	— 650 300
			4000/500	— 275 225
			4000/50	— 0 50
16—	25′	2000′	>4000/1875	— 1500 375
			4000/1525	— 1450 75
			3000/625	— 425 200
17—	25′	2300′	2500-3500/150	— 250 100
			2500/1125	— 1200 75
			4000/1775	— 1875 100

Traverse No.	Sample interval (in ft.)	Length of traverse (in ft.)	Peak anomaly (Cu, ppm) Distance from N. E. end (in ft.)	Anomaly spread (in ft.)
1	2	3	4	5
18—	25′	4725′	4000/75	— 225 150
			2000/250	— 800 550
19—	25′	2650′	2500/975	— 1150 175
			2500/1225	— 1375 150
			3000/1475	— 1625 150
20—	25′	2375′	3000/1050	— 1150 100
		-3075′	2500/1200	— 1425 225
		700′		

TABLE II

DETAILS OF THE GEOCHEMICAL TRAVERSES BETWEEN RAKHA MINES AND SIDESHAR (CHAPRI)

21—	25′	3300′	>4000/1250	— 1325 75
			3500/1425	— 1625 200
			4000/2300	— 2450 150
			3000/2500	— 2600 100
			2500/2750	— 2850 100
22—	10/25′	1250′	>4000/1425	— 1575 150
		-4756′	4000/1600	— 1700 100
		3500′	>4000/1800	— 2275 475
			4000/2480	— 2600 120
			2500/3000/2650	— 2940 290
			4000/2950	— 3000 50
23—	25′	3175′	4000/650	— 875 225
			3000/900	— 975 75
			3000/1000	— 1200 200
			>4000/1350	— 1625 275
			3000/2800	— 2925 125
24—	25′	2750′	4000/1225	— 1650 425
			4000/2100	— 2200 100
25—	25′	2250′		No anomaly.
26—	25′	1900′	1500/1000/1200	— 1350 150
27—	25′	2100′	4000/75	— 150 75
			3500/1500	— 1575 75
			2000/1950	— 2000 50
28—	25′	1875′		No anomaly.

Traverse No.	Sample (in ft.) interval	Length (in ft.) of traverse	Peak anomaly (Cu, ppm) Distance from N. E. end (in ft.)	Anomaly spread (in ft.)	
1	2	3	4	5	
29—	25′	2000′	2500/1125	— 1225	100
30—	25′	1525′	2500/475	— 525	50
31—	10′	1380′		No anomaly.	
32—	10′/25′	1700′		” ”	
33—	25′	2250′		” ”	
34—	25′	1800′		” ”	
35—	25′/10′	1830′	2500/930	— 990	60
			2500/1140	— 1170	30
			3000/1470	— 1610	140
36—	50′	4000′	3000/600	— 750	150
			2500/950	— 1050	100
			3000/1150	— 1250	100
			3000/2200	— 2100	100
			1500/3950	— 4000	50
37—	25′	1500′	2000/825	— 925	100
			2500-3500/1050	— 1325	275
			4000/1375	— 1425	50
38—	10′/25′	1550′		No anomaly.	
39—	10′/25′	2200′	1250/1050	— 1150	100
			1250/1950	— 2050	100
40—	25′	1800′	4000/1550	— 1725	175
41—	50′	3000′	2500/1900	— 2000	100
			3000/2550	— 260	100
			4000-3550/2800	— 3000	200
42—	25′/10′	1300′	1500/1225	— 1275	50
43—	50′	2440′	2500/0	— 150	150
			3000/850	— 950	100
			4000/2200	— 2300	100
44—	25′	1100′	4000/850	— 1000	150

TABLE III

DETAILS OF THE GEOCHEMICAL TRAVERSES BETWEEN PURNAPANI AND SURDA

45—	50′	1550′	2500/450	— 550	100
			3000/650	— 750	100

Traverse No.	Sample interval (in ft.)	Length of traverse (in ft.)	Peak anomaly (Cu, ppm) Distance from N. E. end (in ft.)	Anomaly spread (in ft.)
1	2	3	4	5
46—	50′	2100′	4000/800 — 900	100
			2000/550 — 650	100
			4000/1750 — 1800	50
			4000/1900 — 2100	200
47—	50′	3600′	2000/200 — 300	100
			4000/1150 — 1600	450
			4000/1750 — 1800	50
48—	50′	3000′	2500/1200 — 1300	100
			4000/1450 — 1150	100
49—	50′	1900′	4000/500 — 700	200
			4000-3000/1050 — 1400	350
50—	50′	2000′	750/2000	—

CONCLUSIONS

The analytical data bring out numerous copper anomalies in relation to the background value which averages 50 ppm in the area. This background value is higher than the average copper content of normal soil which probably is of the order of 20 ppm. The study of relative frequency of peak anomalies shows that the number of peaks of higher values, particularly those above 4,000 ppm, are much more numerous than the peaks of lower values. In view of the present limit of determination, the actual values of peaks above 4,000 ppm, are unknown, but the large of some of the anomalies at this limit suggests that they may end in higher peaks. However, the frequency of high values indicates a general richness of metal content in the soils of this area.

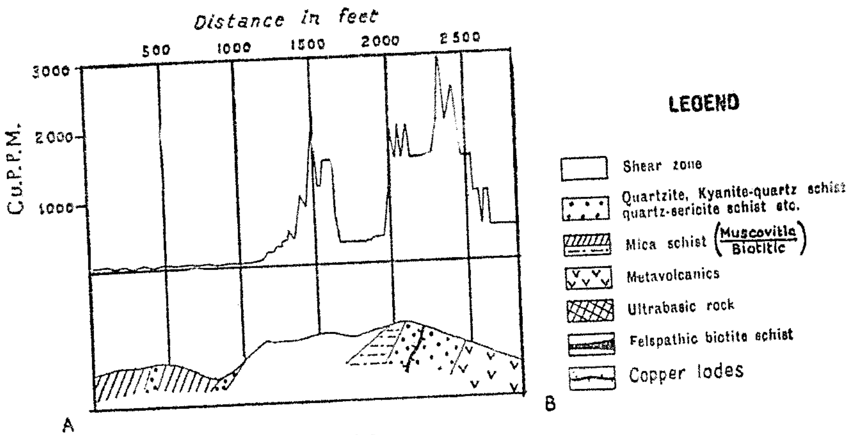
The most noticeable fact about the anomalies obtained in the area is their general persistence, both along and across the strike of the country rocks, in spite of wide fluctuations within comparatively short distances. There is, however, a significant pattern of distribution of the chemical highs. They are particularly abundant in the traverses falling in the Rakha Mines - Sideshar area (Table I) and Purnapani-Surda area (Table III) and comparatively few in the central portion between Chapri and Purnapani (Table II).

The geochemical anomalies developed in the soil bear a definite relation to the mineralized shear zone and the disposition of the lodes. In general the copper value shoots up rather abruptly from the region of 50 ppm to 1,000 ppm or more, once the shear zone is reached. Again, in this zone the metal content increases sharply close to a known lode, and the peak anomalies either rest directly on the lode or occur in close proximity as shown in Figs. 2, 3 and 4, which represent three sections along geochemical traverse lines. From the study of the two accompanying maps, it may now be observed that in the majority of cases the anomalies correspond to the known copper lodes. It also becomes apparent that the position of the highest peaks, with values of 4,000 ppm and above, is located at or very near the main lode.

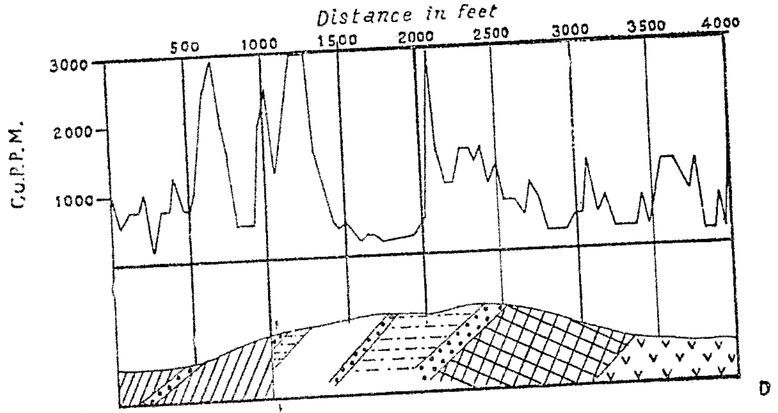
Usually, there is more than one peak anomaly in most of the geochemical profiles, and in some cases as many as five of them are present. When closely spaced, these anomalies may represent a single source, but when widely separated they probably represent different veins. A particular feature of the anomalies in this area is their unusually broad and rounded character. The spread of anomalies, shown in the tables above, varies widely, ranging from 50 feet to as much as 550 feet in some cases. The high order of anomaly combined with the large spread suggests very little leaching and considerable dispersion downhill. The comparatively weak anomalies in a particular zone which cause fluctuations in the profile, may be due to dilution of the soil in the topographic depressions. The most plausible explanation for the broad nature of anomalies can perhaps be found in the thick zone of primary haloes which is a characteristic feature of the mineralized zone in this area. The high peaks probably represent richer veins or lodes. Multiple lodes which are common in this area may also give rise to similar geochemical profiles even without the associated primary haloes.

The group of conspicuous anomalies located south of the main mineralized zone is of considerable importance as these indicate another persistent zone of mineralization, of which very little is known at present. At Rakha Mines these anomalies, often of a very high order, occur on the quartzite ridge or at its southern flank. Most probably these are related to the southernmost lode in this area which, according to the available reports, carries up to 9.64 percent copper. At Surda also, strong anomalies have been picked up in the epidiorite country where old workings exist but nothing is known so far about the nature of occurrence of the ore. Along the same zone and in the area in between, significant anomalies were noted wherever the traverse lines reached the area.

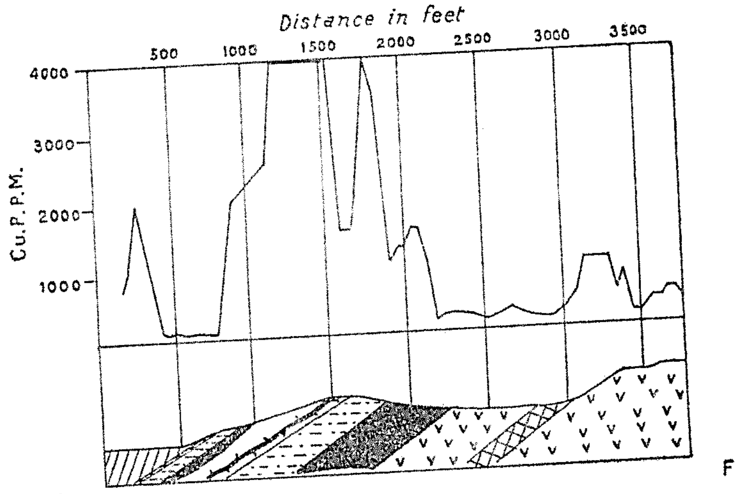
Test analyses for cobalt were carried out in some soil samples collected from the zones of high copper content to ascertain the relative distribution patterns and their possible application in localising the anomalous regions within narrow limits. The values obtained for cobalt generally show a variation from 10 ppm to 50 ppm and only in a very few cases the metal content goes



Section along A-B



Section along C-D.



Section along E-F

above 100 ppm. Although there appears to be a general tendency of higher cobalt content at the regions of peak anomalies for copper, no definite correlation is possible due to the flat nature of the curves because of the low range of variation in the values for cobalt.

From a few samples for arsenic and nickel, it is observed that for arsenic there is no significant variation in its distribution pattern, but nickel values show appreciable variation within the wide range of 40 to as much as 400 ppm. The copper ores from Rakha Mines and Mosaboni are known to carry pentlandite and millerite and as such a systematic study of the distribution pattern of nickel may be a useful supplement in the future geochemical prospecting in the copper belt.

The geochemical anomalies bear a close relation to the Spontaneous Polarization and Magnetic indications obtained during the earlier geophysical surveys in the area carried out by Messrs. P. C. Paul, K. R. M. Simha and H. V. Nagaraja Rao. In Pl. II the geophysical indications have been plotted alongside the chemical highs to enable a closer study of the results obtained by these methods. As the plotting involved transference of data from two different types of base maps originally used for the surveys the location of the points indicated in the plate may not be quite accurate. In view of this it would be desirable to correlate only the broad aspects or pattern of anomalies obtained by these methods. The geophysical anomalies plotted are mostly based on S. P. data, but in most cases these have a general agreement with the magnetic measurements, although local variations are common.

S. P. and Magnetic measurements were taken at 50 feet intervals along each of the traverses which were normally spaced 1,000 feet apart and carried across the strike of the country rocks. Detailed sub-traverses at 100 feet and 200 feet intervals were taken at promising areas to delineate the anomalous zones as shown in the accompanying map (Pl. II).

In conformity with the geochemical anomalies, most of the geophysical indications are confined to the main shear zone along the line of old workings. In both cases, fairly persistent high values were obtained in the Rakha-Sideshar area and similar relation exists in the Kendadih-Surda portion of the belt. In the latter tract the predominating magnetic highs have been explained due to the presence of magnetite-bearing quartzite and basic igneous rocks. But persistent geochemical anomalies in this area suggest appreciable copper mineralization and the magnetic highs may be ascribed to the probable prevalence of pyrrhotite and associated apatite-magnetite veins rather than to the presence of separate magnetic bodies. Moreover, the geological observations do not support the interpretation of the geophysicists, as the peaks, except the southern-most set, are restricted to the biotite-chlorite schists and kyanite-sericite quartzites. It may, however, be noted that the geophysical indications are much more numerous than the geochemical highs. Besides, the pattern of the geophysical peaks is much more regular than the geochemical ones.

In the central portion, between the Sideshar and Kendadih, geophysical anomalies with high values were often noted in a comparatively geochemically barren ground. This disagreement of results may perhaps be due to the greater depth of ore bodies, beyond the limit of diffusion.

The high magnetic values common in the area west of Rakha Mines have also been explained as being caused by the effects of concealed magnetic bodies in the area. Considering the nature of mineralization in this area, which consists predominantly of apatite-magnetite veins, this appears to be a plausible explanation, but the conspicuous geochemical anomalies indicate definite existence of copper.

From a study of the disposition of the peaks, both geophysical and geochemical, as well as the old workings an attempt can be made towards tracing the lodes in this area. It appears that there are at least three persistent lodes, two of which are included in the main shear zone and the third runs along a parallel shear zone to the south near the contact of meta-volcanics and the southern band of quartzite. Of these three the northern-most lode which includes the main Rakha lode appears to be more persistent and may ultimately correspond to the main ore body at Surda which is under development.

In the light of the present investigation, a systematic drilling programme in critical areas is recommended to assess the workability of the lodes. Besides proving the indications obtained in this particular area, the drilling campaign will be helpful in the appraisal of the geochemical methods and its applicability in the comparatively unknown portion of the belt.

ACKNOWLEDGEMENT

The authors are indebted to Messrs. John A. Straczek and F. N. Ward, of the United States Geological Survey for their initial guidance in the investigation in the field and laboratory respectively. It is a pleasure to acknowledge gratefully the co-operation of the officers of the Chemical section of the Geological Survey of India who carried out analytical work of over 4,500 soil samples.

GEOCHEMICAL PROSPECTING FOR GOLD-BEARING LODES IN THE KOLAR GOLD FIELDS, INDIA

S. NARAYANASWAMI *

ABSTRACT

The gold-bearing lodes of the Kolar Gold Fields in Mysore State, India, occur in regionally metamorphosed mafic volcanic rocks of Precambrian age. Of the four lodes which are now being worked in the field, the main Champion lode is a quartz vein zone containing native gold, togther with minor tourmaline, sparse scheelite, magnetite, ilmenite, galena, pyrrhotite and arsenopyrite. The three gold-bearing western sulphide lodes (Mc Taggart East lode, Mc Taggart West lode and Oriental lode), which have been recently developed in the Nundydroog mine in the northern part of the field, are mineralogically similar to the Champion lode, but much richer in sulphides, pyrrhotite, arsenopyrite, pyrite, chalcopyrite and sphalerite. Spectroscopic examination of the ores does not reveal appreciable amounts of trace metals other than lead in the Champion lode and other than arsenic and copper in the sulphide-bearing western lodes.

Three experimental geochemical soils sample line were spaced at intervals across the strike of the projected outcrop zone of the sulphide lodes and over the underground workings of the Nundydroog mine, and they have shown high arsenic anomalies over the Oriental, Mc Taggart West and Mc Taggart East lodes. The overlapping dispersal of arsenic in soil from these closely spaced lodes precludes close location of individual lodes. In view of the lenticular nature of the ore shoots and variation in arsenopyrite content in the lodes, both along the strike and down-dip, closer spacing of the sample lines will be necessary to outline ore shoots more precisely, There is no appreciable concentration of copper in the soil over the sulphide lodes. Further experimental work will be necessary to determine the possibility of using lead in the soil samples to locate sulphide-poor, gold-quartz lodes.

INTRODUCTION

Experimental geochemical prospecting was carried out in the Kolar Gold Field in Mysore State, India, during 1955 to find out the usefulness of soil sampling to locate and trace gold-bearing lodes in the field. Recovery of gold by washing soil and alluvium has been done since ancient times, and traces of gold are dispersed in the soil all over the field; but no practical method to

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* *Geological Survey of India.*

test for gold in the soil is yet available; an indirect method of testing for other trace metals associated with gold in the lodes was therefore adopted. Gold has been known to have been mined in the Kolar Gold Field from ancient times, and the present mines, operated by Messrs. John Taylor & Sons (India) Limited, have been in production for more than seventy years. The present work was mainly a reconnaissance soil sampling survey in the Nundydroog mine area at the northern part of the present mining belt (Fig. 1). Location Map), where gold-bearing quartz lodes and gold-bearing sulphide lodes are being worked underground. Because of extensive mining and surface debris, no site has yet been found suitable within the mining field for testing the sulphide-poor gold-quartz lodes, which have been the most productive lodes in the field till now. It should be emphasized that the present work is only preliminary, and additional studies are planned for the near future.

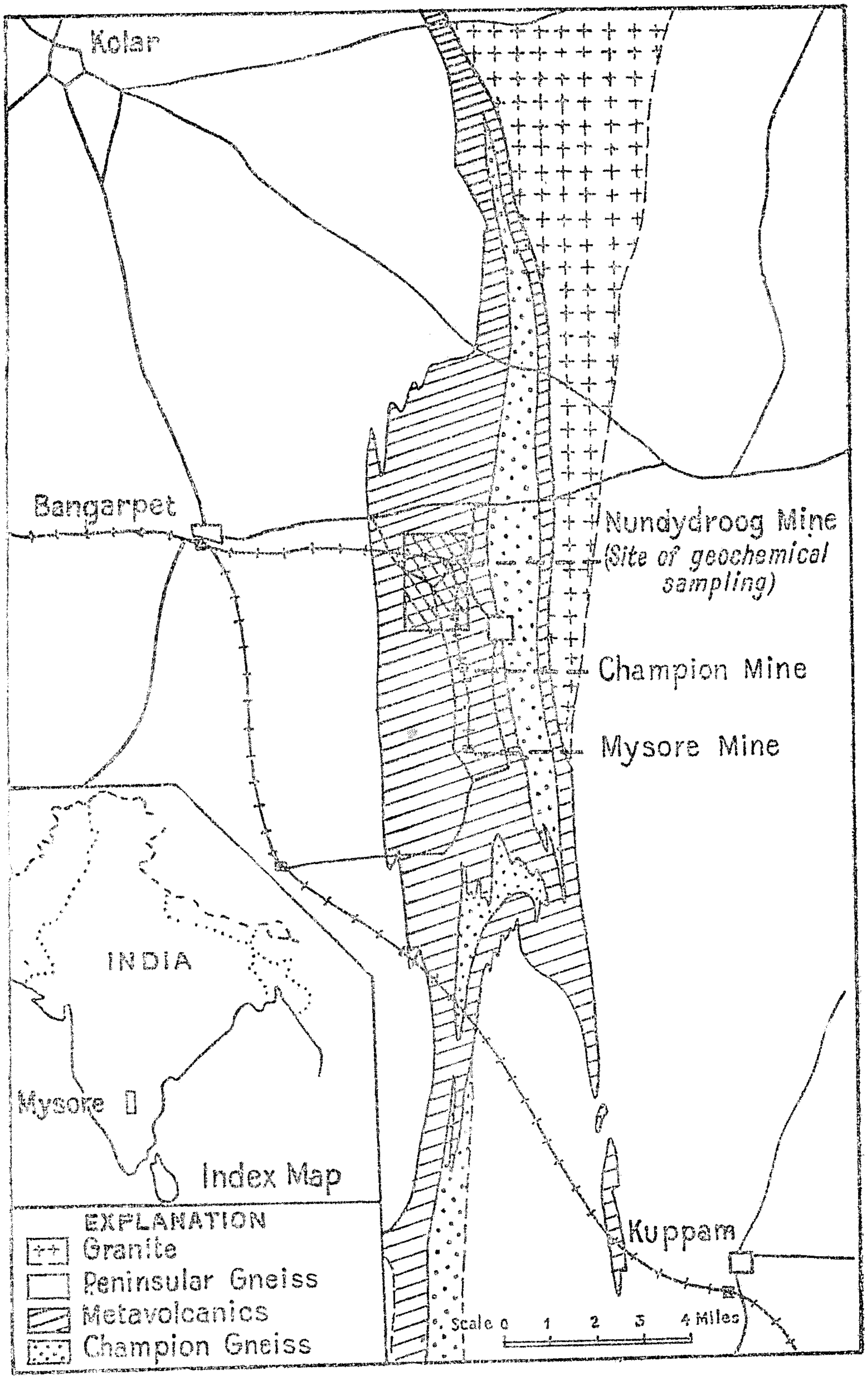
The sampling was carried out during January and February 1955 in the course of a program of detailed mapping of the Kolar Gold Field which was started by the Geological Survey of India during the fieldseason 1954-55. Messrs. N. Gopalakrishnamurty, D. Venkatramanan, and K. Appavadhanulu, Assistant Geologists, G.S.I. collaborated with the writer in sample Collection. A field laboratory for rapid analysis of the samples on the spot was set up by Mr. P. D. Malhotra, Chemist, G.S.I., who analyzed all the soil samples.

PHYSIOGRAPHY AND GEOLOGIC SETTING

The Kolar Gold Field is situated in the eastern part of the State of Mysore in southern India. The area is at the eastern edge of the Mysore Plateau and is a plain of low relief with an average elevation of about 21,950 feet above mean sea level. The climate is cool and dry with an average annual rainfall of about 30 inches. The soil cover is generally thin, ranging from a few inches to several feet except along stream courses which are filled with soil wash. The soil is of a deep reddish-brown or brownish-grey variety and is of residual origin, derived from the weathering of meta-volcanic rocks.

The principal rocks of the area comprise a suite of regionally metamorphosed mafic volcanic rocks of Precambrian age which form a part of the Lower Dharwar system. The rocks include fine-grained massive amphibolites, schistose amygdular amphibolites, medium to coarse-grained dark amphibolites and green fibrous amphibolites. A fine- to medium-grained porphyroblastic gneiss, known locally as Champion gneiss, occurs at the base of the amphibolite series along the eastern margin of the schist belt. Intrusive ortho-gneisses and granites surround the schistose series of rocks. All the rocks are traversed by dykes of

Fig.1



Geologic index map of Kolar Gold Field. Mysore State, India.
(After Mysore Geol. Dept.)

dolerite and pegmatite and are injected with vein quartz. The regional strike is northerly and the rocks dip steeply to the west.

GOLD-BEARING LODES

Among at least 6 gold-bearing lodes which are known, only four lodes —the Champion lode together with its branches, the Mc Taggart East lode, the Mc Taggart West lode and the Oriental lode— are now being worked in the field. The other lodes have not so far been adequately prospected and their economic value is not known. All the lodes have a northerly strike and dip about 70 degrees to the west. The Champion lode, a gold-bearing quartz vein zone, has been mined over a strike length of nearly five miles and to depths close to 10,000 feet. The three sulphide-bearing western lodes, which are roughly parallel to the Champion lode - (1) the Mc Taggart East lode about 850-900 feet west of Champion lode, (2) the Mc Taggart West lode about 1,100-1,200 feet west of Champion lode, and (3) the Oriental lode about 1,700 feet west of Champion lode – were discovered recently and are now being developed in the Nundydroog mine in the northearn part of the field.

MINERALOGY

The Champion lode is a vein zone composed of a series of parallel veins, stringers and lenses of bluish-grey to white translucent quartz. The lode ranges in thickness from a few inches to 20 feet and has an average thickness of about 5 feet. The lode contains native gold, together with minor tourmaline, sparse scheelite, magnetite, ilmenite, galena, pyrrhotite and arsenopyrite. The sulphides are very irregularly distributed and are estimated to make up less than 1 per cent of the lode. Spectroscopic examination of the ore did not reveal appreciable amounts of trace metals other than lead, which accords with the field observation that galena is the most abundant visible sulphide.

The gold-bearing western lodes are mineralogically similar to the Champion lode, but are much higher in sulphides. The sulphides include pyrrhotite, arsenopyrite, pyrite, chalcopyrite and sphalerite in descending order of abundance. Parallel stringers, lenses and veins of white to bluish-grey quartz occur within the mineralized zone. The sulphides make up roughly 10 to 15 per cent of the lode matter. The lodes pinch and swell along the strike and down dip; they range in thickness from a few inches to 25 feet, and average about 6 feet. The Oriental lode is the thickest of the three sulphide lodes. Except for arsenic and minor copper, spectroscopic analysis of the ore from the western lodes did not give appreciable amounts of other trace metals, including nickel, cobalt, antimony and lead.

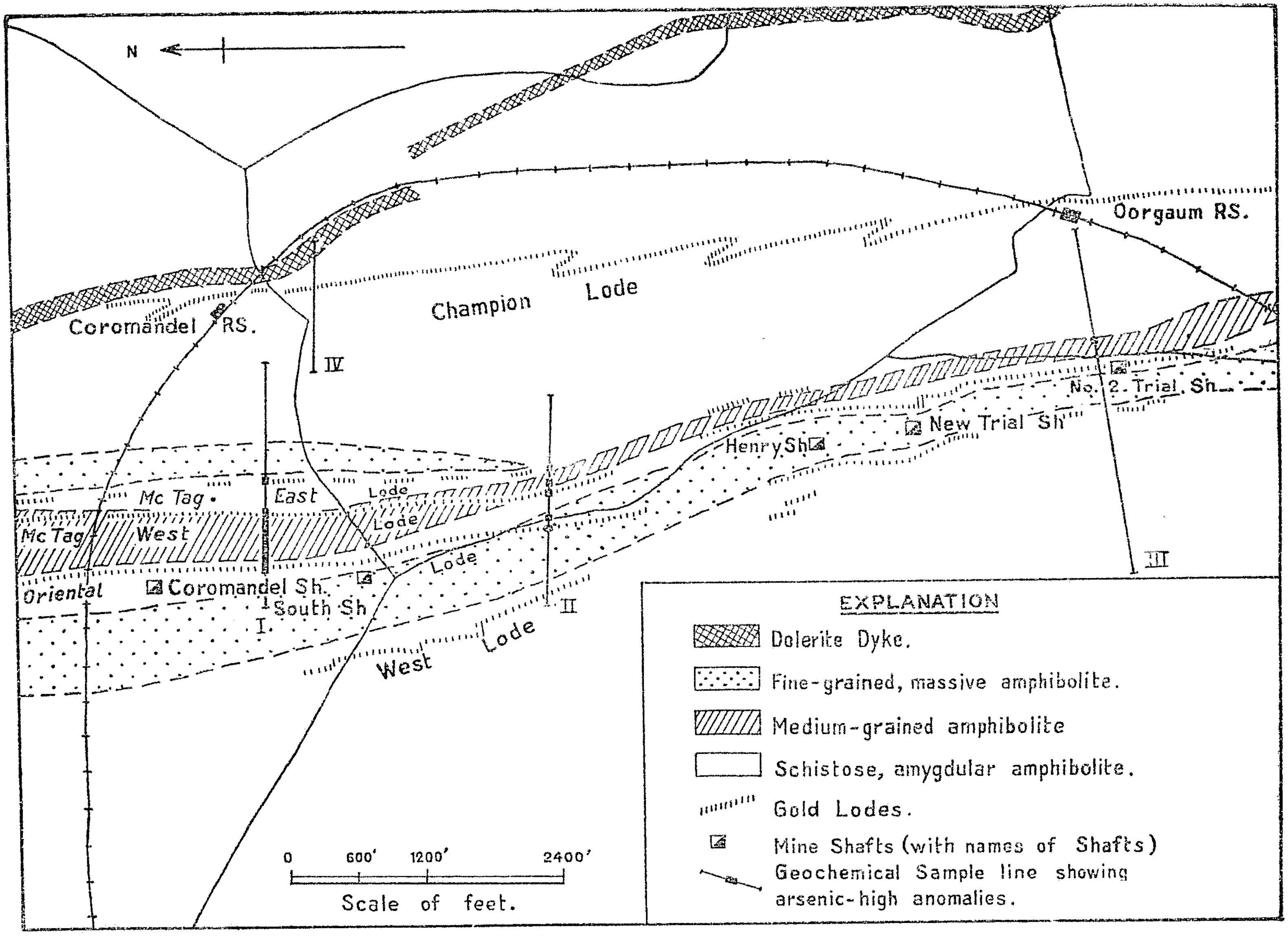


Fig. 2. Geological map of Nundydroog mine area showing geochemical sample lines.

GEOCHEMICAL INVESTIGATIONS

The Nundydroog mine area (Fig. 2) was selected for geochemical study because much information on underground geology of the western lodes is available, the surface area is least disturbed by mining, and rock and tailing dumps are few. The study was concentrated on the projected outcrop zone of the sulphide-bearing lodes over the present underground workings of the mine. Arsenic appeared to be the most feasible metal for determination as, (1) arsenopyrite was known to be present in abundance in all of the sulphide lodes and was fairly widely, though not uniformly distributed, (2) gold in the lodes is known to be intimately associated with arsenopyrite and it was thought possible that high grade ore shoots might be distinguishable from lower grade ore or mineralized rock, and (3) the arsenic determination is relatively simple and rapid. A comparison of the gold values on the mining company's assay maps with my observations of the mineralogy in different parts of the lodes in the mine indicated that gold is associated with arsenopyrite and high gold values and abundant arsenopyrite go hand in hand. Arsenic was therefore tested for in all the soil samples.

Copper war also tried in the first sample line, but since there was only a slight concentration of this metal reflected in a very low anomaly (Fig. 3), Copper was not determined in analysis of subsequent soil samples.

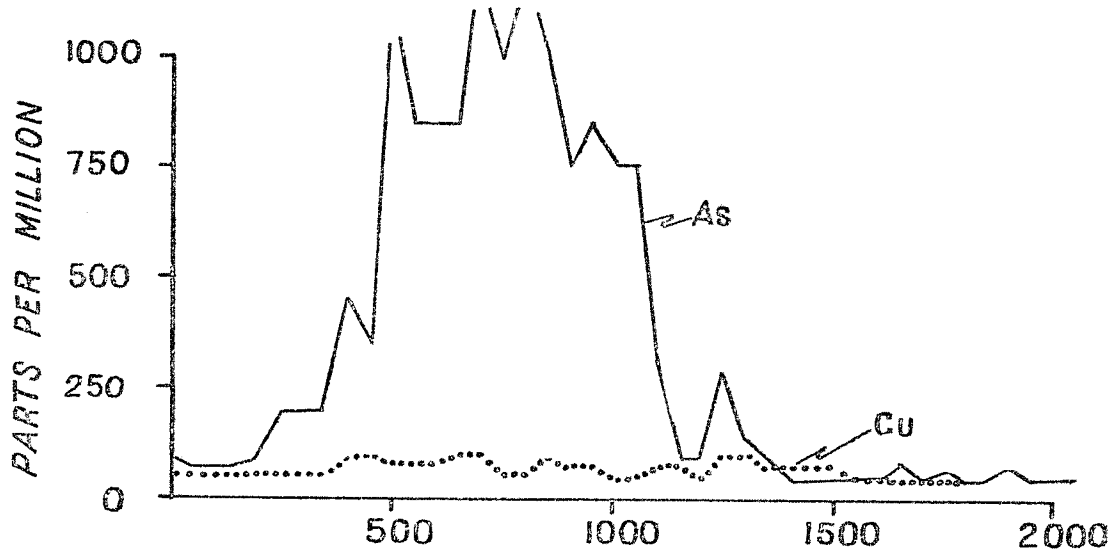


Fig. 3. Dispersion of arsenic and copper in soil along sample line I. Nundydroog mine K.F.G.

Samples from one small experimental line (Sample line IV) across the probable outcrop of the Champion lode in the northern part of Nundydroog mine were tested for lead. No other soil sample traverses were located over this lode because the entire five-mile-long outcrop zone has been mined in the old days by open-cast pits and much of the ground is now covered with dumps or is built up and covered with reworked soil. Contamination under these circumstances would be unavoidable and difficult to evaluate.

The possibility that silver may prove even more useful than arsenic in locating the goldlbearing lodes was realized, especially as the arsenic-poor gold-quartz lodes might be located by this method. But essential laboratory equipment for quick analysis of silver was not available.

LOCATION OF SAMPLE LINES

Three sample lines were run at intervals across the western lodes and a fourth short line across the Champion quartz lode as shown in Figure 2. The interval between sample lines I and II is about 2,500 feet, and that between sample lines II and III about 5,300 feet. The large interval of 5,300 feet between the two latter lines could not be avoided, as no suitable site of undisturbed ground was found, because of buildings and dumps around the Henry Shaft.

SAMPLING PROCEDURE

The soil samples were collected from pits placed at 50-foot interval along the sample lines. The pits measured about 8 inches by 8 inches in cross section, and were dug with a pointed steel bar to a depth of 18 inches. In order to check the possibility of surface contamination, the soil samples were collected from three depths levels, 6 inches, 12 inches and 18 inches below the surface. In view of the close spacing of the three western lodes, a 50-foot sample interval was chosen in the present experimental survey in order to segregate, if possible, the dispersion pattern of each individual lode, although a 100-foot spacing probably would have been adequate for a systematic survey of the entire belt. The sample lines and sample stations were all located on a plane-table map with a scale of 360 feet to the inch.

The soil from each horizon was dried on the spot, sieved through screens of 5 mesh and 20 mesh to the inch, and about 5 grams of the fines collected in waterproof alkathene plastic bags, numbered and sealed. There was practically no vegetation in the area and the humus content of the soil is very low.

METHOD OF ANALYSIS

Arsenic was determined by a spot test method, utilizing a modified Gutzeit apparatus, a method used by the United States Geological Survey (Almond, 1953). The soil sample was fused with KOH, dissolved in HCL and an aliquot used to develop a coloured spot on filter paper soaked in mercuric chloride. This was compared with standard spots.

Copper and lead were determined by the method used by Almond and Morris (Almond and Morris, 1951), but by using 1 : 3 HNO_3 digestion instead of dilute sulphuric acid as recommended by the United States Geological Survey (Almond, 1953). Copper was estimated by dithizone, using ammonium citrate buffer and a pH of 1.5 to 2.0. The colour of copper dithizonate was matched against suitable standards. Lead was also estimated by developing the colour of the lead dithizonate, using a buffer composed of ammonium citrate, potassium cyanide and hydroxylamine hydrochloride.

DISCUSSION OF RESULTS

High arsenic values, far above local back ground levels of less than 50 ppm, were found over the surface trace of the sulphide lodes, but in some cases the individual lodes could not be precisely located. The lodes are so close to each other and arsenic so widely dispersed that anomalies of individual lodes apparently overlap each other.

All the samples from the three depth levels, 6 inch, 12 inch and 18 inch, along sample line I were analyzed for arsenic, but only samples from 12 inch and 18 inch depths were analyzed from sample line II. Samples from only 12 inch depth were analyzed from sample line III. The results are shown graphically in Figure 4. It may be seen from the anomaly curves for sample line I and sample line II (Fig. 4 a and 4 b.) that there is no evidence of any surface contamination. The anomaly curves are more or less the same for the three depth-levels sampled, although the arsenic values are relatively high or low, and the anomaly peaks are correspondingly high or low. The shallow samples would have served equally well to bring out the arsenic anomaly. The 12 inch depth was finally selected for sampling and analysis, as a precautionary measure to avoid possible surface contamination and also with the hope of locating individual lodes more accurately. Bedrock was usually 18 inches below the surface.

ARSENIC ANOMALY

The background value in all the lines over the country rock is less than 50 ppm, arsenic. On sample line I, there is a major peak with values of over

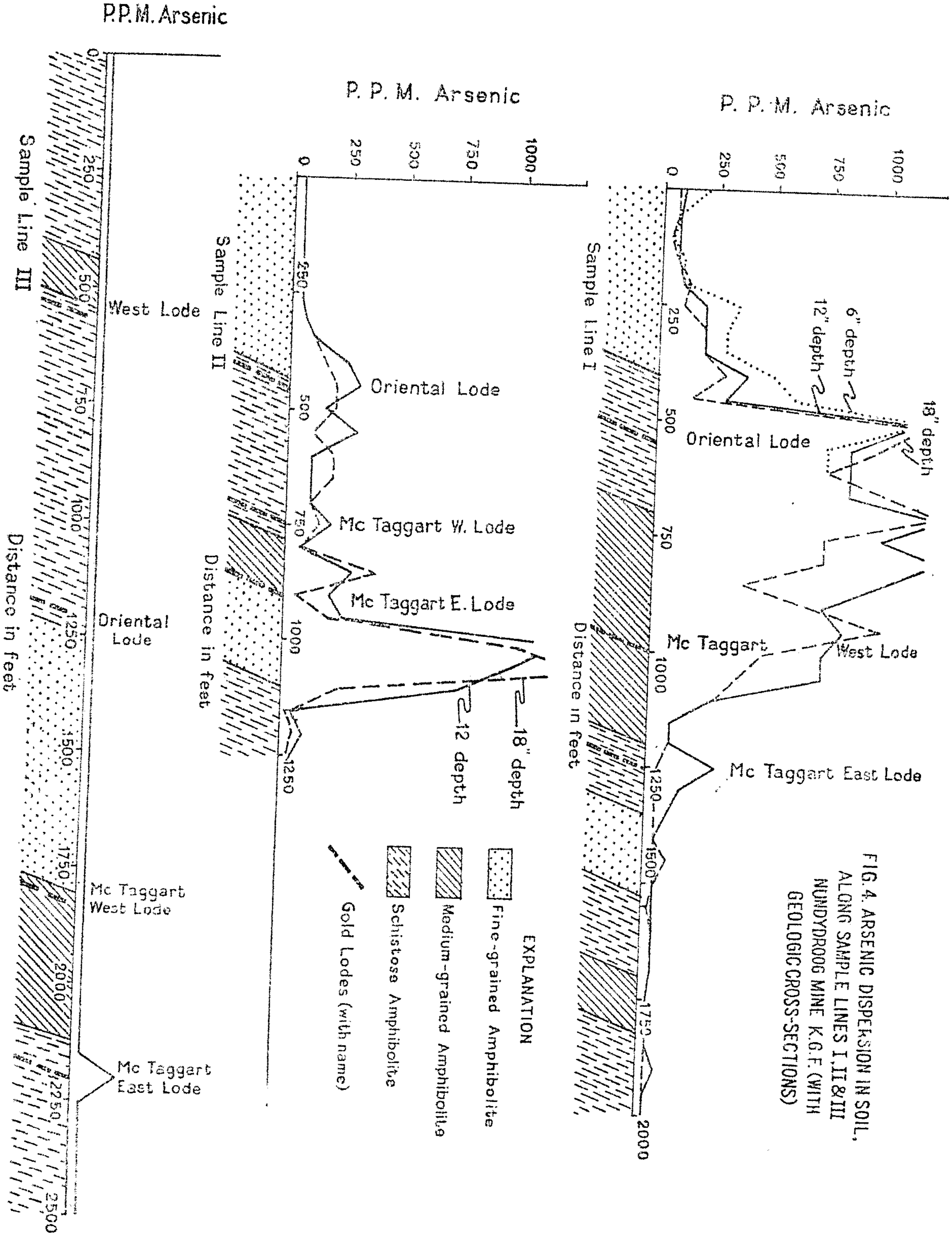


FIG. 4. ARSENIC DISPERSION IN SOIL, ALONG SAMPLE LINES I, II & III NUNDYDROOG MINE K.G.F. (WITH GEOLOGIC CROSS-SECTIONS)

1,000 ppm of arsenic over the combined area of Oriental lode and Mc Taggart West lode, and a minor peak with maximum value of 300 ppm over the Mc Taggarts East lode. Within the major anomaly, there is a minor peak with maximum value of 850 ppm over Mc Taggart West lode. The large anomaly over the combined area of the Oriental lode and the Mc Taggart West lode may be due mainly to the Oriental lode which is known from underground workings in the South Shaft area to be the thicker of these lodes.

In sample line II there are two small peaks with maximum values of 200 ppm over the Oriental lode, a small peak with maximum value of 200 ppm over the Mc Taggart West lode, a small sharp peak with maximum value of 400 ppm between Mc Taggart West and Mc. Taggart East lodes, and a very sharp high peak with a maximum of over 1,000 ppm towards the stream over the Mc Taggart East lode. Migration of the soil and of arsenic downslope eastward is likely. There are indications of old workings along the Oriental lode and the Mc Taggart West lode, from which soil and waste material have been removed and thrown over the eastern side of the old pits. The double peaks of the arsenic anomalies over the Oriental lode and Mc Taggart West lode seem to be due to contamination of the soil at the eastern side of these lodes by waste material from the old workings. The high peak in the arsenic anomaly over the Mc Taggart East lode may be partly due to greater soil wash towards the stream and resulting contamination. The much smaller anomalies over the Oriental lode and the Mc Taggart West lode along this sample line are most probably due to the low arsenopyrite content of the lodes, but this point could not be checked, as there are no underground workings near the surface at this locality.

Along sample line III all the samples showed less than 50 ppm arsenic, except for a stray value of 200 ppm in one sample whose location roughly coincides with the probable outcrop position of Mc Taggart East lode. This condition reflects what is known of the lodes in underground workings in this area. South of the Henry Shaft, only the Mc Taggart West lode has been developed in underground workings of the New Trial Shaft in Nundydroog mine and in the No. 2 Trial Shaft in the Champion mine. All the lodes here are known to pinch out gradually and disappear south towards the Champion mine. The Mc Taggart west lode, exposed in underground warkings of No. 2 Trial Shaft of Champion mine, south of sample line III, is lenticular, and payable lengths of the lode are usually very short. The Oriental lode is also apparently not strongly developed south of the Henry Shaft, but there are no underground workings on this lode in that area.

Closer spasing of the sample lines along the strike will probably be necessary to bring out the arsenic anomalies as it is so widely dispersed that anomalies of individual lodes are not distinguishable with centainty. It might be possible to bring out individual lodes more cleary by sampling bedrock.

SAMPLING OVER THE CHAMPION LODE

No systematic sampling has yet been done to test the feasibility of using geochemical survey over the gold quartz lodes in the area. The single short line of samples taken across the Champion lode (Sample line IV, Fig. 2) shows no apparent concentration of lead in the soil. It is proposed to locate suitable sites along the strike extensions of the lode just outside the mining belt to test the suitability of the method.

When equipment for testing silver in the soils is available, it is also proposed to carry out systematic soil analysis for silver in the area to determine the feasibility of using silver for locating the gold-bearing quartz lodes as well as gold-bearing sulphide lodes in the field.

HYPOGENE DISPERSION OF ARSENIC IN THE VICINITY OF SULPHIDE-BEARING LODES

In addition to soil sampling an experimental sampling of the wall rock at regular intervals was also carried out in a small cross-cut at the western side of the Oriental lode on the 38 level from the Henry Shaft to test the hypogene dispersion of arsenic in the vicinity of a lode and to find out the possibility of detecting the presence of sulphide-bearing blind ore bodies underground. The arsenic values of 7 samples of the wall-rock collected at intervals of 5 feet are shown below:

Sample Number	Distance from lode	Arsenic Value	Nature of wall-rock
G.1	5 feet	50	Fine-grained, amphibolite.
G.2	10 feet	100	Thin zone of altered wall rock with micaceous partings.
G.3	15 feet	50	Fine-grained amphibolite.
G.4	20 feet	200	Zone of altered wall-rock with micaceous
G.5	25 feet	200	partings and fine quartz stringers.
G.6	30 feet	50	Fine-grained amphibolite.
G.7	35 feet	50	Fine-grained amphibolite with minor zones of micaceous partings.

The high arsenic values seem to be associated with narrow zones of primary mineralization paralle to the main lode, and the unaltered amphibolite in between these zones show only feeble backgroun values of 50 ppm arsenic or less. There does not seem to be any gradual increase of arsenic values in the wall rock toward the lode, which is generally expected in primary hypogene dispersion of metal in the wall rock on either side of an ore deposit. The gold-bearing lodes in the field are known to be highly folded and repeated at places; many branches of the lodes had been missed during the mining of high-grade ore in the old days. It is proposed to continue this experimental work by more systematic sampling of wall rock at different parts of the lodes in the future to conclusively test the use of geochemical prospecting underground for exploration of blind ore bodies.

CONCLUSIONS

The following tentative conclusions may be drawn from the preliminary experimental geochemical soil survey in the Kolar Gold Field:

1) Gold-bearing sulphide lodes of Kolar Gold Field which carry appreciable amounts of arsenopyrite can be located by analysis of overlying soils for arsenic.

(2) A reconnaissance soil survey in the outcrop area over the underground workings of the gold-bearing sulphide lodes of the Nundydroog mine has shown high arsenic anomalies over the Oriental, Mc Taggart West and Mc Taggart East lodes, but overlapping dispersal of arsenic in soil from these closely spaced lodes precludes close location of individual lodes.

(3) The intensity of high arsenic anomalies is related to the arsenopyrite content of the lodes; but low arsenic anomalies, or values of arsenic not above background levels may overlie ore shoots that do not reach the surface.

(4) In view of the lenticular nature of the ore shoots and variation in the arsenopyrite content in the lodes, both along the strike and down-dip, closer spacing of the sample lines will be necessary to outline ore shoots more precisely.

(5) There is no appreciable concentration of copper in the soil despite the presence of minor chalcopyrite in the sulphide lodes.

Further experimental work is required to determine if the sulphide-poor gold-quartz lodes can be located by analysis of soil samples for lead, and the possibility of utilization of silver as the detecting element should be determined. Experimental work should also be continued underground to conclusively test the usefulness of analyzing wallrock in the vicinity of lodes to locate blind ore bodies.

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GEOCHEMICAL STUDIES IN THE ZAWAR ZINC-LEAD AREA, UDAIPUR DISTRICT, RAJASTHAN, INDIA

J. A. Straczek * and K. Ganeshan * *

ABSTRACT

The Precambrian mesothermal zinc-lead deposits of the Zawar area, Rajasthan, India, are localized along fault and shear zones in dolomites and dolomitic rocks of the middle Precambrian Aravalli system. Geochemical investigations included study of the hypogene distribution of zinc and lead and of the surficial supergene dispersion pattern of these metals.

There is no evidence of significant hypogene migration of lead or zinc away from fracture controlled replacement veins in the host rock. Evidently influx of ore metal sulfides was through fractures along which replacement occurred on very steep diffusion gradients.

The supergene dispersion pattern of the ore metals in rock is normal. Lead is relatively immobile and reflects closely the primary distribution. Zinc is evidently leached from veins and stringers and precipitated in nearby wall rocks; its limited tendency to migrate gives rise to anomalies that broadly reflect the underlying pattern of primary mineralization.

Dispersion patterns of ore metals in soils in one small area sampled appear to reflect underlying mineralized zones but are perhaps modified by alluvial contamination.

Gossans appear also to carry abnormally high amounts of the ore metals.

For the geologic conditions at Zawar geochemical prospecting appears to be a valuable tool to locate mineral deposits.

INTRODUCTION

India has an ancient history of mining and smelting of ores of non-ferrous metals, recorded in numerous long abandoned old mine workings, prospect pits, slag heaps and ruins in mineral districts scattered throughout the country. But present production of non-ferrous metals in India is small, and ever increasing demands are being met largely by imports. It is imperative, therefore, that internal production be increased. Old mineral districts must be geologically mapped and studied in detail and prospecting and exploration in areas determined to be geologically favorable must be carried out in order to prove known depo-

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sits and to find new ones. To guide exploration and facilitate the discovery of ore deposits geochemical prospectig was begun early in 1954 by the Geological Survey of India, with the establishment of a rapid-method chemical laboratory at Calcutta and the initiation of a field program of sampling and trace analysis of rocks and soils in mineral districts already under intensive geological study. One of the first field investigations of the method was in the Zawar zinc-lead area. Udaipur District, Rajasthan.

The Zawar deposits were worked from the time of their purpoted discovery late in the 14th century to the begining of the 19th century when the mines were abandoned. In 1946, after exploratory work during War II by the Geological Survey of India disclosed an ore deposit at the site of what is now the Mochia mine, they were brought into production again. Smelting of zinc appears to have been carried out in Zawar at least 200 years before the introduction of commercial zinc smelting in Europe. The presence of about 200,000 tons of residues and clay retorts from zinc smelting operations, and about 35,000 tons of lead slags, attests to the scale and duration of past mining and smelting operations. The Zawar area is the only producing lead-zinc district and is the largest known occurrence of this metals in this country.

During the period of ancient mining intensive prospecting and development was carried on over the whole of the mineralized ground so that few favorable localities were left undisturbed. These ancient operations are evidenced by hundreds of large and small pits and open stopes, and the debris from these workings is widespread. This condition necessarily limited the scope of geochemical studies not only because of probable contamination of soils over most of the area but because the old workings so thoroughly explore the geologically favorable ground. Accordingly, the geochemical approach to the finding of zinc and lead deposits at Zawar was directed mainly at determination of the general applicability of the method, which would then be applied to geologically similar, but less intensively explorated areas, and to new areas.

LOCATION AND PHYSIOGRAPHIC SETTING

The Zawar area is about 340 miles southwest of Delhi, capital city of India, and 16 miles south of the city of Udaipur, Udaipur District, Rajasthan State (formerly Rajputana) (Fig. 1). The greatest concentration of known deposits are in an area of about 25 square miles that lies near the east side of the north to northeasterly trending Aravalli range in northwestern India. The topography is rugged. Steepsided ridges controlled by resistant beds rise from 300 to 1,000 feet above intervening hilly lowlands and narrow valleys. Nearly all of the known zinc-lead mineralization occurs on the hills and rigdes, the highest of which are just over 2,000 feet in altitude.

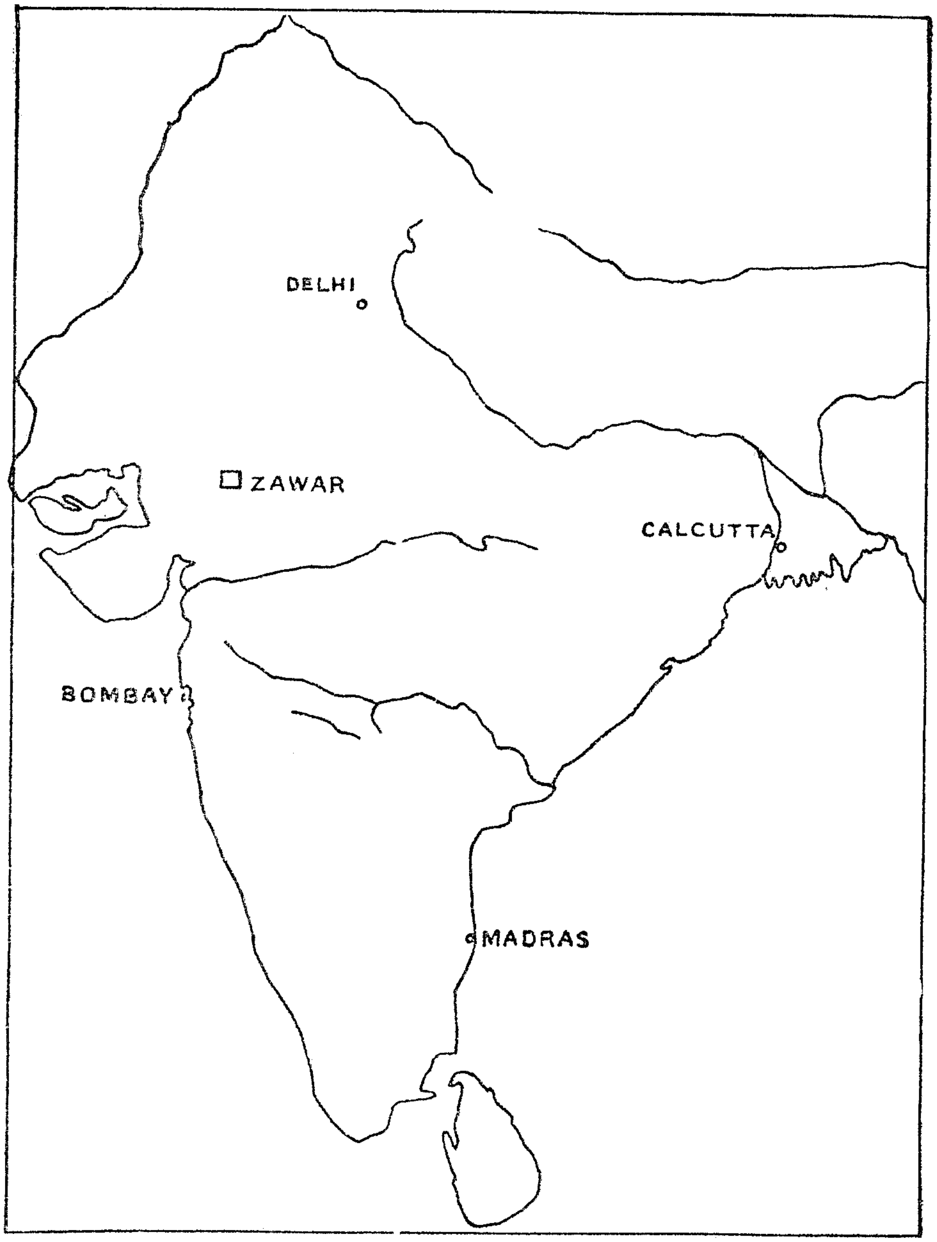

Fig. 1. Index map of India, showing location of the Zawar zinc-lead area.

Even summit levels of flat topped hills about the Zawar area are remnants of a widespread, gently warped, uplifted and dissected surface of peneplanation that revels highly deformed rocks of diverse types. It is believed to be a resurrected surface of pre-Deccan trap (Late Cretaceous or older) age. The present drainage system of the area has in part been superposed across strike ridges of resistant rock and is therefore in part inherited from an old drainage system presumed to have been developed on a cover of post-peneplane rocks now entirely stripped away by erosion during and subsequent to the uplif of the Aravalli range. The highest hills and ridges of the area are now several hundred feet below the old surface.

CLIMATE

The climate is monsoonal, semi-arid, with an average annual rainfall of 25 to 30 inches, 90 to 95 per cent of which falls between the months of June and September, generally in torrential downpours of short duration. Maximum temperatures during the pre-monsoon hot season reach 120 degrees Fahrenheit, and the diurnal temperature fluctuation is as much as 40 degrees. Minimum temperatures during the months of January and February occasionally fall just to the freezing point. The sharply demarcated wet and dry seasons, coupled with the high run-off during the monsoon period, gives rise to an ephemeral drainage system, which is typical throughout this part of India.

ACKNOWLEDGEMENTS

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GENERAL GEOLOGY

The rocks of the Zawar area are part of the Precambrian Aravalli system of northwestern India and include a low grade assemblage of metamorphosed sedimentary rocks that totals 11,000+ to 17,000+ feet in thickness, together with minor metamorphosed and unmetamorphosed mafic igneous rocks. The detailed geological column for the Zawar area is presented for the first time:[1]

GEOLOGICAL COLUMN

Quaternary

- Recent to subrecent (alluvial soils and low river terrace deposits)
- Pleistocene (?) (high terrace deposits)

——— unconformity ———

Tertiary (?)

- Eocene (?) (olivine dolerite dykes of apparent Deccan trap age)

Precambrian

- Precambrian (meta-dolerite dykes and stocks)

Precambrian	Thickness (feet)
Aravalli system	
Tiri series	
Zawar formation (phyllite and slate, with subordinate interbedded dolomite, quartzite, autoclastic breccias, conglomerates and quartz phyllite)	3,000+
Borai Magra formation	
Harn member (quartzite)	0— 500
Mochia member (mainly dolomite, gritty arkosic dolomite and dolomitic arkose; subordinate phyllite and quartzite)	0—1,500 +
Mandli formation (gritty and conglomeratic greywacke, in part dolomitic; impure quartzite; phyllite)	1.000—3,000
Kathalia formation (carbonaceous phyllite, phyllite, and subordinate dolomite)	3,000—3,500
Kanpur formation (quartzite and dolomite)	400—900
——— unconformity ———	
Sisa Magra series	
Dantali formation (quartzite)	2,000—2,500
——— unconformity ———	
Sisa Magra formation (quartzite conglomerate)	2,500+

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[1] A detailed report of the geology and zinc-lead deposits of the Zawar area is in preparation by the senior writer and his co-workers of the Geological Survey of India.

The lowest stratigraphic unit, the Sisa Magra formation, is known to be one of the basal formations of the Aravalli system (Heron, 1953), but neither the base nor the top of the system is exposed in the Zawar area.

The structural pattern is exceedingly complex and is the product of two distinct major periods of tectonic activity each of which was characterized by intense folding and faulting. Dips of beds and foliation are commonly steep and locally beds are overturned. Folds are isoclinal and fold axes plunge at moderate to steep angles. The major faults include mainly high angle longitudinal and oblique faults that have apparent displacements of up to several thousands of feet, and minor faults, related to the major ones, have developed in the competent beds. These faults are in turn offset by high angle transverse faults. Axial planes of major isoclinal folds and longitudinal faults have highly curved traces; these structures having been folded during the second major tectonic epoch.

The major periods of tectonic activity that affected the Aravalli rocks of northwestern India are of early or middle Precambrian age. The later periods of structural disturbance were far less intense and produced mainly high angle gravity faults and minor folds (Heron, 1953).

SOILS AND ROCK WEATHERING

Rock exposures are widespread. There is no extensive alluvial or residual soil cover even in the lowlands. Conditions of weathering and erosion produce only relatively thin, immature, brown soils that show little evidence of zoning. The soils contain numerous angular fragments of relatively fresh rock and overlie essentially unweathered bedrock. Talus deposits are not common and where developed are thin and of small areal extent.

GEOLOGY OF THE ZINC-LEAD DEPOSITS

GENERAL FEATURES

Zinc-lead mineralization is restricted almost entirely to the dolomite and dolomitic rocks of the Mochia member of the Borai Magra formation. Minor mineralization occurs also in the thin dolomite members of the Zawar formation, and more rarely in the Harn quartzite member of the Morai Magra formation. The deposits are deplacement veins and vein zones controlled by fractures and relatively small faults most of which dip steeply and are nearly parallel to the strike of the host rocks. Minor mineralization occurs along some of the late transverse faults which indicates that mineralization postdates or overlaps the period of latest faulting. There is evidence only of very minor post-mineral deformation. The olivine dolerite dykes and the fractures which localize them are post-mineral in age, although some of the dykes apparently are emplaced along pre-mineral faults.

The deposits are outlined by numerous old pits and stopes that follow the mineralized zones. The ancient miners worked the ore zones to depths of as much as 500 feet below highest outcrops. The old workings indicate that the deposits are tabular bodies, generally steeply dipping to vertical, which range in width from a few inches to 140 feet and in length from several feet to nearly 3,000 feet. The Mochia mine, the only operating mine in the Zawar area, presently producing about 300 tons per day, is on a mineralized zone outlined by the longest and widest old workings of the area (Fig. 3); new underground exploration and development of this deposit confirms that the ore body is at

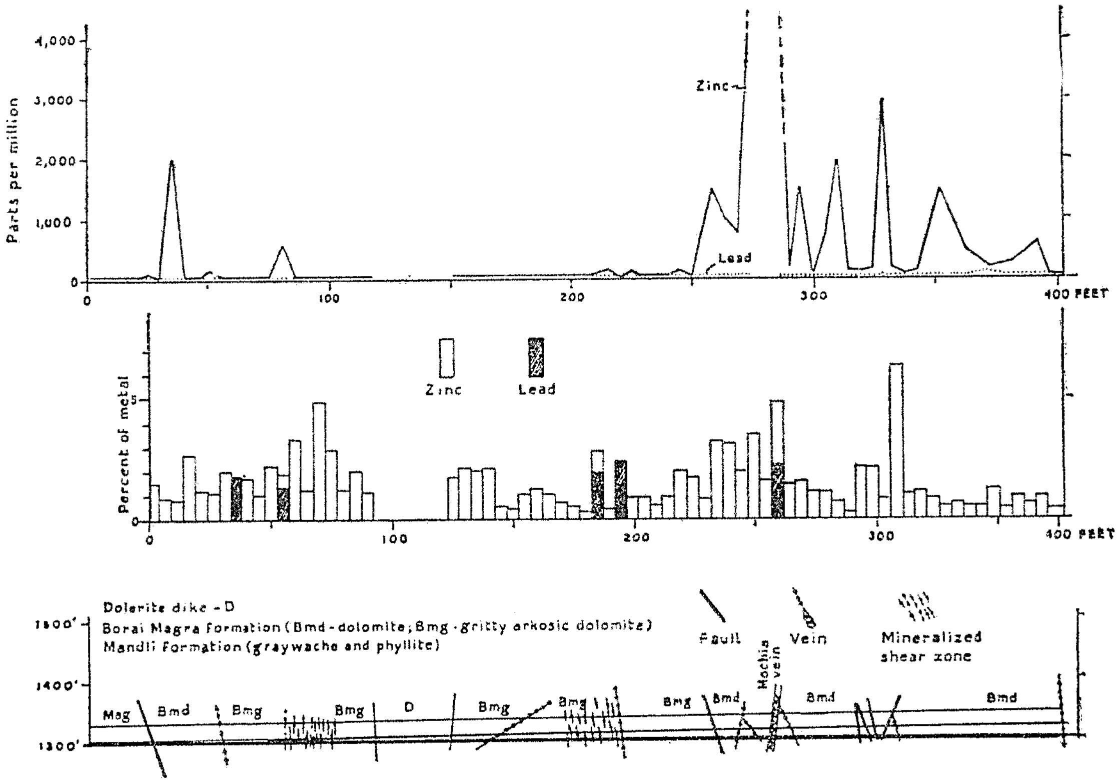

Figure-2.

CORRELATION OF GEOLOGY, ASSAY VALUES AND APPARENT HYPOGENE DISPERSION
OF
ZINC AND LEAD IN No.6 ADIT

50 0 50 100 FEET

least as large as that indicated by the old workings. In fact, there is strong evidence that mineralization on the Mochia may be continuous for a length of nearly one mile.

MINERALOGY AND ALTERATION

Ore is not generally visible in the upper parts of the old workings, although narrow veins and stringers of sulphides, together with their supergene alteration products can generally be seen. Sphalerite, galena and minor pyrite are the most commonly visible sulphides. In the Mochia deposit sphalerite is the predominant ore mineral and galena is next in abundance. As well as minor pyrite, arsenopyrite and chalcopyrite are sparse minerals; rare tetrahedrite (?) is also present. Native silver and argentite are common but very minor supergene minerals, which become less abundant in depth. Gangue minerals are minor in amount and are irregularly distributed; they include small veins and stringers of coarse to fine grained milky quartz with associated microcline, and stringers of crystalline dolomite. Partly oxidized sulphide veins in the Mochia mine contain limonite smithsonite, anglesite and plumbian aragonite, and in places fractures and cleavage surfaces in the host rocks are coated with malachite.

Wall rock alteration is characterized by the local development of amesite and sericite along shear planes and vein contacts in the mineralized zones, especially in the gritty arkosic dolomite and dolomitic arkose; but there is no appreciable alteration of the host rocks between pre-mineral shears and fractures. Alteration is closely associated with sulphides and is so restricted in distribution and extent that it is not a useful guide to ore.

OXIDATION

The mineralized zones form no conspicuous outcrops and in general appear to be poorly exposed, which is not surprising in view of the comparative lack of resistant minerals in the lodes. Where seen in extensions away from old workings the zones are manifested by veins and stringers of limonitic gossan, and in places similarly distributed iron oxides can be seen in the dolomite and dolomitic rocks between old workings. It is evident that the old miners were guided in their prospecting by the present of gossan outcrops, which they must have found from experience were underlain by ore minerals. Where the mineralized zones were covered, the presence of fragments of limonite in surface debris and thin soils probably led the old prospectors to the source deposits.

Oxidation is normally of shallow depth, ranging from an inch or so to several feet, although incomplete oxidation in the Mochia mine locally extends

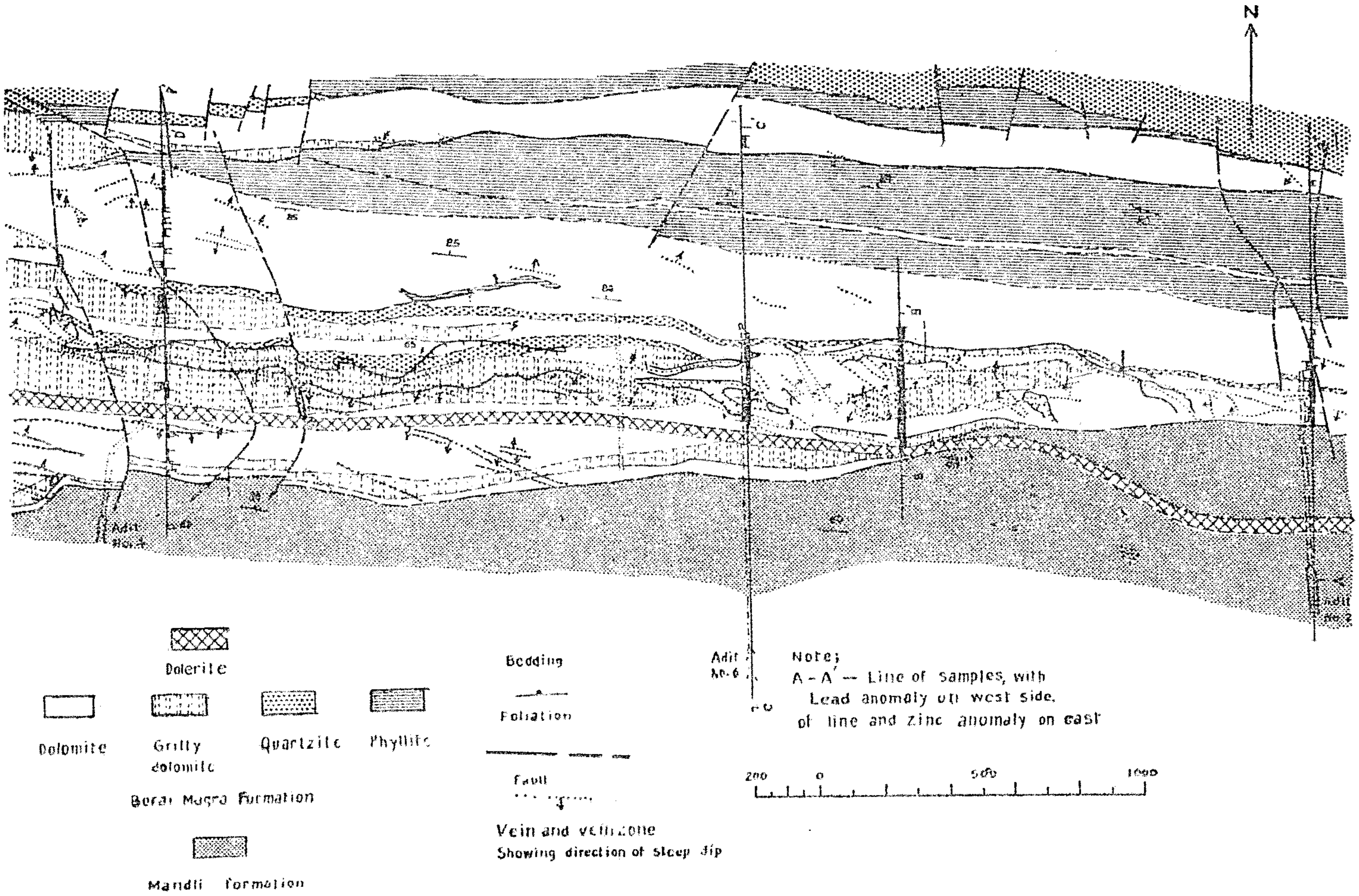

Fig. 3. GEOLOGICAL MAP OF THE MOCHIA MINE AREA
SHOWING ROCK SAMPLE LINES AND RELATION OF ANOMALIES OF ZINC AND LEAD
TO
ZINC LEAD VEINS

to a depth of as much as 450 feet. Deep oxidation is evidently restricted to narrow, fault controlled veins, but in the bordering mineralized wall rock, where the sulphides occur in discontinuos stringers and veinlets, oxidation is shallow. Ore bodies of supergene ore minerals apparently were not formed.

AGE OF MINERALIZATION AND CLASSIFICATION

The deposits are Precambrian in age. Mineralization may be genetically related to post-Delhi (Precambrian) – pre-Vindhyan (late Precambrian) granitic rocks of the Aravalli range. The deposits are considered to fall in Lindgren's mesothermal range, possibly lower mesothermal considering the presence of minor microcline in genetically associated quartz veins.

GEOCHEMICAL STUDIES

Geochemical studies involved: 1) determination of the primary dispersion pattern ore metals and some associated minor metals in fresh host rocks in the Mochia mine, 2) evaluation of the supergene dispersion pattern in surface rock across the veins and vein zones of the Mochia mine area, as related to the known distribution of the ore minerals and to the primary dispersion pattern, and 3) finding the range values of the ore metals in soils near mineralized zones. The Mochia mine area was selected for study of the primary and secondary dispersion pattern of zinc and lead in rock for the obvious reason that it is the only area with extensive accessible underground workings, and consequently much information is available on the nature and distribution, and localization and control of mineralization. However, soil sampling could not be done in the Mochia mine area owing to the wholesale contamination of soils from the numerous old mine workings, and another mineralized area on Zawar Mala ridge, which lies about 3 miles southwest of the Mochia mine, was selected for this study.

Practical considerations of time and economy led to the decision to restrict geochemical investigations to the favourable dolomites and dolomite rocks of the Mochia member of the Borai Magra formation, which so clearly localize most of the known deposit and all of the known ore deposits. It was believed that the results of these studies would be applicable to the location of zinc and lead mineralization in similar rocks in other formations of the area, as well as outside the area. This does not mean, however, that geochemical investigations in terrain underlain by phyllites and other unfavourable rocks might not have scientific or even practical value. Pre-mineral faults, mineralized where they cut across dolomite, extend across the unfavourable rocks, and ore bearing solutions might have risen anywhere along them. It is conceivable that such channelways would be reflected in measurable geochemical highs, and that some channelways might lead to deposits in dolomites which do not reach the surface, or which reach the surface some distance away as extensions of plunging folds or plunging fault segments.

METHODS OF ANALYSIS

All of the analyses of rock and soil samples were done in the headquarters laboratory at Calcuta. Zinc, lead and copper were determined by the rapid nitric acid digestion method with dithizone as the analytical reagent (Bloom and Crowe, 1953). No check was made for the completeness of extraction of the ore metals by this semiquantitative method. It is realized that the actual metal content of individual samples is not as significant as are the comparisons of relative amounts present, and these comparisons in general should be valid for each rock or soil type sampled, although the percentage extraction for each element determined, for the different rock types and for different soil types, may be variable. Since mineralization is confined to one general type of rock in the Zawar area and the soil in the one area sampled is typically low in organic constituents and not abnormally high in clay components, the factor of variable and low extraction was assumed to have little importance, particularly as the difference between high and low values of the ore metals analyzed as found to be great. Specific quantities of values of copper, lead and zinc of less than 50 ppm were not determined.

Arsenic was estimated by a spot test method utilizing a modified Gutzeit apparatus (Bloom, 1953).

For analysis of rocks the samples were crushed to minus 10-mesh, quartered, and ground in a mullite mortar to pass a minus 80-mesh stainless steel screen. For soils, the portion passing through an 80-mesh screen was analyzed (Lovering, Huff and Almond, 1950).

BACKGROUND VALUES

Normal or background values of heavy metals in rocks and soils in unmineralized areas form the basis for the recognition and interpretation of higher than normal values which we define as geochemical anomalies or "highs". But recognition of highs is not difficult when the difference between high and low values is great. If the lowest determined values also approximate known normal values in rocks and soils elsewhere, highs can be identified with a fair degree of confidence.

Apparently unmineralized fresh dolomites from the Zawar area were sampled and analyzed for zinc lead, and some samples were analyzed also for copper and arsenic. Dolomite of the Kathalia formation, nowhere known to be mineralized, was found to contain less than 50 ppm of both zinc and lead. Carbonaceous dolomite of the Zawar formation and an unmineralized lens of Mochia dolomite from the west side of the Zawar area contained less than 50 ppm of each of zinc, lead, copper and arsenic. Similar local background values were obtained for these metals in Mochia dolomite in the Mochia mine area, as well as on Zawar Mala ridge. Background values were not determined for soils outside the mineralized areas. Local background levels of zinc in soil overlying Mochia dolomite on Zawar Mala ridge were of the order of 100 ppm, and of lead were less than 50 ppm, which suggests that there may be slight enrichment of zinc in soils derived by weathering of the Mochia dolomite, but little of lead.

HYPOGENE DISPERSION OF HEAVY METALS

The Mochia ore deposit is localized along a main pre-mineral fault and fault zone and along subsidiary faults and shear zones. Veins and vein zones mark these faults and shear zones which were the principal channelways of mineralization, and beetwen them the wall rocks contain visible sulphides in the form of fracture controlled, irregular to parallel, discontinuous replacement veinlets and stringers, separated by rock in which finely disseminated pyrite is the only visible sulphide. Nowhere in the Mochia mine is the dolomite and dolomitic host rock entirely free of ore metal sulphides, as shown by inspection and by mine assay maps, and the boundaries of the ore body are gradational. The contrasting depositional environment of the ore sulphides, on the one hand along faults and shear zones, and on the other, as stringers and veinlets in the wall rock, is reflected both in the texture of the ore minerals, and in the distribution of sphalerite and of the distinctly later galena. In the fault-controlled veins the ore metal sulphides are commonly very fine-grained but in the wall rock ore zone they are generally coarser, and, except in the area of the lead ore shoot in the eastern part of the ore body where the zinc-lead ratio is lowest, galena is confined to the fault-controlled veins, or channelways of mineralization.

The process of deposition is postulated as follows:

Ore solutions ascended comparatively small openings along faults and shear planes and penetrated the fractured wall rocks. Deposition took place in a dynamic environment along the channelways where permeability was intermittantly reestablished by recurring movement along the faults, and the already deposited sulphides where granulated, recrystallized, and replaced by new additions of sulphides. In contrast, deposition in the wall rock fractures occurred in a relatively static environment in that solutions probably did not move, or at best moved very slowly through them. The sulphide forming constituents appear to have moved into the fractures by diffusion through solutions that filled them. As the initial open spaces were filled by sulphides continued influx took place by diffusion through an intergranular film of fluid; diffusion must have been a two-way process, with sulphide forming constituents moving outward from the channels as the displaced wall rock components and those of the replaced earlier sulphides moved back into the channels. The question might be raised: how much if any movement of the ore forming constituents occurred by intergranular diffusion through unfractured parts of the wall rock? Was there dispersion of ore metals in unfractured wall rock, and if so, was there more widespread dispersion in the coarser-grained gritty arkosic dolomite as contrasted to the normal fine-grained dolomitic host rock? The arkosic dolomite, in which the matrix dolomite is regionally recrystallized, might be excepted to be more permeable than the fine-grained dolomite (Ohle, 1951).

SAMPLING PROCEDURE

Only the megascopically unmineralized rock between visible sulphide stringers and veins was sampled, and the results were tied in with available assay values of channel or chip samples. Samples were taken along the walls of the adit crosscuts at some definite interval of five feet or more by collecting several chips and pieces of rock over a width of about six inches, after first knocking off the outer layer of dirty rock exposed to the mine atmosphere. Any pieces with visible stringers of sphalerite or galena were rejected and careful note was taken of the proximity to veins and mineralized zones. Points falling on veins or closely spaced veinlets of sulfides were not sampled.

RESULTS

Values of zinc, lead copper and arsenic were all found to be low, generally below the adopted lower limit of analysis in the graywackes and phyllites of the Mandli formation. The highest zinc values were 50 ppm, found in two samples in number 6 adit, one 40 feet south and the other 200 feet south of the Mochia dolomite contact. In one sample 6 feet south of the Mochia contact the lead content was 75 ppm, the highest amount found. Arsenic did not excede 25 ppm in any sample of the Mandli rocks. The generally low values of all of the elements determined would oppear to suggest that they are not the result of a low extraction factor inherent in the analytical method, although this conclusion needs verification.

In the Mochia dolomite and dolomitic rocks, values of zinc were found to rise far above background values at or near the contact with the Mandli formation in all three adits sampled, but lead value reamined uniformly low in all but a few samples. Copper and arsenic values were determined only for 50 background levels.

Comparison of geochemical values obtained in fine-grained dolomite with those in the arkosic dolomite and dolomitic arkose in number 6 adit (Fig. 2) seems to indicate that in general, high zinc anomalies are localized in normal dolomite. That this is only an apparent and not a real relation is shown by comparison of geochemical results with mine assay values (Fig. 2), and by the facts that in number 4 adit the results (not illustrated here) apparently show the opposite relation, with the lowest values of zinc being in he fine-grained dolomite.

If the results of geochemical studies in number 6 adit are compared with the known distribution of veins and mineralized zones shown in the geologic section, there seems at least a general relation with the main, or Mochia vein, as the zinc values are higher as the vein is approached. But there is no consistent relation evident for veins and mineralized zones other than the Mochia vein in this section (Table 1). Moreover, comparison of the results with mine assay values likewise shows no apparent relation; zinc assay values cannot consistently be correlated either with known veins and mineralized zones or with geochemical values. Explanation for this apparently anomalous situation probaly lles in the variation in the distribution pattern of minor fracture-controlled veinlets and stringers in the host rock between veins and mineralized shear zones. Where minor veinlets and stringers are closely spaced, even though the grade of the rock is low, it is more difficult to reject such veinlets from the geochemical samples than where they are less closely spaced.

TABLE 1

HYPOGENE ZINC AND LEAD CONTENT OF HOST ROCKS NEAR VEINS MOCHIA MINE

Location	Sample number	Description	Values (ppm) Zn	Pb
No. 6 adit	19	Dolomite, 1 foot north of contact with Mandli formation; 6 inches north of 1 inch pyrite-arsenopyrite-sphalerite vein, and 2 inches south of similar vein.	< 50	< 50
	26	Gritty arkosic dolomite, 1 foot north of contact with fine-grained dolomite marked by 1 to 3 inch sphalerite-galena vein.	< 50	< 50
	30	Gritty arkosic dolomite 1 foot south of strong zone of 1 to 2 inch sphalerite stringers.	600	< 50
	33	As above, 6 inches south of 1 to 2 inch sphalerite vein.	< 50	< 50
	53	Finely gritty arkosic dolomite, 1 foot south of 1 to 2 inch galena-sphalerite vein.	125	< 50
	82	Dolomite, 3 inches from galena-sphalerite vein.	75	50
No. 4 adit	194	Gritty arkosic dolomite 3 to 6 inches south of 2 inch sphalerite-galena vein.	50	50
	206	As above, 4 feet south of 6 inch sphalerite-quartz-galena vein.	500	< 50
	208	Same rock, 4 feet north of vein near sample 206.	500	50
	219	Same rock, 3 feet south of 2 inch sphalerite vein.	< 50	< 50

The fact that values comparable to background levels are present close to some veins (Table 1) appears to suggest that there is little significant dispersion of zinc or lead in unfractured rock. However, the higher values of zinc obtained in some samples would appear to negate this and to indicate that zinc at least is locally dispersed. The possibility that this zinc was present as fracture controlled veinlets which were accidently inocrporated in the samples, and not as a disseminated granular or intergranular dispersion, could not yet be dismissed. A final check was therefore made at headquarters where samples of dolomite or dolomitic host rock were obtained from large specimens of fresh ore taken from stopes along the Mochia ore zone (Table 2). The samples came from inclusions of host rock in ore, or from slabs of rock caught between closely spaced parallel sulphide veins, and none were more than 2 inches from bounding sulphides.

TABLE 2

ZINC AND LEAD CONTENT OF HOST ROCK IN THE MOCHIA ORE BODY

Sample number	Zn (ppm)	Pb (ppm)	Description
A	<50	<50	Fine-grained or normal dolomite inclusion in high grade sphalerite-pyrite ore. Contains finely disseminated pyrite.
B	50	<50	Dolomite inclusion from ore high in galena and sphalerite. Contains pyrite, as above .
C	<50	<50	Gritty arkosic dolomite from moderately high grade sphalerite ore. Pyrite, as above.
D	50	<50	Gritty arkosic dolomite with finely disseminated pyrite. From specimen of high grade ore.

It is apparent that the host rock in the Mochia ore ozne only contains values of zinc and lead comparable to background levels. There is little evidence of greater dispersion in the coarser-grained arkosic dolomite as compared with the fine-grained dolomite.

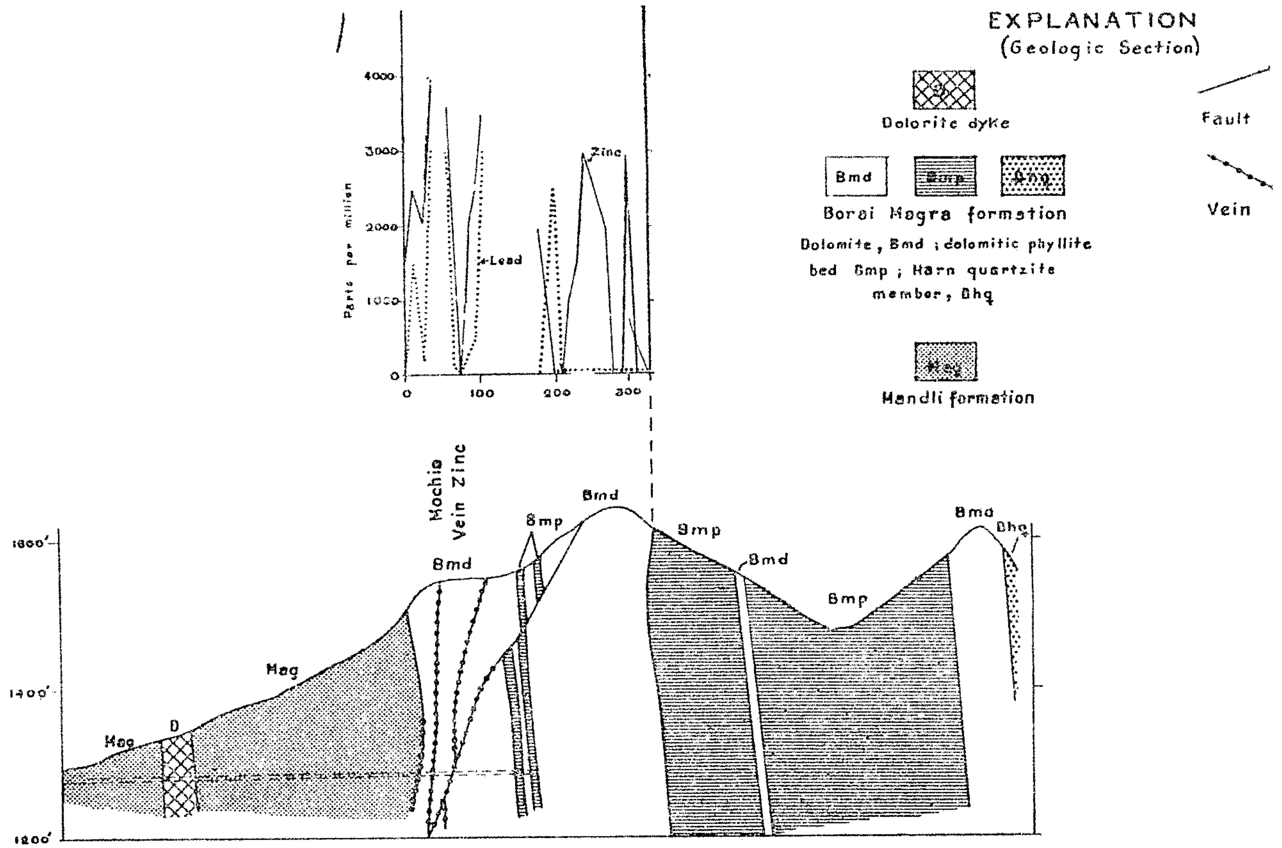

Fig-4 GEOLOGIC SECTION A-A' THROUGH NO-7 ADIT AND DISPERSION PATTERN OF ZINC AND LEAD IN SURFACE ROCK

DISPERSION OF ZINC AND LEAD IN SURFACE ROCK

The zinc and lead content of surface rock in the Mochia mine was determined along four lines across the westerly trending Mochia vein zone and other mineralized zones and veins in the dolomites and dolomitic rocks. This study was directed at determination of the presence and range of anomalies of zinc and lead, and at finding how closely existing highs of these metals reflect the known primary distribution of galena and sphalerite in the Mochia deposit.

The surface map (Fig. 3), on which the geochemical sample lines have been plotted, shows the geology of the Mochia mine area. As seen on this map controlled by a shear fault system that has a westerly strike and dips 70 to 85 degrees south, clearly transecting the bedding of the host rocks which dip steeply north. The zone converges eastward on the longitudinal fault that forms the contact between the Mochia rocks and the rocks of the Madli formation, and in the area of convergence there are numerous systematically disposed mineralized fractures, most of which have been mined out at the surface. This area, between number 6 and number 7 adits, is the locus of the richest and widest part of the Mochia ore body (up to 220 feet wide on number 2 level), and is also the locus of that part of the ore body richest in lead.[2] The surface workings in general appear to be localized only along the high grade vein zones. These facts determined the general location of the rock sampling lines, while the specific locations were chosen over the sites of the mine adits through which detailed geologic sections were available.

SAMPLING PROCEDURE

Samples of surface rock were collected every 10 feet along the sample lines, and were obtained by breaking chips or fragments of rock with an ordinary geologic hammer, care being taken to take rock free from adhering, possibly contaminated soil. The samples were placed in cloth bags together with numbered slips of paper. Sample lines and stations were established with tape and Brunton compass. No attempat was made to sample bedrock overlain by thick surface rubble.

RESULTS

Significantly high anomalies of zinc were found, which in general coincided with known veins and vein zones, but lead anomalies were far less widespread.

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[2] Ore boundaries are not indicated in the illustrated geologic sections in which only the principal veins are shown.

The results of analyses are shown graphically in Figures 4 to 7, in which the values are correlated with the geologic sections, and are also generalized on the geologic plan (Fig. 3), which shows the anomaly zones of zinc and lead for values of 500 ppm (approximately 10 times background levels), or more. Values of both zinc and lead were found to range from background levels of 50 ppm or less, to plus 3,000 ppm for lead and plus 4,000 ppm for zinc. Wide major anomalies of zinc, with many samples containing more than 4,000 ppm, were found over and near the Mochia vein zone in all four lines of samples. The greatest width, 375 feet, if it is assumed that the anomaly is continuous across

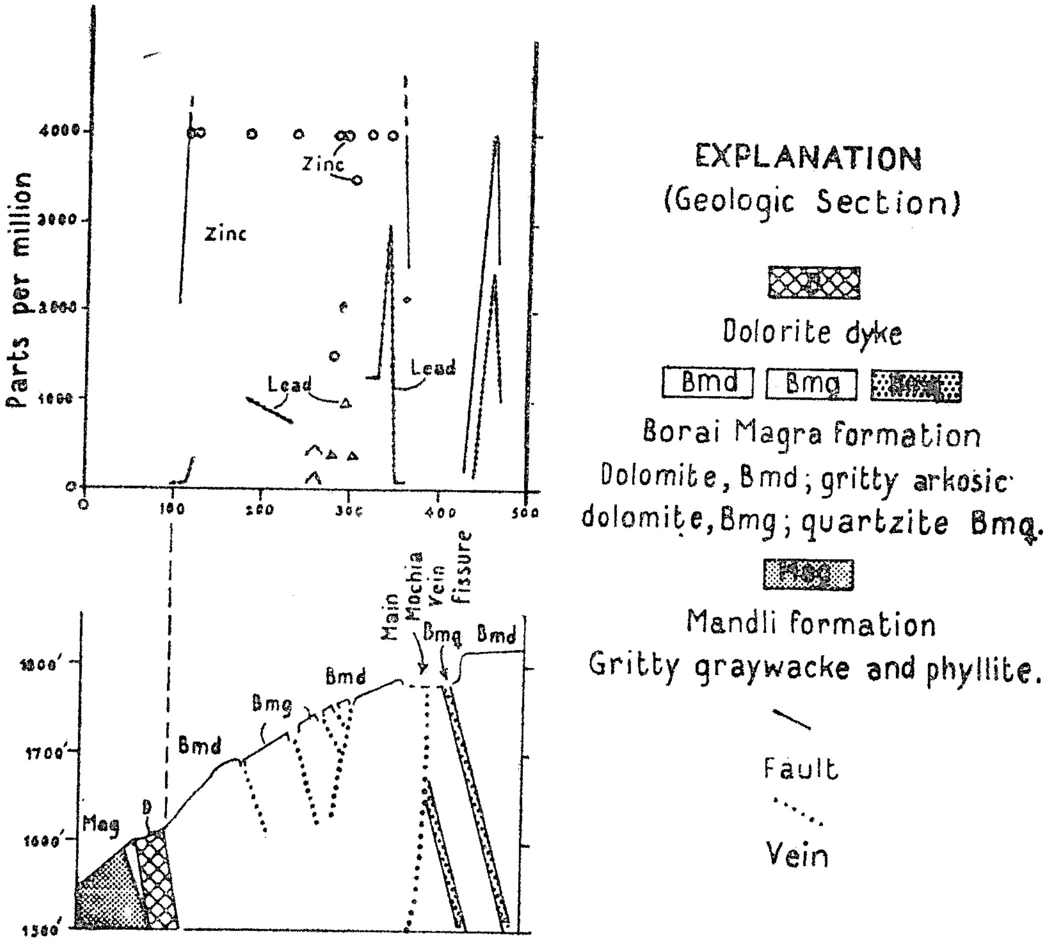


Fig. 5 - GEOLOGIC SECTION THROUGH B-B' AND SURFACE DISPERSION PATTERN OF ZINC AND LEAD

the old pit on the Mochia vein zone, was on line B-B' (Fig. 5). On two lines, C-C' and D-D' (Figs. 6 and 7), samples of rock taken near the edge of the open stopes along the Mochia vein zone showed very low values of zinc, probably because the surface rock here had been stripped away during mining, and the resulting values therefore only reflect the low levels of primary dispersion.

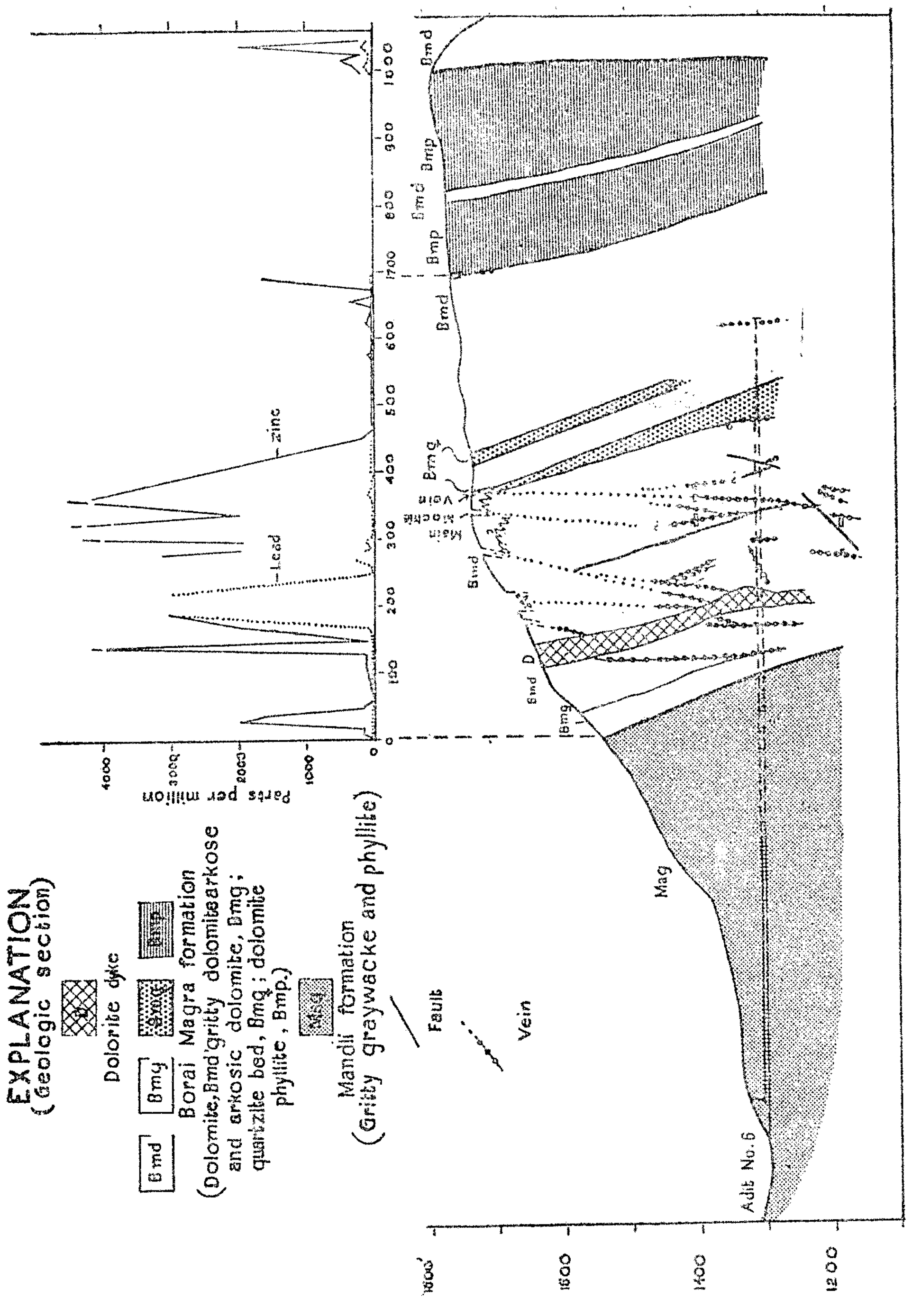


Fig. 6 GEOLOGIC SECTION C–C' THROUGH NO. 6 ADIT AND DISPERSION PATTERN OF ZINC AND LEAD IN SURFACE ROCK

Away from the Mochia vein zone zinc anomalies in general tend to be narrow. Many anomalies span known narrow veins and group of veins that are marked by old workings (lines C-C' and D-D', Fig. 3), or extend across apparent extensions of veins from nearby workings. But some of these anomalies

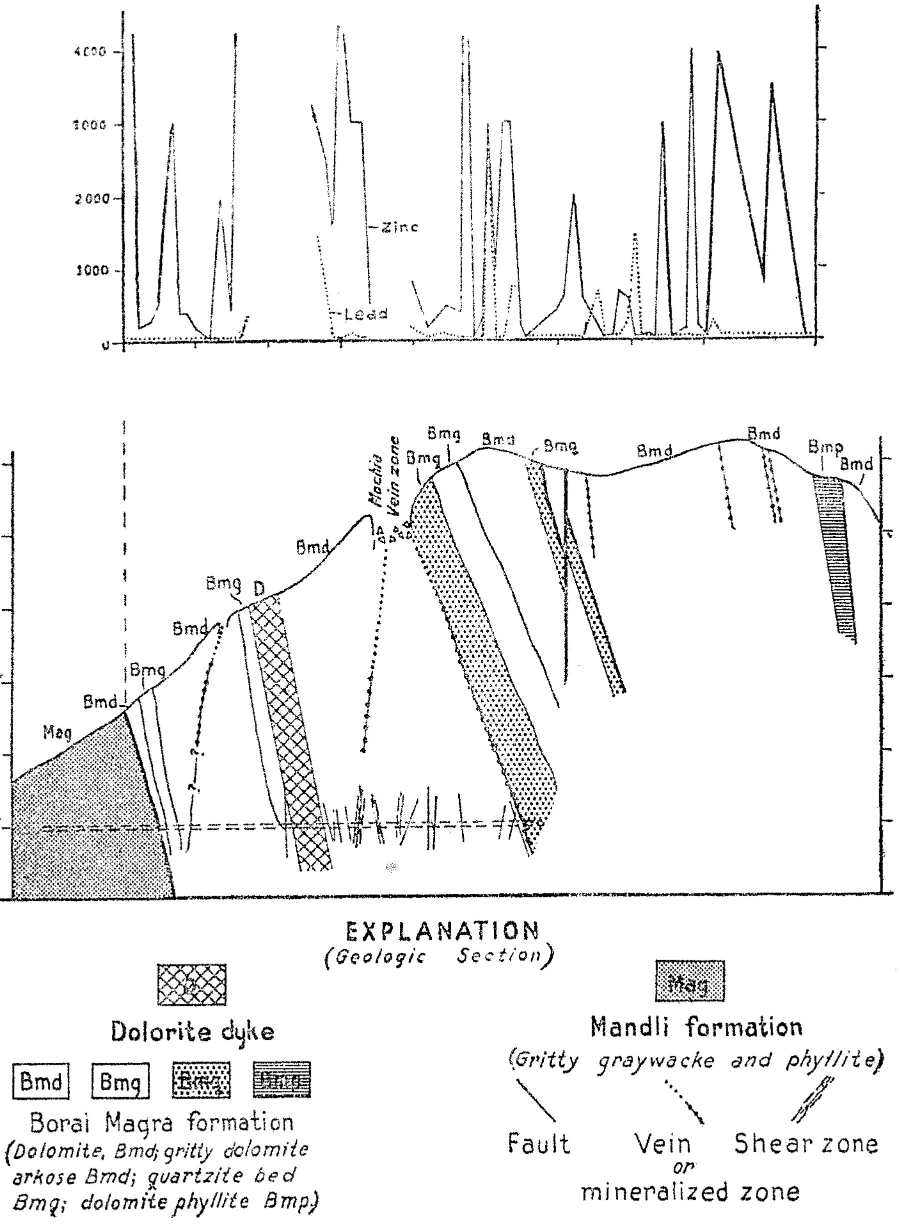
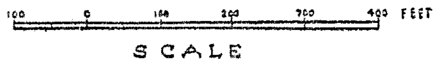


Fig. 7 - GEOLOGIC SECTION D-D'
AND
DISPERSION PATTERN OF ZINC AND LEAD IN SURFACE ROCK



are not known veins and are inferred to span unknown vein or zones of minor veinlets and stringers, or to overlie zones along which only traces of sulphides were left to mark the passage of ore-bearing solutions.

Lead anomalies are not only fewer and more widely spaced than those of zinc but are generally narrower. Where they occur the lead anomalies coincide rather closely with those of zinc. These results are not surprising in view of the known localization and distribution of galena in the underground workings, and in view of the known relative immobility of lead as compared to zinc, under supergene conditions of alteration. The widest and most closely spaced lead anomalies were found to occur along lines A-A' and B-B' is over the west plunging lead-rich ore shoot of the Mochia deposit, whose upward extension and eastern border apparently overlaps line A-A'. These results, while they do not warrant a positive conclusion, nevertheless strongly suggest that the lead ore shoot has been brought out in the surface dispersion pattern of zinc and lead.

DISPERSION OF ZINC AND LEAD IN SOIL

On Zawar Mala ridge systematic geochemical studies were made of soils in the small cultivated area, just north of the Zawar Mala mineralized area. where the veins and vein zones are typically outlined by numerous old workings. The soil covered tract, which has a width of about 1,000 feet and a length of about 3,000 feet, occupies a very shallow valley in dolomite, in which the drainage is northward, away from the mineralized area. The drainage channel is ephemeral and is so shallow that it is difficult to trace across the cultivated fields. Sampling of soils was carried out here because it appeared to be the only feasible site for soil studies in the whole of the Zawar area. It was hoped that the effects of contamination from past mining operations would not obscure the natural dispersion pattern of zinc and lead. The area was especially interesting because the apparent projection of one of the major mineralized zones of Zawar Mala ridge, marked by one of the largest open pits on the ridge, and recently proven by an exploration adit, extends through the soil covered ground (Fig. 8).

SAMPLING PROCEDURE

Soil samples were taken along two west trending lines 500 feet apart, the southernmost being about 1,400 feet away from the nearest old mine workings. The sample interval was ten feet, which was subsequently proven to be unnecessarily close. The samples were collected from a depth of about 12 inches below

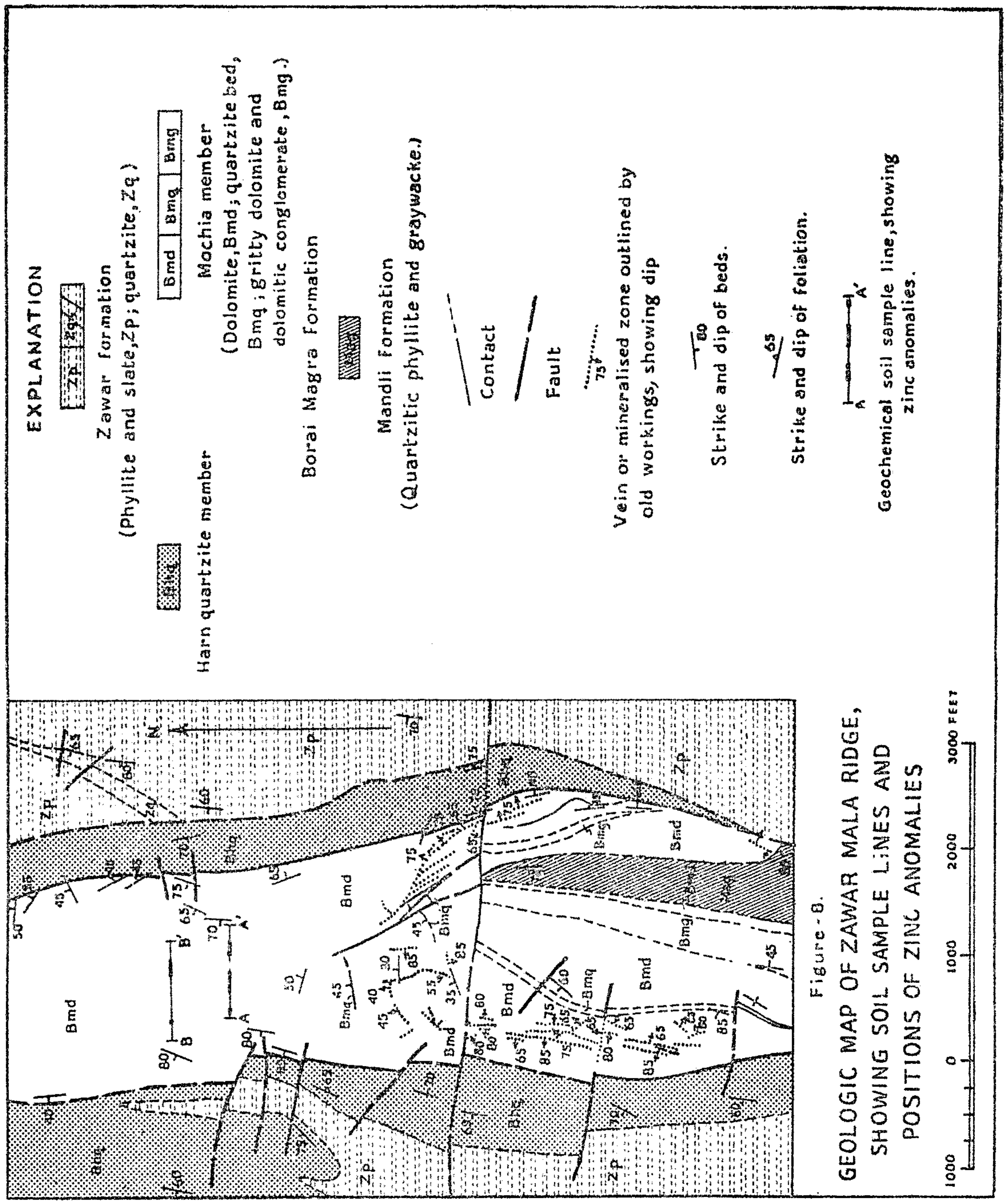


Figure-8.

GEOLOGIC MAP OF ZAWAR MALA RIDGE, SHOWING SOIL SAMPLE LINES AND POSITIONS OF ZINC ANOMALIES the surface, or about 6 inches below the base of plowing, as indicated by the looseness of the cultivated layer of ground as compared with the undistubed soil below. A pointed steel bar about four feet in length was used to loosen the soil at the sample station and the soil sample was collected from the bottom of the holes, care being taken that it was not contaminated by soil introduced from above. It was then screened, first through a 5-mesh and then through a 20-mesh brass wire screen. The minus 20-mesh fraction was placed in a screw top aluminium container which had a capacity of several ounces of soil, far too large of course for the weight of sample required.[3] As the sampling was done at the height of the dry season, the soils were dry.

The sample lines were surveyed by tape and Brunton compass and were carefully located and plotted on areal photographs.

RESULTS

High anomalies of lead and zinc, far above local background levels, were encountered on both lines of soil samples. The lowest zinc values were of the order of 100 ppm, and the highest values were more than 4,000 ppm. Lead ranged from less than 50 ppm to more than 3,000 ppm. The anomalies are shown graphically in Figure 9, and the anomaly peaks of zinc have been plotted on the sample lines in figure 8. Except for one anomalous narrow high of lead on line A-A' (at 550 feet), which may be due to local contamination innasmuch as the high value involves only one sample, the lead anomalies reflect closely those of zinc. Only the broad high of zinc on the eastern side of line A-A' is not coincident with a high of lead. This general concordance of lead values with those of zinc lends support to the idea that the anomalies of these metals result from the incorporation of lead and zinc into the soil from underlying mineralized zones, perhaps extensions of the vein system to the south, on the east side of the ridge.

The relatively small anomalies on the east and west sides of line A-A' and on the west side of line B-B' almost certainly reflect underlying mineralized zones since they are on the sides of the soil covered valley where the ground slopes toward the center of the valley, and the soils are thin and rocky and appear to have been derived locally. But the wide major anomalies of both lines are on the flat alluviated valley floor, where the soils are at least several feet thick and contain only minor coarse rock debris. These soils appear to have been transported in large part from the head of the valley to the south and were apparently derived by weathering of highly mineralized rocks. The soils were evidently already high in zinc and lead as they were deposited in the bottom

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[3] The aluminium containers, which were unsatisfactory because they were easily dented and the lids often jammed, have now been replaced by alkathene plastic bags.

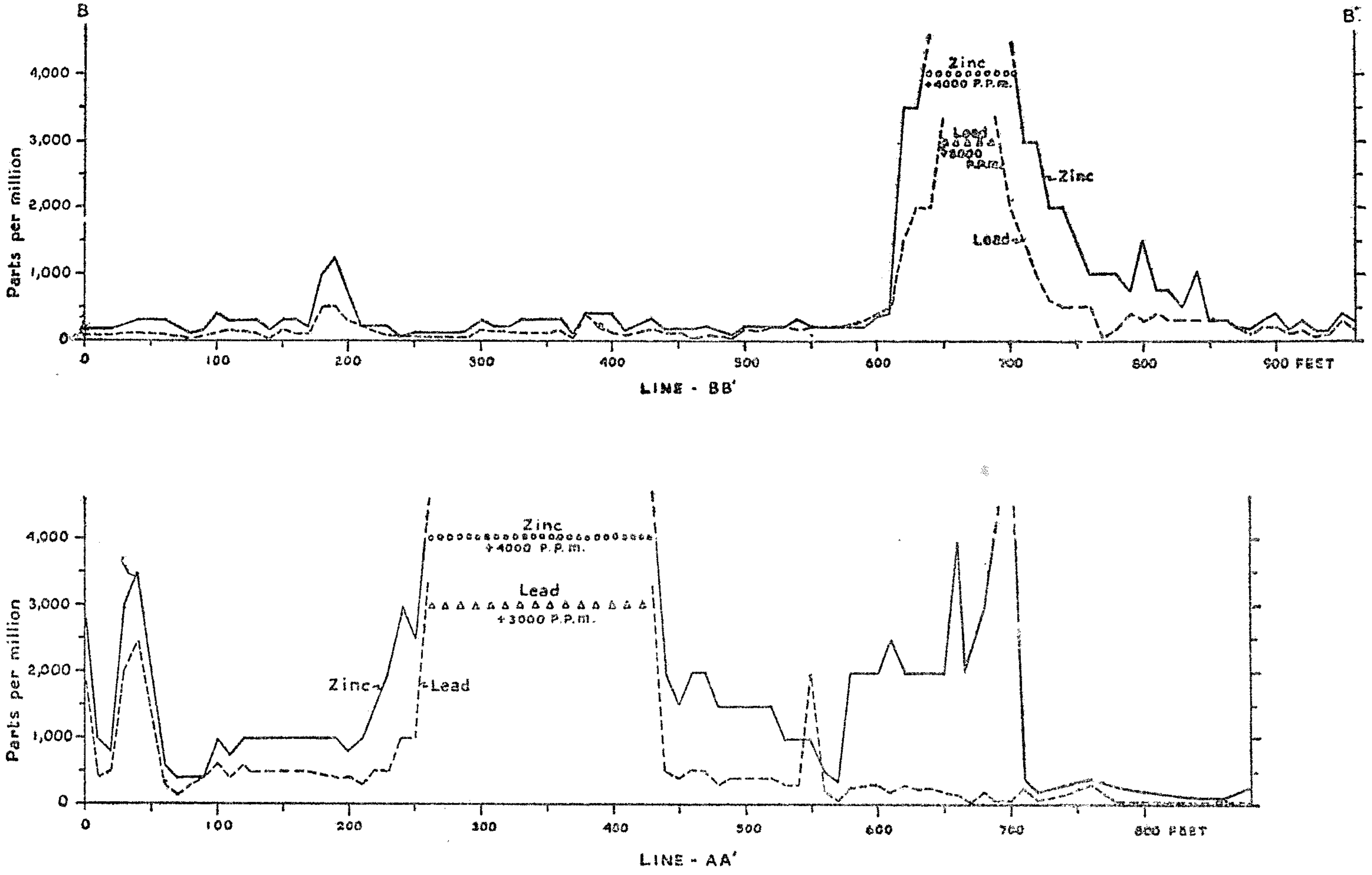

Figure - 9.

DISPERSION PATTERN OF ZINC AND LEAD IN SOIL, ZAWAR MALA RIDGE.

of the valley, and these major anomalies of zinc and lead may be trasported. Unless the area is test pitted and the soil sampled down to bedrock, probably no positive conclusions can be made as to the cause of any of these anomalies, but it is a fair conclusion that abnormally high localized values of zinc and lead do occur in the soils on Zwar Mala ridge, and that these anomalies confirm the presence of lead and zinc mineralization, either below the soil or at the head of the alluviated valley, or both. The known presence of zinc and lead deposits at the head of the valley supports the derivation of the anomalies through alluviation, and the attitudes of known principal veins, combined with the presence of anomalies on the sides of the valley where the soils are residual, suggest that mineralization may well extend under the alluviated tract. The presence of such anomalies in a virgin or unexplored area would certainly warrant extension of soil sampling and exploration by test pitting, which would lead to the source deposits whether they underlie the soil or occur on the bordering hill slopes.

METAL CONTENT OF GOSSANS

Gossans over known mineralized zones consist of yellowish to reddish brown and red hydrous ferric oxides, or limonite. Most limonite appears to be indigenous, which is not surprising view of the presence of dolomite, a highly reactive host rock, but none seems to have particularly diagnostic textures and structures that would suggest the type of sulphide from which it was derived.

Some limonite replaces dolomite or is a product of weathering of ferruginous dolomite. It is of interest, therefore, to determine the heavy metal content of the limonite to learn if it is diagnostic of the type of underlying primary mineralization present, or if the limonite does in fact represent the oxidized portion of a sulphide zone. Accordingly, samples of gossans from known mineralized zones on Zawar Mala ridge (Fig. 8), were collected and analyzed (Table 3).

TABLE 3

METAL CONTENT OF LIMONITIC DOLOMITE AND GOSSANS FROM ZAWAR MALA RIDGE

Sample	Metal content (ppm)			
	Zn	Pb	As	Cu
1	>4,000	1,500	—	—
2	2,000	50	—	—
3	3,000	100	—	—
4	200	150	—	—
5	>4,000	>3,000	—	—
6	>4,000	200	—	—
7	3,000	100	—	—
8	>4,000	100	—	—
9	>4,000	100	—	—
10	1,000	50	—	—
11	>4,000	150	—	—
12	1,500	75	—	—
13	>4,000	300	—	—
14	>4,000	100	—	—
15	2,500	2,000	50	<50
16	2,500	>3,000	100	<50
17	>4,000	>3,000	750	<50

Samples 1 to 14 of Table 3 are of weathered dolomite containing different proportions of limonite and were collected from the large and extensive old workings on the east side of Zawar Mala ridge (figure 8). The last three samples consist only of limonite and also are from Zawar Mala ridge.

The result of analyses shown in Table 3 indicates that both zinc and lead are present in the mineralized zones represented by the limonitic dolomite and gossan. Like the surface rock in the Mochia mine area the zinc to lead ratio is high, though variable, and apparently reflects the general preponderance of zinc over lead in the primary zone. There is no concentration of copper in the gossans, but the arsenic content appears to have a wide range.

Limonite is extensively developed in a sheared dolomite member of the Zawar formation, about 2.5 miles west of the Mochia mine. The limonite zone has a width of about 25 feet and a length of about 175 feet and has been prospected by a few shallow pits which did not reach the base of the oxidized zone. Although the limonite was similar in appearance to that associated with known zinc-lead deposits, part of it appeared to have been derived by the weathering of the ferruginous. Specimens of the material were collected and analyzed (Table 4).

TABLE 4

METAL CONTENT OF GOSSAN IN DOLOMITE OF THE ZAWAR FORMATION

Sample	Metal content (ppm)		
	Pb	Zn	As
1	150	500	150
2	1,000	100	600
3	33	250	150
4	33	100	150

The abnormally high metal content of the limonite in sample one and two suggests that the material is a gossan. Samples three and four appear to be mainly oxidized ferruginous dolomite which apparently has been slightly enriched in zinc and perhaps arsenic.

About three miles south of the Zawar Mala ridge area shown in Fig. 8, there is a copper prospect, marked by several old prospect pits in Harn quartzite near a fault contact with Mochia dolomite. The pits and dumps show considerable gossan and locally there is visible malachite, very minor chalcopyrite, chalcocite and pyrite. In places the dolomite contains limonite. Abnormally high amounts of Cu, Zn, and Pb were found to occur in samples of limonite material from this area, as shown in Table 5.

TABLE 5

METAL CONTENT OF GOSSAN FROM COPPER PROSPECT

Sample	Description	Metal content (ppm)		
		Cu	Zn	Pb
1	Quartzite with limonite	400	75	250
2	As above. and visible malachite.	1,500	125	2,000etaoinshrdlu
2	As above.	1,500	125	2,000
3	Dolomite with limonite.	600	100	200
4	Limonite	>4,000	100	>3,000
5	”	>4,000	125	>3,000
6	”	>4,000	>4,000	>3,000
7	Limonite veinlet in dolomite.	>4,000	100	>3,000

The mineralized zone here appears to contain copper as well as zinc and lead, coopper and lead being in general higher than zinc which except for one sample is low. The high copper values and the high lead-zinc rations, which are not typical of the gossans over the Zawar zinc-lead deposits, suggest a distinct type of primary mineralization, high in copper and lead and possibly low in zinc.

CONCLUSIONS

The process of emplacement of metal sulphides in the Zawar deposits was one of replacement of the host rocks from solutions that occupied or moved through available fractures, but there was little dispersion of lead or zinc, or apparently of copper or arsenic in the rocks bordering the replacement veins and veinlets. Appreciable hypogene migration of primary constituents into unfractured host rock from the ore-bearing solutions is apparently evidence only by disseminated pyrite in the dolomite and dolomitic host rocks.

High anomalies of zinc and lead obtained in surface rock form a supergene dispersion pattern that outlines the traces of known veins and vein zones. Zinc is more widely dispersed than lead which is relatively immobile and reflects closely the primary pattern of concentration. But zinc does not move far; is leached from the mineralized zones and precipitated nearby in the reactive carbonate host rocks. In this rock environment, high zinc to lead ratios in surface rock apparently can be taken to indicate a preponderance of zinc in the primary zones.

Abnormally high amounts of zinc and lead in soils from a secondary dispersion are related to weathering of underlying mineralized zones and to movement of these metals from mineralized zones in surrounding rocks from the soils were derived.

Gossans not only carry abnormal values of heavy metals but the kinds of metals present may give a clue as to the general nature of primary mineralization.

The geochemical method of prospecting is a valuable tool in the finding of deposits of lead and zinc in order to localize exploration directed toward the discovery of ore bodies. Under the geologic conditions at Zawar, sampling and analysis for heavy metals of gossans and surface rocks and soils appear to be effective techniques of geochemical prospecting. Reconnaissance geochemical sampling of the many reported occurrences of "iron ore" throughout the Aravalli range in order to ascertain which, if any, of these deposits are gossans, would be a logical first step in rapid relatively inexpensive prospecting of this terrain.

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GEOCHEMICAL EXPLORATION IN THE RIO RIBEIRA DE IGUAPE LEÁD DISTRICT, BRAZIL

G. C. Melcher *

ABSTRACT

More than 25,000 dithizone analyses for lead were made in an extensive geochemical work including a regional search for hidden deposits in favorable limestone areas, and a detailed examination of the lead content of soils near known deposits to aid in determining the extension of veins under the eluvium.

The average lead content of soils in the Rio Ribeira de Iguapé district was found to be 20-30 ppm. Anomalies with a maximum of 8600 ppm lead were found. All known lead occurrences produced clear geochemical anomalies.

In regional prospecting, soil samples containing more than 100 ppm lead from two or more adjoining stations are believed to be of economic interest. The areal extent and intensity of the anomalies permit a qualitative estimate of the size of the underlying mineralization.

The geochemical technique used indicated that large areas were barren and could be eliminated as unpromising for further prospecting or explorations. Several new anomalies were found in hitherto unknown places where trenching is now being carried out. At known prospects the direction of the veins and their approximate size could be determined as a guide for exploration. The total unit cost of one lead determination is Cr$12.00 (less than US$ 0.15). The method is by far the fastest, most efficient, and cheapest way of prospecting in an area like the Rio Ribeira de Iguapé valley.

INTRODUCTION

The Rio Ribeira de Iguapé lead district has an area of about 1,200 sq km and is located in the border region between the states of São Paulo and Paraná, Southern Brazil (Fig. 1).

Until recently this district was the only source of lead ores in Brazil. Production in 1955 was 3,600 metric tons lead and 4,200 kilogram silver, over 95 percent of this total being produced by the Panelas mine. More than 50 lead prospects are known in the district, but most of them are small and little exploration has been done to prove their reserves.

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The area is mountainous and slopes of 30-40° are common, especially in calcareous terrain. Many hill tops have been levelled by a pre Devonian peneplane, uplifted to about 1,100 meters, and deeply dissected. Elevation of Rio Ribeira at Iporanga is about 150 meters. Virgin forest and thick brush cover most of the region.

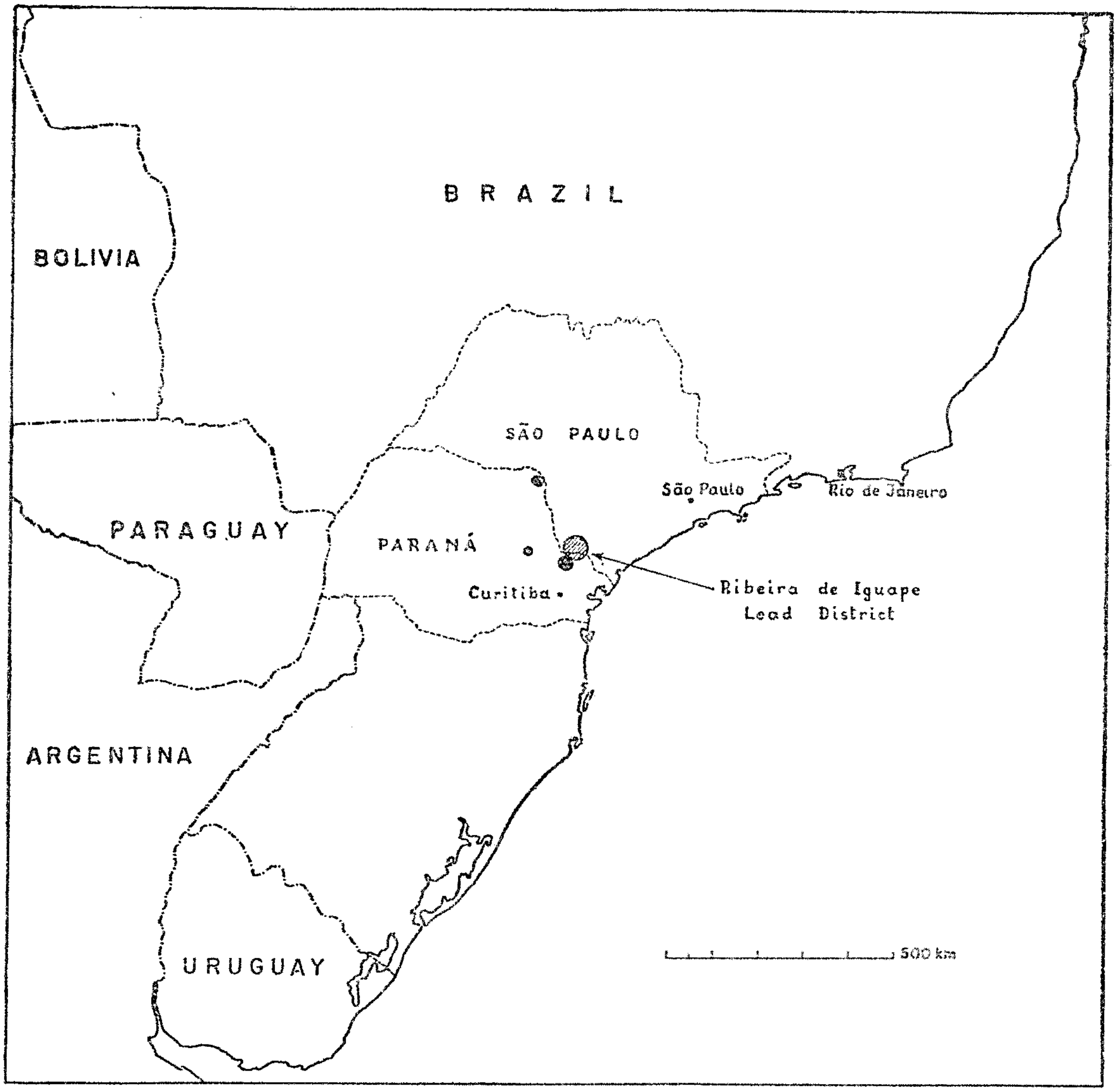

Fig. 1. Location of the study area.

The district is crossed by the federal São Paulo-Curitiba highway. The Panelas, Furnas and Lageado mines are served by second class roads, but most prospects are accessible only by mule trails.

GENERAL GEOLOGY

The area is part of a large belt of Precambrian metasediments and intrusives belonging to the São Roque Açungui series. Among sedimentogeneous rocks phyllites and micaschists predominate with intercalated quartzites, conglomerates and arkoses. In the upper part of the series occur one or more dolomitic limestone formations, several hundred meters thick and interbedded with argillaceous layers. The sediments were folded and faulted by SE-NW compression. Isoclinal folding predominates in the phyllites, and most limestone bodies also show strong dips, except the Furnas limestone, which has an average dip of 55° and the Lageado limestone, which forms a shallow syncline. The grade of regional metamorphism is low, corresponding to the greenschist facies in the northern part of the area, with a slight increase towards the southeast. Late orogenic porphyritic granodiorites intruded the sediments and are believed to be the source of the ore bearing solutions. Some large gabbro sills and stocks are probably also Precambrian. Diabase dikes usually oriented N40°W, can be correlated with Triassic Paraná plateau basalts.

Figure 2 shows schematically the distribution of acid intrusives, limestone bodies and non-calcareous metasediments.

ORE DEPOSITS

All lead deposits are located within the limestone bodies. Galena, sphalerite and pyrite are the predominant primary minerals. Cerussite, smithsonite, calamine and limonite occur in the oxidation zone. Quartz and calcite are the more important gangue minerals. Ore bodies are lenses or chimneys, rarely over 1 meter thick. The structure of the deposits is usually simple. Intersections of certain bedding planes with fractures were the most favorable loci for ore deposition. At Lageado the ore occurs as horizontal cigar shaped bodies where vertical fractures cut impure limestone beds. In the Furnas mine the chimneys occur at the intersection of a N60°E 55°NW bedding plane with N40°W vertical fractures. The Panelas veins are also parallel to bedding, but cross fractures did not control enrichment substantially there.

Scope of geochemical exploration — Practically all limestone areas are covered by a residual clay soil blanket, which averages 1 meter in thickness. Because of its inaccessibility the district has never been investigated systematically and it was assumed that unexposed ore bodies or deposits may exist without a readily identifiable gossan. Geochemical exploration seemed a possible answer to the problem of locating new prospects. Experimental work gave promising results, and it was decided to carry out a large scale campaign to search for hidden deposits in favorable limestone bodies, to obtain more information about known deposits which have not been explored adequately, and chiefly to prove the value of a method whose importance seems to be increasing rapidly, but which had not yet been tried in Brazil.

This work was carried out from July 1955 to July 1956, as part of an investigation of the lead and zinc resources of the Rio Ribeira de Iguapé valley, made by the Departamento Nacional da Produção Mineral in cooperation with the United States Geological Survey.

ACKNOWLEDGEMENTS

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SAMPLING

For planning the most efficient sampling method which would permit the detection of any exploitable deposit with a minimum number of samples, it was necessary to determine how accurately the chemically analyzed small soil sample which by most current methods is only a fraction of a gram (Lakin, Almond and Ward, 1952), represents the lead content in soils within a certain radius and to determine what type of geochemical anomaly is produced by any significant mineralization in the given geological environment. Preliminary work was done at the Furnas mine, Vieira, Pinheiros and Descanso prospects. Over 2,000 tests were made by Bloom and Crowe's (1953) method at this experimental stage of the work.

Size of samples.—Samples were taken with a 1 inch diameter auger, 1.2 meters long. Soil samples of 10 to 20 grams were usually collected in a paper envelope. To determine how accurately a 0.1 gram fraction represented the whole sample, 10 random 0.1 gram splits were taken from each of 10 samples from different localities. Results of analyses are listed on Table 1.

TABLE 1

LEAD CONTENT IN 10 RANDOM SPLITS FROM EACH OF 10 SOIL SAMPLES:

	1	2	3	4	5	6	7	8	9	10
LEAD (ppm)	-20	20	70	50	80	120	140	200	320	600
	-20	20	80	50	60	160	140	160	400	600
	-20	20	80	70	60	120	120	160	320	1000
	-20	30	70	60	60	120	140	200	320	800
	-20	20	60	50	80	120	120	200	320	1200
	-20	30	60	60	40	120	140	200	400	600
	-20	20	60	60	60	140	120	160	480	800
	-20	20	60	50	60	120	100	160	320	800
	-20	20	70	50	80	160	120	200	320	1000
	-20	20	70	60	60	120	100	160	320	800

These results were considered satisfactory. Distribution of traces of lead in samples with less than 200 ppm seemed fairly uniform. Stronger variations were found in the richer samples but no analysis failed to disclose an anomalous lead content. During later routine work several hundred repeat tests were made and with very few exceptions results always showed good agreement. It was concluded that for geochemical exploration purposes, a 0.1 gram fraction adequately represented the whole sample.

Depth of sampling — Samples were taken at several localites at depths of 0.3, 0.6 and 1.2 meters. It was found that usually in one auger hole variation of lead content was less than 30 percent, except at strong anomalies, where results were more erratic but always high. A standard depth of about 0.6 meters was adopted for routine work.

Area represented by individual sample — Experimental sampling traverses were made at known occurrences to determine what area was adequately represented by a single sample, and consequently the maximum spacing of sampling points which would still reflect the distribution pattern of lead in soils with sufficient accuracy for prospecting work. Results are shown on Figures 3 and 4.

They indicate that even comparatively thin ore veins of little economic value produce anomalies several tens of meters wide, and that therefore in geochemical exploration an individual sample can be considered to be representative of the soil within a radius of at least five meters.

Shape and position of geochemical anomalies — In the Rio Ribeira district the strike of mineralized structures is usually parallel to the general strike of the limestone formations. The three profiles shown on Fig. 3 are spaced 400 and 600 meters from each other but the close correspondence of their peaks along strike can be noticed. Traverses at the southwestern extension of the Furnas mine disclosed clear anomalies more than 500 meters beyond the known exploitable mineralization. The small Vieira prospect also produced an anomaly of over five times background value with a length of more than 600 meters. Therefore anomalies several hundred meters long and some tens of meters wide were expected to exist over deposits of economic value.

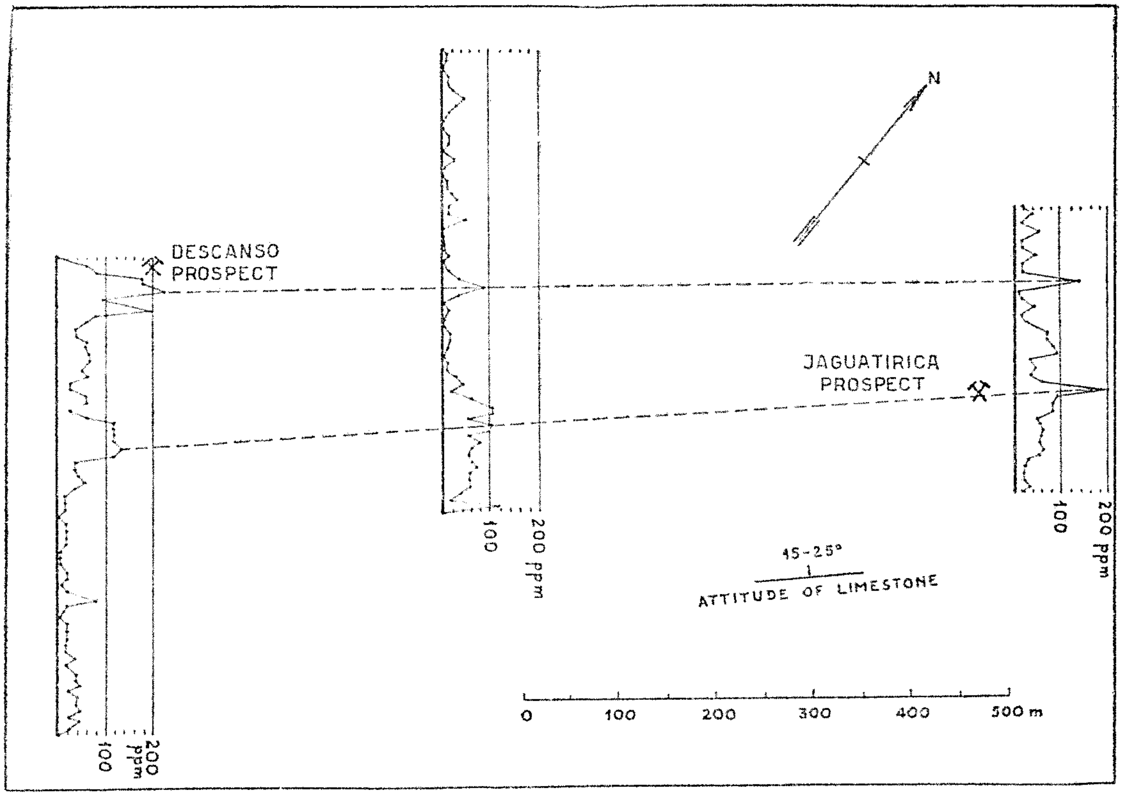
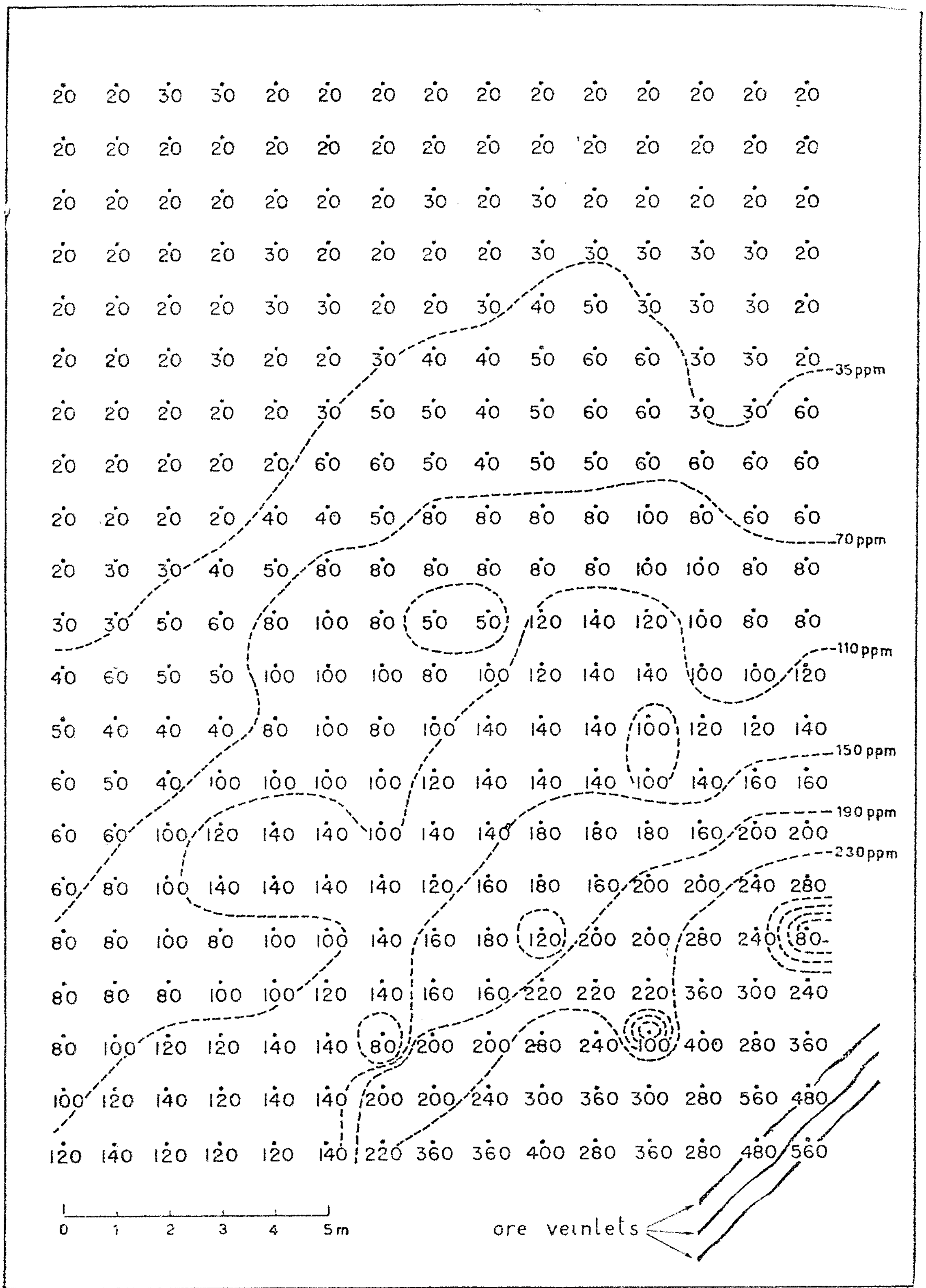


Fig. 3. Lead content in soil at Serra prospect.

Sampling method used in geochemical exploration—From the above observations it seemed probable that traverses with sampling stations every 10 meters, spaced a few hundred meters apart and normal to the general strike of the limestone formations would reveal any significant mineralization in this area. For more detailed work, when additional information about a known occurrence was desired, traverses were spaced 30 or 50 meters.



20	20	30	30	20	20	20	20	20	20	20	20	20	20	20
20	20	20	20	20	20	20	20	20	20	20	20	20	20	20
20	20	20	20	20	20	20	30	20	30	20	20	20	20	20
20	20	20	20	30	20	20	20	20	30	30	30	30	30	20
20	20	20	20	30	30	20	20	30	40	50	30	30	30	20
20	20	20	30	20	20	30	40	40	50	60	60	30	30	20
20	20	20	20	20	30	50	50	40	50	60	60	30	30	60
20	20	20	20	20	60	60	50	40	50	50	60	60	60	60
20	20	20	20	40	40	50	80	80	80	80	100	80	60	60
20	30	30	40	50	80	80	80	80	80	80	100	100	80	80
30	30	50	60	80	100	80	50	50	120	140	120	100	80	80
40	60	50	50	100	100	100	80	100	120	140	140	100	100	120
50	40	40	40	80	100	80	100	140	140	140	100	120	120	140
60	50	40	100	100	100	100	120	140	140	140	100	140	160	160
60	60	100	120	140	140	100	140	140	180	180	180	160	200	200
60	80	100	140	140	140	140	120	160	180	160	200	200	240	280
80	80	100	80	100	100	140	160	180	120	200	200	280	240	80
80	80	80	100	100	120	140	160	160	220	220	220	360	300	240
80	100	120	120	140	140	80	200	200	280	240	100	400	280	360
100	120	140	120	140	140	200	200	240	300	360	300	280	560	480
120	140	120	120	120	140	220	360	360	400	280	360	280	480	560

Fig. 4. Distribution of lead in soils at Pinheiros prospect.

Sampling crews were recruited from inhabitants of the area and consisted of three workers and a cook. One man cut the trail, the second drilled the auger hole and the third collected and numbered the samples, staking every tenth sampling station. Usually the crews camped in the field, sending their samples to the laboratory weekly. Average daily production was 120 samples, trail cutting being the slowest part of the work. In flat, open terrain more than 300 samples could be collected daily by one crew. Altogether, over 25,000 samples were collected.

ANALYTICAL PROCEDURE

Preparation of sample solution — Satisfactory results were obtained by fusing the sample with sodium bisulfate and disintegrating the cooled melt with 1:5 hydrochloric acid, previous to colorimetric lead estimation. This method was used in all preliminary work but was a comparatively slow procedure, consuming more than half of the total time necessary for one lead analysis. Methods of preparing sample solution employed by different authors differ widely; from solution in hot concentrated nitric acid (Lakin, Almond and Ward, 1952) to solution in 0.01N hydrochloric acid (Davidson, 1953), and it was considered of interest to try out which reagent would give fastest and consistent results. Six samples from the Rocha prospect were attacked in 13 different ways and the lead content in the solution estimated by the dithizone method, each test being repeated three times. Results are shown on Table 2.

The figures indicate that all the reagents used dissolve some of the lead contained in the samples and that the amount of metal in solution indicates in a qualitative way the lead content of the soil samples. In geochemical prospecting, where the main objective is to detect anomalously high lead values, any of these methods of preparing the sample solution could be used. However, results obtained with several acids on different samples are not proportional. For example, bisulfate fusion followed by 1N citric acid solution dissolved practically the same amount of lead as heating with 1N or 0.1N citric acid for samples 4 and 5, but gave much higher values for samples 1, 2, 3, and 6. Concentrated hydrochloric acid produced higher results than sodium bisulfate fusion followed by disintegration in 1:5 hydrochloric acid for samples 3, 4, 5 and 6, but lower values for sample 2. Comparative tests were made with samples from other localities, and they also showed that different acids do not dissolve proportional amounts of lead. However, in all cases attack by hot 1:5 hydrochloric acid gave fairly high results and was later used for all routine work, because this procedure was both fast and cheap.

Routine procedure of lead determination — A scoopful corresponding to 0.1 gram of dry, finely powdered soil was boiled for about 10 seconds with

TABLE 2

LEAD CONTENT IN 6 SOIL SAMPLES EXTRACTED BY DIFFERENT REAGENTS. (ppm)

	SAMPLE	METHOD OF EXTRACTION												
		1	2	3	4	5	6	7	8	9	10	11	12	13
LEAD (ppm)		30	20	30	30	30	20	20	—20	—20	30	—20	—20	—20
	1	30	—20	30	30	30	20	20	—20	—20	30	—20	—20	—20
		20	20	30	20	30	—20	20	—20	—20	20	—20	—20	—20
		400	80	200	200	120	60	120	30	30	40	30	30	—20
	2	280	60	120	180	160	50	100	20	30	40	30	20	—20
		280	80	160	140	140	40	100	20	20	40	30	20	—20
		160	160	200	300	140	80	240	40	30	90	70	50	30
	3	200	160	360	300	180	80	240	30	30	80	60	50	20
		200	100	360	300	180	60	240	30	30	80	60	20	—20
		1280	680	1440	1000	720	480	720	400	280	560	560	280	120
	4	1200	560	1440	1200	720	400	720	320	280	540	500	200	120
		960	480	1440	1200	840	560	640	320	240	500	480	120	120
		400	160	860	800	240	320	720	100	100	140	160	70	50
	5	360	280	1120	720	300	300	640	100	100	140	140	60	40
		480	140	1120	720	360	240	640	70	60	140	120	50	30
		140	200	280	240	200	160	240	30	40	80	60	50	20
	6	120	180	320	280	240	140	240	30	30	80	60	40	—20
		160	160	300	300	240	140	240	30	30	80	70	40	—20

1—Fusion with sodium bisulfate, disintegration of melt in hot 1:5 HCl
2—Fusion with sodium bisulfate, disintegration of melt in hot citric acid
3—Solution in hot concentrated HCl
4— ,, ,, ,, 1:5 HCl
5— ,, ,, ,, 1:20 HCl
6— ,, ,, ,, 1:100 HCl
7— ,, ,, cold 1:5 HCl
8— ,, ,, hot concentrated acetic acid
9— ,, ,, ,, 1:5 acetic acid
10— ,, ,, ,, 1N citric acid
11— ,, ,, ,, 0.1N citric acid
12— ,, ,, ,, 0.01N citric acid
13— ,, ,, ,, 1N sodium citrate

3 ml of hydrochloric acid. The solution was diluted with 7 ml water and 2 ml transferred to a 30 ml separatory funnel. Three drops of thymol blue indicator in 0.2 percent alcoholic solution, and 10 ml buffer complexing solution was added. The pH was adjusted to 8.5 with 1N ammonium hydroxide, and 5 ml 0.001 percent dithizone solution in carbon tetrachloride added. If the alkalinity of the buffer solution had been adjusted previously (see below) the titration with ammonium hydroxide was not made. After shaking for 15 seconds the color of the carbon tetrachloride layer was observed. If the original, green dithizone color remained, the sample contained only background amounts of lead and the solution was discarded. If mixed colors appeared, the tetrachloride layer was transferred to a 30 ml cylinder with 10 ml of 0.1 percent sodium cyanide solution, excess dithizone removed by shaking and the lead content estimated by comparison with standards corresponding to 20, 40, 60, 80, and 100 ppm. Higher lead values were estimated by diluting the final lead dithizonate solution with carbon tetrachloride or repeating the test with a smaller aliquot.

Samples were assayed in batches of 20. Three hundred tests could be made daily by two workers in a small laboratory.

Buffer complexing solution — Buffer complexing solution was prepared by dissolving 8 g sodium cyanide, 40 g sodium citrate and 1.5 g hydroxylamine hydrochloride in 1000 ml water. The small amount of hydroxylamine hydrochloride was sufficient to prevent oxidation of the dithizone.

It was found that in long of tests the mixture of sample and buffer solution consumed the same amount of ammonium hydroxide in order to adjust the pH to 8.5. By simple experiment the amount of sodium cyanide necessary in the buffer solution to obtain a pH of 8.5 in the mixture could be determined, and this modified buffer solution could then be used for a large number of tests. Thereby, the titration step with ammonium hydroxide was avoided. Usually 10 to 11 g of sodium cyanide per 1000 ml buffer solution were required. The pH was then checked at regular intervals with special indicator paper (range from 8.2 to 10).

Purity of reagents — It is usually recommended that reagents used in geochemical prospecting work should be of analytical grade or the solutions purified to avoid high blank tests. However, some technical grade reagents contain very small amounts of lead, and if only this metal is sought, they can be used with good results at a much smaller cost. During the present work analytical reagents were used initially, but later were replaced by technical products. Most commercial sodium cyanide, ammonium hydroxide and hydroxide and hydrochloric acid proved to be practically free of lead. Some sodium cyanide had a relatively high lead content but other commercial brands contained no determinable amount of the metal. Water from a spring issuing from diabase bedrock could be used without purification. Blank tests were made every time a new solution was prepared and even with technical reagents no perceptible color appeared in the final carbon tetrachloride layer.

COST OF GEOCHEMICAL PROSPECTING

The average cost of sampling, including transportation to the laboratory, was approximately Cr $ 6.50 per sample (1 cruzeiro = US $0.012 at the current free market exchange rate). Envelopes, chemicals and laboratory equipment cost Cr$ 3.00 per sample. Wages of laboratory personnel were Cr$ 2.50 per unit, including all accessory work. The total expenditure for one lead determination was therefore Cr$ 12.00 (US$ 0.15). This figure does not include the wages of the geologist who spent about half of his time supervising the work. The whole laboratory equipment cost less than than Cr$ 5,000.00 (US$ 58.00).

RESULTS

The geochemical prospecting work covered an area of about 100 sq km in which geological conditions for lead mineralization were considered favorable and several prospects already known. To judge from the absence of large anomalies, it seems improbable that any deposits comparable in size to Panelas, Furnas or Rocha could exist in this area. The occurrence of veins too short to be detected by traverses spaced a few hundred meters or not parallel to the general strike cannot be ruled out, but in the authors opinion would not justify closer spaced sampling.

Several small anomalies were found in the neighborhood of Apiaí (Fig. 2), but by comparison with known deposits, they do not indicate exploitable ore bodies. The geochemical anomalies found in the limestone body west of Itaóca are comparatively extensive and strong indicating a good possibility for exploration by trenching.

Although not originally planned for detailed investigations, the geochemical work proved its usefulness for estimating the size of known occurrences and indicating the possible extension of veins. From the anomalies obtained at the southwestern extension of the Furnas mine, the existence of some ore seems possible there. At Rocha (Fig. 5) the length and position of the mineralized zones could be clearly outlined and served as a guide for exploration. The Três Barras prospects proved to be very limited on the surface. The clear and continuous anomalies obtained at Serra would probably justify some exploration in that area. At Pinheiros, Vieira and Bôa Vista, where underground exploration has been started several times, the lead content of overlying soils does not indicate exploitable deposits. Negative results, obtained at several localities where limonite considered possibly to be gossan had been found, seem to exclude the presence of commercial lead ore.

The largest mining company in the district, PLUMBUM, S. A., started an extensive geochemical investigation of their property at Panelas, spacing stations on a grid 10 by 25 meters and making lead estimations by the above described method.

CONCLUSIONS

The lead content in soils over the non-mineralized parts of the limestone bodies in the Rio Ribiera de Iguapé district is low and uniform, rarely exceeding 20-30 ppm. Over lead ore deposits the lead content in soils rises to a maximum of 8600 ppm, and the anomalies are usually a few hundred meters long and several tens of meters wide.

In regional prospecting by wide-spaced traverses any anomaly of over five times back-ground value on two or more adjoining stations would deserve checking by a closer spaced sampling procedure. Traverses spaced 30 or 50 meters with stations every 10 meters usually gave a good idea about the underlying mineralization when compared with anomalies corresponding to known deposits in the area. The 0.1 gram samples represent the soils within a radius of several meters with enough accuracy for geochemical exploration work.

The analytical laboratory procedure employed does not permit an exact determination of the lead content in soils, but is accurate enough for the detection of lead values which characterize a geochemical anomaly, possibly corresponding to an economic deposit. Geochemical exploration is certainly the fastest, most efficient and cheapest way of prospecting in an area like the Rio Ribeira de Iguapé district.

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A SURVEY OF GEOCHEMICAL EXPLORATION IN EASTERN CANADA

J. E. Riddell *

ABSTRACT

Geochemical exploration techniques have been widely used in Eastern Canada during the period 1952-1956. Most of the surveys have been carried out as an aid in the search for base metal deposits in the Maritime areas south of the St. Lawrence River.

A number of companies have established their own analytical laboratories but the majority of small companies still make use of custom analytical facilities. Field kits for soil and water determinations are commercially available.

The bulk of the geochemical exploration work has been confined to the testing of soils and to a lesser extent, the testing of water, alluvium, and vegetation. Many of the surveys were carried out to test previously located geophysical anomalies or favorable geological structures. Several groups employed geochemical methods as primary reconnaissance techniques to locate metalliferous secondary dispersion fans and trains in colluvium, alluvium and water.

At the present time research work is in progress on the dispersion patterns developed in the heavily glaciated Precambrian areas, and on the adsorption of metals by lacustrine sediments.

A resume will be presented of the field and laboratory methods employed by the larger exploration groups and their opinions as to the usefulness of the geochemical method.

INTRODUCTION

Although the Eastern Canadian mining fields have been the scene of intensive application of geochemical techniques during the past two years, it should be pointed out that the Eastern Canadian operators were behind Western Canada and the United States in the recognition of applied geochemistry as a satisfactory exploration medium.

From the viewpoint of exploration geochemistry Eastern Canada may be divided into two distinct areas:

1) The Appalachian province, lying in the south and eastern part of the Dominion, in which there is a moderate to strong topographic relief, well-

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developed drainage patterns frequently dendritic, light glaciation in general, and finally a humid temperate climate and fairly rapid weathering of the bed-rock. Within this province it is possible, in many areas, to map bed-rock formations by the rock fragments present in the soils. Glacial erosion has not completely removed the pre-glacial residual soils. On the other hand these more or less residual soils may be overlain by characteristic glacial and glaciofluvial deposits of limited extent and thickness.

2) The Precambrian Shield province. These areas have low to moderate topographic relief, deranged drainage patterns, and strongly glaciated bedrock mantled by various types of glacial and glaciofluvial deposits. Furthermore most of the Shield lies north of the Appalachian zone and weathering processes have been restricted by the lower temperatures and a decrease in rainfall. The streams, most of which are consequent on Pleistocene deposits, are still cutting through these unconsolidated deposits. In many areas however the mantle of drift is thin, the drainage patterns are structurally controlled, and the streams flow on or close to the bed-rock. Much of this northern glaciated area is covered by lake or muskeg and consequently geochemical exploration techniques have not been used as extensively as in the Appalachian belt.

The earliest reported geochemical survey work in Eastern Canada was that of Dr. A. Bell in the Gaspé Copper Area, who during the middle forties carried out a number of soil and water surveys in the central section of the Gaspé peninsula of Quebec. These surveys were carried out in an area of strong topographic relief and deep weathering, in which mechanical and chemical dispersion of the products of weathering are probably at an optimum in so far as Eastern Canada is concerned .Dr. Bell, was undoubtedly influenced by the fact that the Gaspé Copper deposits are exposed on a side-hill on which a very large talus has formed, and float from this area has been transported by valley glaciation and stream action for many miles downstream. As a matter of fact it was by tracing this float upstream that Alf Miller, the discoverer of Gaspé Copper, first located the original find.

Subsequent to Bell's work, Dr. H. V. Warren of the University of British Columbia carried out studies on the distribution of base metals in vegetation in various mineralized areas across Canada. Some of this work was in the Eastern sections.

Early work in the maritime region was carried out by the author for the Quebec Department of Mines. Water and vegetation surveys were carried out in 1951 and these were followed in 1953 by a fairly detailed reconnaissance type survey in central Gaspé using colluvium as the sampling medium. Samples were collected from the base of the slopes and analyzed for base metals.

In the Precambrian areas the earliest work carried out was by E. O. Chisholm of the Ontario Department of Mines, who in 1950 tested lake waters and soils in the central Ontario area for zinc. Carl Bischoff of Noranda has carried out extensive soil surveys in the Noranda-Chibougamau base metal areas, and although much of this work is of a private nature he has published papers indicating that the surveys were successful in a number of cases.

In general geochemical work in the Precambrian glaciated areas has lagged far behind the work in the Appalachien belt. This is in a large part due to the obviously more favourable environment of the latter in so far as applied geochemistry is concerned.

Reconnaissance geochemical techniques have not been as readily accepted by the Canadian exploration companies as the detailed geochemical surveys. In Canada the pioneer of the reconnaissance method was Dr. H. V. Warren who made wide use of water sampling in the Western Cordillera during the late forties and early fifties.

In Eastern Canada the writer carried out a reconnaissance type survey for base metals in the Eastern Townships of Quebec in 1951. This survey was based on the analysis of stream waters. The results obtained indicated that there was a distinct geochemical zoning but no discoveries of economic importance were made.

The first large scale surveys known to the author were carried out by Selco Exploration Company Limited, in New Brunswick and Gaspé. These surveys made use of a sediment sampling technique devised by Hawkes and Bloom and the determination of the ammonium citrate soluble fraction of the heavy metals present in these samples. A paper on the results of this exploration work is being presented at this meeting by Dr. Hawkes and others. These reconnaissance surveys were carried out in 1954-55 but had been preceded by a brief test run in 1953. In 1955 a number of other exploration groups were making use of reconnaissance type sediment or water surveys in the Appalachian Province of Eastern Canada. The bulk of the reconnaissance surveys have been carried out in the search for base metals.

Although published information is not available, it is known that the large Canadian nickel companies have used geochemical water surveys in the search for new nickel deposits for a number of years. Most of these nickel surveys have been carried out in the Precambrian areas. The results of the surveys are not available.

Apart from these water surveys no other reconnaissance type surveys had been reported in the Precambrian areas of Eastern Canada up to 1956. At the present time there are at least three and possibly more, surveys of this type in progress in these areas. Two of these surveys are in the Grenville province near the southern margin of the Shield and the third is in the Labrador area.

Most of the geochemical exploration work in Eastern Canada has been devoted to the search for base metals and nickel. A small amount of work has been carried out on columbium and uranium deposits but with no published results.

Apart from the work on secondary dispersion phenomena there has been extensive unpublished work on the wallrock alteration surrounding base metal and other types of ore deposits. This work has been carried out by graduate students and government agencies. There is an increased interest in the study of the geochemistry of ore deposits in Eastern Canada with a view to supplementing the intensive structural studies that are normally carried out in mining districts.

Apart from these general studies that have been carried out by independent geochemists and government agencies there has been an increasing amount of geochemical survey work carried out by the mining companies and their exploration subsidiaries. To illustrate this point — in Eastern Canada in 1952 there were no custom or private analytical facilities setup to handle the samples taken in geochemical exploration work. In 1956, however, there were at least five private laboratories capable of handling various types of geochemical analyses, and in addition a number of custom laboratories stet in operation servicing this area. It is of interest to note that the earliest laboratories to handle geochemical analyses in Eastern Canada were either commercial laboratories or University laboratories. The private laboratories of the mining companies have been staffed from these sources and the present analytical productivity of the mining companies is far in excess of that of the custom facilities. Although these mining company laboratories handle the bulk of the analytical work, the smaller mining groups, the individual companies, and the prospectors make use of the customary analytical facilities.

Field kits for making heavy metal determinations are available from the commercial and university laboratories for the use of field men and prospectors.

EXPLORATION TECHNIQUES PRESENTLY IN USE

During the early part of the period under consideration, the bulk of the geochemical work was confined to soil sampling. These samples were taken on a grid pattern and so spaced as to ensure the intersection of mineralized zones if such existed. Sampling depth was either fixed at some suitable depth below the surface or at some recognizable soil horizon, e.g. the 'B' horizon of the podzolic profile. Apparently only a few operators have made extensive use of the A_0 horizon, probably because of biological vagaries which are not fully understood and interfere with a strictly geological interpretation. In general the results of such surveys indicate that, in so far as the base metal distribution is concerned, the lead content in soils is the most reliable indication of the distribution of the base metallization in the underlying rock. This is true whether lead is of major or minor importance in the mineralized zone. The distribution of copper in soils has indicated that copper is more widely dispersed than lead, but that the highest copper values are fairly close to the bedrock source except in areas of very active weathering and erosion. The distribution of zinc in soils tends to be erratic when considered relative to bedrock source, with the highest values present existing at favourable points of concentration along the secondary dispersion fans and trains rather than in the immediate vicinity of the mineralized zone. Most of these areas of zinc accumulation are in topographic lows, particularly in zones of stagnant drainage such as swamps and lakes, or in seepage areas where underground drainage emerges at the surface. Such topographic lows are frequently due to zones of structural deformation in the bedrock, e.g. graphitic shear zones, and many of these zones are good conductors. This unfortunate co-incidence of secondary geochemical highs and geophysical conductors, has led to many disappointments when the zones were drilled.

On the other hand the use of geochemical soil surveys has made it possible in many cases to differentiate barren conducting zones and mineralized conductors. At one time this was held against the geochemical method, it being the grievance of the exploration groups that "the geochemical surveys failed to locate conducting zones of massive sulphides that the geophysical surveys indicated".

In the soil surveys the samples which have been collected are first dried at 100C, then sieved through a 100 mesh screen and the oversize rejected. The — 100 mesh fraction is then analyzed for its metal content. The sample is attacked with hot acid leach, or bisulphate fusion is used, and the extract is tested for heavy metals using dithizone as a reagent. The dithizone is dissolved in some organic solvent such as carbon tetrachloride, chloroform, xylene or toluene. It should be noted that attempts have been made to make use of partial extraction techniques in soil work, but in general with only moderate success. It is apparent, from research work presently being carried on, that partial extraction techniques involving dilute ammonium citrate solution as the extractant is variable as to its effects between different minerals, e.g. 100% of the metal may be extracted from quartz, 50% from amphiboles hornblendes, and 80% from micas.

Although biogeochemical surveys were employed to some extent at first, they are not used widely in Eastern Canada at the present time. It has been the author's experience that this type of survey is less readily handled than the soil survey. This is due to a number of factors, one of the most important of which is the collection of samples. In order to obtain suitable samples for the vegetation survey it is necessary to have a reasonably uniform distribution of individuals of one species, and this requirement is a restriction on adequate sampling coverage. Another factor is the relatively low ratio of abnormal values to background values in samples of conifers growing in soils overlying mineralized and unmineralized bedrock. This factor is in the order of 2 or 3 to one, whereas the equivalent factor for soils is 30:1 to 100:1 or even higher. On the other hand soil samples are readily gathered, stored, shipped and prepared. For these reasons detailed geochemical survey work in Eastern Canada has been predominantly of the soil survey type. It should be pointed out, however, that there is a promising field for biogeochemical work in the northern areas where there are extensive tracts of muskeg containing more or less uniform ecologic assemblages and in which soil samples are difficult if not impossible to obtain.

During the past few years Eastern Canadian operators have devoted more attention to the reconnaissance types of geochemical survey. These may be divided into three groups, soil surveys, water surveys and sediment surveys.

Although reconnaissance soil surveys have not been extensively used in Eastern Canada, two surveys of this type have been carried out, one in New Brunswick and the other, the colluvium survey previously mentioned, in the Gaspé. In the New Brunswick survey, sampling was carried out on a 1000 foot grid pattern with a view to locating a favourable zone. Although the results of this survey were successful in locating a mineralized deposit, it is now felt, because of the effect of drainage on the distribution of metal values in soils, that the use of a fixed grid pattern in well drained areas is not desirable.

In water surveys the normal method is to take water samples and test them in the field. The size of the samples has been between 100-500 millilitres depending on the background values in the areas. The samples are tested with dithizone in an organic solvent as a general reagent for the detection of the heavy metals. In general these surveys have been successful in locating concentrations of zinc mineralization. Surveys for nickel have made use of di-methyl-glyoxime in alcohol as a specific reagent.

It has been found that there is considerable variation in the concentration of metals from a given source in the waters draining that source. This variation appears to be dependent on the amount of precipitation in the area during the period immediately preceding sampling, the height of the water table in the area, the type of country rock present and other factors which are difficult to evaluate on the spot or without detailed studies.

A factor which is against the use of water surveys is the difficulty of transporting the sample to the laboratory for check analysis, or for analysis for metals for which there is no suitable field test at the present time. This has resulted in the practice of field testing the samples for heavy metals without confirmatory laboratory checks.

In considering the relative merits of water sampling as compared to sediment sampling it should be pointed out that for actual follow-up work in the field, once a 'hot' area has been located, water testing is very useful. The samples are uniform in composition on any given day and can be collected and tested very rapidly. On the other hand it is not always possible to return to an area under different conditions of precipitation, etc., and obtain confirmatory results. This means that for regional reconnaissance work water sampling is not entirely satisfactory. Another factor which militates against the use of water surveys is the dominance of zinc in natural waters as compared to other, more valuable, metals. The geochemical pattern which develops in essentially a zinc pattern.

Analytical methods used in water testing derive in large part from those described by Huff, and Warren and Delavault, although modifications have been made of these tests to either increase the sensitivity or to simplify them. Ordinarily, however, the difficulty in water testing is not the detection of mineralized zones, but the differentiation between metal derived from broad low-grade areas of disseminated mineralization and that from more highly concentrated mineralized zones which might form an ore deposit. This is particularly true of zinc which is widespread in sedimentary rocks and which also is associated with most mineralized zones of hydrothermal origin. It is also true of nickel which is widely dispersed in the form of sulphides in basic rocks and which is leached on weathering.

In the Appalachian area the water sampling technique has been to take samples at intervals along streams. Here, as previously mentioned, the drainage patterns are well developed with few areas of deranged drainage. Futhermore the train is of some length, being of the order of two to four miles. In the Precambrian areas the technique has been somewhat different; in these areas it has been necessary to sample not only the streams but also the more or less stagnant water in the muskeg areas and in the lakes. Where lakes are sampled it is customary to take samples along the margin of the lake and also from various points across the lake surface. Muskegs are sampled on a grid pattern.

During the past year a new technique has been employed in which ion exchange resins placed in suitable locations in the drainage pattern are permitted to take up metal for a certain definite period. These resins are then collected and analyzed for their metal content. An advantage of this method is that a permanent sample is obtained which can be taken to a laboratory and specifically analyzed for a variety of metals.

The most recent development in reconnaissance techniques has been the use of sediment collected from various drainage ways as the sample material. In general it has been found that the length of the dispersion train from a major base metal deposit in the Appalachian zone has been in the order of from two to four miles. In favourable circumstances the trains are detectable for 10 to 12 miles. The cut off point is normally taken as two miles below the outcrop, and a suitable sampling interval employed.

Samples of fresh sediment taken from the stream bottom and samples of alluvium taken from the stream bank or flood plain are collected and analyzed for their heavy metal content using the Hawkes-Bloom dithizone technique. In this technique the ammonium citrate extractable metal of the sample is determined on the theory that chemisorption is the most important factor in the development of the dispersion train. There have been cases, however in areas of high topographic relief, in which there has been very active stream downcutting in post-Pleistocene time, where total extraction of the metal from the sample yielded more significant results than the partial extraction method. This is taken to indicate that in these areas mechanical dispersion of detrital particles derived from the weathering of the mineralized outcrop is of more importance than chemical dispersion of metal in solution.

In the Precambrian areas sediment surveys have been little used up until this year. During the summer of 1956, however, there were at least three regional type surveys being carried out. Two of these surveys were in Greenville province of the Shield and the third is in Labrador. It is too early to judge whether or not the sediment survey will be successful in these areas, but the writer can say that at least one of these surveys is producing an extremely interesting geochemical pattern which appears to be in agreement with the geology of the area concerned. One factor which is detrimental to the use of pure sediment surveys is the fact that the muskegs and lakes form natural traps for metal in solution because of their high content of organic material which is an effective adsorbent. Further the biogeochemical factor must be considered because algae and bacteria can remove metal from solution. In many parts of the Shield, the stream gradients are low and there is little mechanical dispersion at the present time. Nonetheless most of the base metal and radioactive deposits of the Eastern Shield are undergoing chemical weathering and hence soluble metals are being dispersed into the drainage ways.

CURRENT RESEARCH

At the present time a number of problems concerned with applied geochemistry are being investigated at the various Universities. The author can only speak with authority concerning the work presently being carried out at McGill where the problems undergoing investigation are as follow:

1) Adsorption of base metals on minerals.
2) Field investigation on the distribution of base metals in glacial soils and the effect of pH and redox potential on the transportation of these metals.
3) Distribution of base metals in lake sediment and the use of lake sediments in reconnaissance type surveys.
4) The relationship of radioactivity to accumulations of oil and natural gas.
5) The dispersion train from zones of radioactive mineralization.
6) Continuation of wall rock alteration studies around base metal deposits.

Some of these investigations have been partially completed and the following results are of interest:

1) The adsorption of base metals from dilute solutions by rock forming minerals is dependent on

   a) the concentration of the solution
   b) the pH of the solution
   c) the mineral sorbent
   d) the kind of metal in solution

2) The base metals are adsorbed in increasing amounts on quartz, feldspars amphiboles and pyroxenes, micas, and finally the clay minerals.
3) For dilute solution the following sequence of adsorbability holds

   $Cu > Pb > Zn$ (when expressed in moles)
   or $Pb > Cu > Zn$ (when expressed in micrograms)

4) The partial extraction technique of Bloom removes
   100% of the metal sorbed on quartz.
   50% of the metal sorbed on oligoclase, augite and hornblende.
   80% of the metal sorbed on muscovite.
5) Below certain pH values sorption decreases for the more concentrated solutions. This means that in drainage systems of low pH metal would tend to remain in solution and hence the waters should be tested also.

6) Dispersion fans develop in lakes at the mouths of streams carrying metal in solution.
7) Dispersion zones in sediment in some lakes investigated appear to reflect immediately underlying bedrock mineralization.
8) Secondary dispersion halos are developed in glacial soils up to 20 feet in thickness above bedrock mineralization. There is apparently very little down glaciation dispersion of former gossans that can be detected.
9) The base metals, nickel, and probably uranium give satisfactory trains in heavily glaciated areas.
10) Satisfactory dispersion patterns can be detected in muskegs using either a water test or partial extraction on decomposed vegetation (mosses) or humus.
11) Lichens are apparently capable of taking up and concentrating large amounts of the base metals, even when growing on what appear to be practically barren outcrops.

FUTURE OF GEOCHEMISTRY IN EASTERN CANADA

The trend in the use of geochemical methods in the search for new mineralized areas is upwards, and there will undoubtedly be a great increase in the application of these methods to exploration problems. There is a tendency at the present time for reconnaissance surveys to be carried out with the object of locating certain types of deposits. In view of the cost of collecting samples it is probable that in the future more complete analyses will be carried out with a view to determining the mineral potentialites of an area in general, rather than merely whether or not certain specified metals are present therein.

It is the writers opinion that considerable attention will be devoted to the problem of correlating soil, water and sediment samples with the values contained in the underlying bedrock. Also further work will be carried out on the problem of eliminating the distortion of the soil patterns due to slope and drainage factors, so that the bedrock target may be pinpointed with accuracy.

There will of course be considerable research carried out on the analytical methods employed and it is to be hoped that an equal amount of time will be spent on improving sampling techniques. In so far as the glaciated shield areas are concerned the main problem is that of the muskeg and lake cover; this problem will be attacked with increasing vigor.

In closing may I add that in my opinion, applied geochemistry has won its' spurs in the Canadian exploration field and is well on its' way to ranking with geology and applied geophysics in usefulness to the mineral exploration industry.

GEOCHEMICAL RECONNAISSANCE IN EASTERN CANADA

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J. E. RIDDELL and J. S. WEBB

ABSTRACT

In 1954 and 1955, an area of 27,000 square miles in New Brunswick and the Gaspé Peninsula of eastern Canada was explored for base-metal deposits by a geochemical reconnaissance method based on analysis of stream sediments for readily extractable heavy metals. A total of about 15,000 sediments samples, representing over 4900 sample sites, were collected and analyzed. The regional geochemical pattern thus obtained (1) clearly outlined terrains with favorable geochemical characteristics for the occurrence of base-metal deposits, and (2) located specific drainage areas outstanding promise. Detailed scouting of such drainage areas led to the delineation of 43 local geochemical anomalies, of which the nine most promising were designated for intensive physical exploration. To date, four of these nine have been explored by diamond drilling, and in every case have disclosed evidence of significant base-metal mineralization. Exclusive of geophysical work and diamond drilling, the total cost of the program was $ 150,000, of which roughly half was devoted to reconnaissance sampling, and half to following up the reconnaissance indications.

INTRODUCTION

In 1954 and 1955, the authors of this paper operated under contract with Selco Exploration Company, Limited, of Toronto in carrying out a mineral reconnaissance of a large area in New Brunswick and the Gaspé Peninsula of Quebec, in Eastern Canada (see Fig. 1). According to the terms of the contract, areas of outstanding promise were to be located by geochemical methods, property rights acquired if possible, and then recommendations made to the sponsoring company for detailed exploration by conventional methods.

The authors wish to thank the staff of Selco Exploration Company for their cooperation and many courtesies during the course of the project.

The area under study lies between 45° and 49° north latitude. The climate is maritime, with rainfall averaging about 40 inches per year. The topography ranges from gently rolling in southern New Brunswick to rugged and mountainous, with a relief of 3000 feet in central Gaspé Peninsula. Although the terrane

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was glaciated during the Pleistocene epoch, much of the soil is residual, and the effects of pre-glacial weathering extend to depths of more than 50 feet in many places. Surface drainage patterns are well developed, and lakes are not common except in upland areas of New Brunswick.

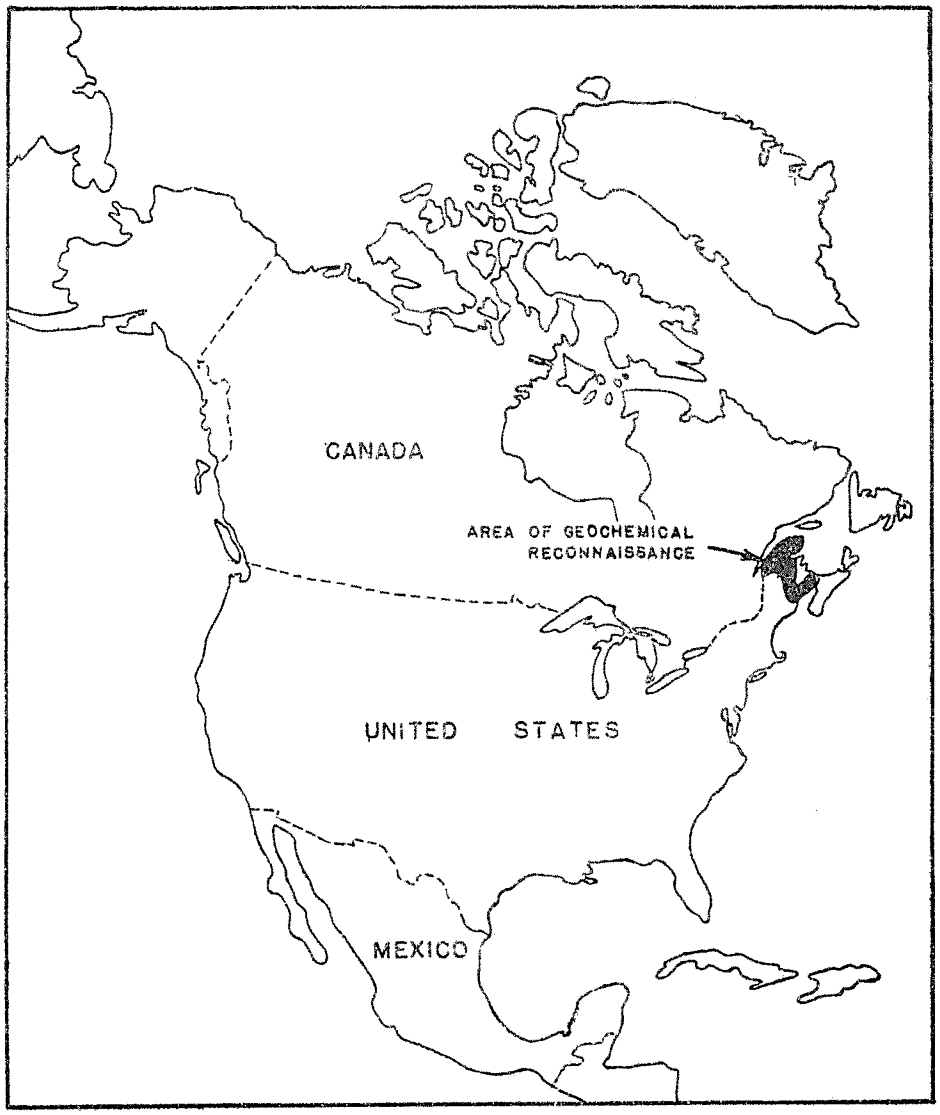

FIGURE 1. INDEX MAP

The geochemical reconnaissance of this area was based on systematic determinations of the exchangeable heavy metal content of modern stream sediments. Studies have shown that the content of exchangeable metal in the sediment of modern streams is a measure of the average metal content of the water in contact with the sediment (Hawkes and Bloom, 1956). The principles of exploration by sediment analysis and by water analysis are identical, in that a higher than normal metal content of the sample may be indicative of metalliferous deposits in the upstream area drained by the stream. In the authors' experience, however, the sediment of streams offers important practical advantages over stream water as a sampling medium in that (1) the effect of short-term variations in weather are eliminated, (2) dry stream channels may be tested, (3) the chemical test is simpler, (4) large-scale operations are more efficient, and (5) samples may be stored for future reference.

The exchangeable heavy metal content of sediments was determined by treatment of a small volume of sample with a cold solution of ammonium citrate, followed by determination of the extracted heavy metals with a solution of dithizone in xylene (Bloom, 1955). Zinc, and to a lesser extent copper and lead, are the members of the heavy metal group that are most commonly present in detectable amounts in the citrate extract of sediments. Thus the method as used was effective primarily in locating only deposits containing substantial amounts of the base metals, and would not be expected to yield indications of deposits consisting primarily of other metals such as tin, gold, or uranium.

The average content of exchangeable heavy metals in the sediment of streams draining unmineralized terrane was found to be about 2 ppm (parts per million), and rarely exceeded 5 ppm. Experimental surveys in the drainage below known but undeveloped base-metal deposits in New Brunswick and the Gaspé Peninsula showed that values of 10 ppm or more extend downstream from most of the deposits as much as 4 miles, and that values between 5 and 10 ppm extend considerably farther (see Table 1). Therefore as an operating rule, it was arbitrarily assumed that a given sample would not fail to indicate the presence of a base-metal deposit in the drainage basin if that deposit occurred within two miles of the sample site.

TABLE 1

LENGTH OF GEOCHEMICAL ANOMALY IN THE SEDIMENTS OF STREAMS DRAINING KNOWN BASE-METAL DEPOSITS IN THE NEW BRUNSWICK-GASPE AREA

Deposit	Observed length of anomaly * in miles	End of anomaly defined by:
Heath Steele Mine	6	Background values at 8 mi.
Anacon Mine	4	Marginal indication at 5 mi.
Brunswick Mine	4	Confluence of stream with large river
Pioneer Prospect	4	Confluence with contaminated stream
Nash Creek Prospect	2.4	Ocean
Keymet Mine	1.0	Background values at 1.5 mi.

* Defined as length of stream course in which the exchangeable heavy metal content exceeds 10 ppm.

TECHNIQUES

It was found that most efficient operation could be obtained by breaking down the exploration routine into separate steps, as follows:

1—Reconnaissance sampling, followed by processing and analysis of samples at field headquarters.

2—Appraisal of reconnaissance data and designation of localities for follow-up surveys.

3—Follow-up surveys, with chemical kits for analysis of samples at the field site.

4—Appraisal of follow-up data and critical geological examination.

5—Property acquisition and preparation of reports of recommendation.

Techniques were continually changing and undergoing improvements throughout the duration of the project. The procedures outlined below are those that were found from experience to be the most effective, and were the ones in use at the end of the project.

RECONNAISSANCE SAMPLING

Before going into the field, an itinerary was planned that would include the maximum number of strategically located sample sites in the time available. On road traverses, 50 miles of linear traverse could usually be covered conveniently in one day; on river traverses about 15 miles was a normal day; and on foot traverses in normal terrane from 5 to 8 miles was standard. The sampling party was equipped with a sampling tool, sample containers, notebook and pencil, and field maps or photos on a scale of one mile to the inch or larger.

At the sample site, the terrane was examined with a view to avoid contaminated samples. The principal sources of field contamination were found to be galvanized culverts and trash; samples, therefore, were taken on the upstream side of bridges and well back from any roadside litter.

Samples, after removal cans. Aluminum containers were chosen in preference to paper or steel containers because they are durable, water-tight, non-contaminating, and non-rusting. Furthermore, they can be marked legibly with a common lead pencil, and can be placed directly in the drying oven without damage.

Four samples were taken at each site, two of fine-grained sediment from different parts of the active channel, and two from the floodplain (bank) within ten feet of the active channel and on opposite sides. It was found that the exchangeable metal content of heavy clay and of well-sorted clean sand was commonly very much lower than that of other types of sediments from the same site; these materials, therefore, were avoided. Unsorted gravel, silt, or mucky material generally gave very satisfactory results. For floodplain samples, the organic silt immediately below the forest litter was commonly collected.

Sample numbers were written in lead pencil on both top and bottom of aluminum cans. Samples were numbered consecutively with simple arabic numerals, as the use of letters hyphens, and other notations was found to lead to confusion. To avoid duplication, at the beginning of the season each sampler was assigned blocks of numbers for his use only. The number or the first sample taken at a given site was used as the site number, and was the number marked on the field map.

Notes were recorded in natebook for type of sample (active or floodplain), texture of sample, and the size and character of the stream.

On return to headquarters, the sampler transcribed his notes to triplicate record forms. The headings of these forms carried spaces for name of sampler, date, general area sampled, and the identification of the field map; beneath the title, columns were provided for sample numbers, sample descriptions, and analytical data. One copy of the record form was kept by the sampler as his temporary record, and the other two were transmitted with the samples to the analyst.

The sampler also was responsible for transcribing the location and numbers of the sample sites from his field map to a posting map in a scale of 2 miles to the inch, which was retained in the office as a permanent record.

PROCESSING AND ANALYSIS OF SAMPLES

The samples were dried by heating the opened cans for about three hours in a medium gas oven. After drying, the samples were passed through a noncontaminating sieve, the coarse fraction discarded, and the fines placed in a properly numbered manila coin envelope peding analysis.

Samples were analyzed for citrate-soluble heavy metals by the procedure described by Bloom (1955). Analytical values were entered in the appropriate column of the record forms. On completion, one copy of the record form was transmitted for the office file, and one retained for the laboratory file. The coin envelopes were then sealed and stored in shallow wooden boxes. Aluminum cans were reclaimed by scouring with a stiff cloth, and removing the penciled numbers with a piece of tissue dipped in xylene.

Appraisal of Reconnaissance Data

Experience has shown that sediments containing more than 19 ppm exchangeable heavy metal could be considered definitely anomalous, that 5 to 10 ppm was a border-line indication, and that anything less than 5 ppm was background. A map showing generalized reconnaissance data was prepared by plotting sample sites, and tracing the symbol for the stream with a heavy crayon for a distance of equivalent to two miles upstream from each site, using red for anomalous, blue for marginal, and green for background. Where several samples were taken at a single site, the values were averaged. Figure 2 is adapted from a small section of the generalized data map of the Bathurst District. The location of known mines and prospects, and of favorable geological and aeromagnetic features were shown on overlay maps on the same scale as the data map.

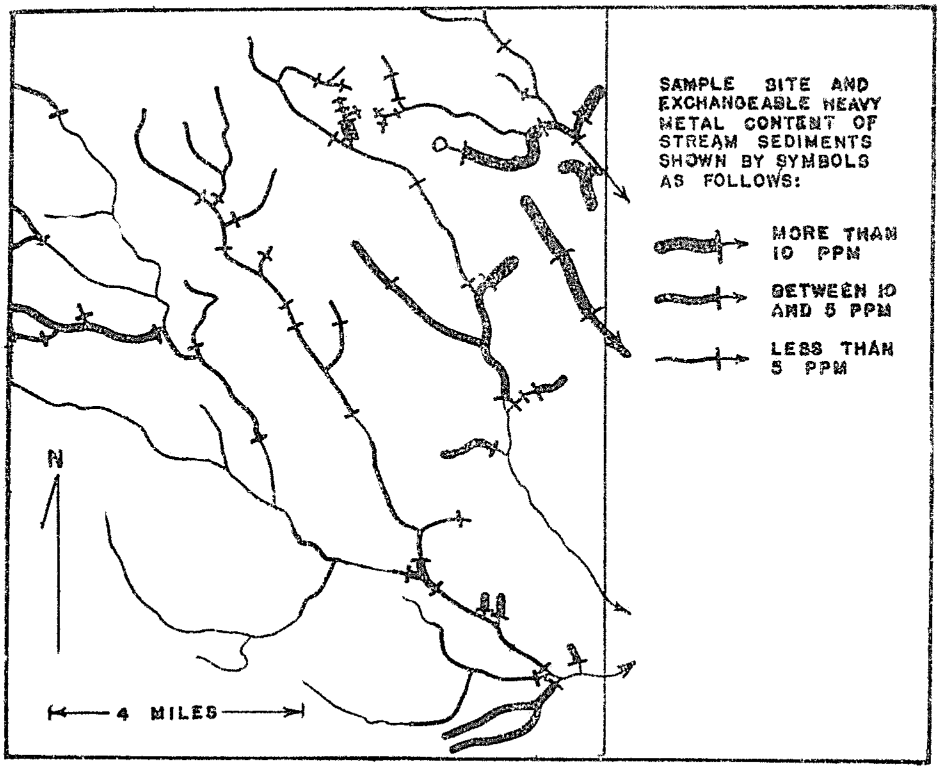

FIGURE 2. EXAMPLE OF MAP SHOWING GENERALIZED GEOCHEMICAL RECONNAISSANCE DATA

Interpretation of the assembled data was based on the following considerations:

1—Grouping of reconnaissance anomalies.
2—Coincidence of reconnaissance anomalies with favorable geologic or aeromagnetic features.
3—Topographic relief: high relief tends to accentuate anomalies because of accelerated weathering.
4—Size of anomalous streams: anomalous values tend to decay in a downstream direction faster than can be accounted for by simple dilution, so that a weak indication in a large stream may be far more significant than a strong indication in a small stream.
5—Texture of samples showing anomalous values: samples containing organic matter normally have a silghtly higher exchangeable metal content than inorganic samples; background values in heavy clays and clean sand may be discounted if they occur in an anomalous area.
6—Effects of lakes and swamps: lakes appear to act as blocks to anomalous drainage patterns; large stagnant areas and systems of beaver ponds may act as suppressants, but small beaver ponds appear to have no effect on the patterns.

No relation was observed between the strength of the stream anomalies and the location of the bedrock source within the drainage basin; thus a deposit near a watershed apparently gave as strong an indication as one located directly in the bed of the stream. However, deposits completely buried beneath swamps would be expected to give little or no indication, because of retarded leaching in the reducing environment of the swamp.

On the basis of these considerations, anomalous areas were selected for field confirmation and follow-up surveys.

FOLLOW-UP PROCEDURE

The first step in following up a reconnaissance anomaly was to revisit the original "discovery" site, equipped with a field analytical kit. Samples from the same general locality were collected and tested in the field for the purpose of confirming the original determinations.

If the original values were confirmed, the sampler then worked upstream, testing samples at suitable intervals from the main stream. Any one of three situations might be found: (1) the anomalous pattern might disappear within a very short distance, suggesting a local and probably unimportant source of metal near the original site; (2) the anomalous values might maintain a more of less even level in the main stream and possibly also in the tributaries as far as the headwaters, suggesting disseminated mineralization or scattered small deposits of no economic interest; or (3) the values might increase progressively to a certain "cut-off" point, and then decay either in steps or abruptly to a background value, suggesting a deposit of economic interest.

If and when a well-defined cut-off was found, the tributary streams on both sides of the main stream were tested, and if anomalous, were also followed up. If no tributaries occurred in the main cut-off area, the sediments on both edges of the floodplain of the main stream were tested to determine the location of possible lateral increments of metal-rich ground water.

When all the well-defined stream channels in the cut-off area had been checked, the soil or muck from swales and spring areas on the hillsides above the cut-offs were tested. Anomalous values in these areas would indicate the intermittent emergence of metal-rich ground water, and suggest a bedrock source directly up the slope of the water table from the sample site.

Figure 3, showing the geochemical pattern in streams near the Nash Creek prospect, illustrates many of the features of a typical follow-up problem. The outline of the mineralized area at Nash Creek has been confirmed by drilling.

APPRAISAL OF FOLLOW-UP DATA

A detailed map similar to figure 3 was then prepared showing the location of stream cut-offs, and the anomalous side-hill sites, together with watersheds and topographic form lines. Air photographs were examined for the possible presence of geologic features or of significant variations in the pattern of vegetation that might be related to mineralization. Anomalous samples were analyzed quantitatively to determine the relative abundance of zinc, copper, and lead. The ownership status of the ground was reviewed, to determine whether it could be acquired by staking.

The area was then revisited by members of the senior staff for critical examination of the geologic setting, with special attention paid to signs of alteration and gossan.

RECOMMENDATIONS

If the conclusions of these studies were favorable,, immediate steps were taken to stake the ground. A report summarizing all the observations leading to the recommendation of the property was submitted to the sponsoring company, with suggestions for further exploration by geophysical methods and diamond drilling.

OPERATIONS

In 1954, the area chosen for reconnaissance was the Gaspé Peninsula and the pre-Carboniferous terrane of New Brunswick, comprising altogether about 27,000 square miles (see Fig. 4). The program was planned for maximum coverage in the time available. Thus speed and hence accessibility became prime considerations in the laying out of sample traverses, with the effect that sampling was confined almost entirely to passable roads and major waterways.

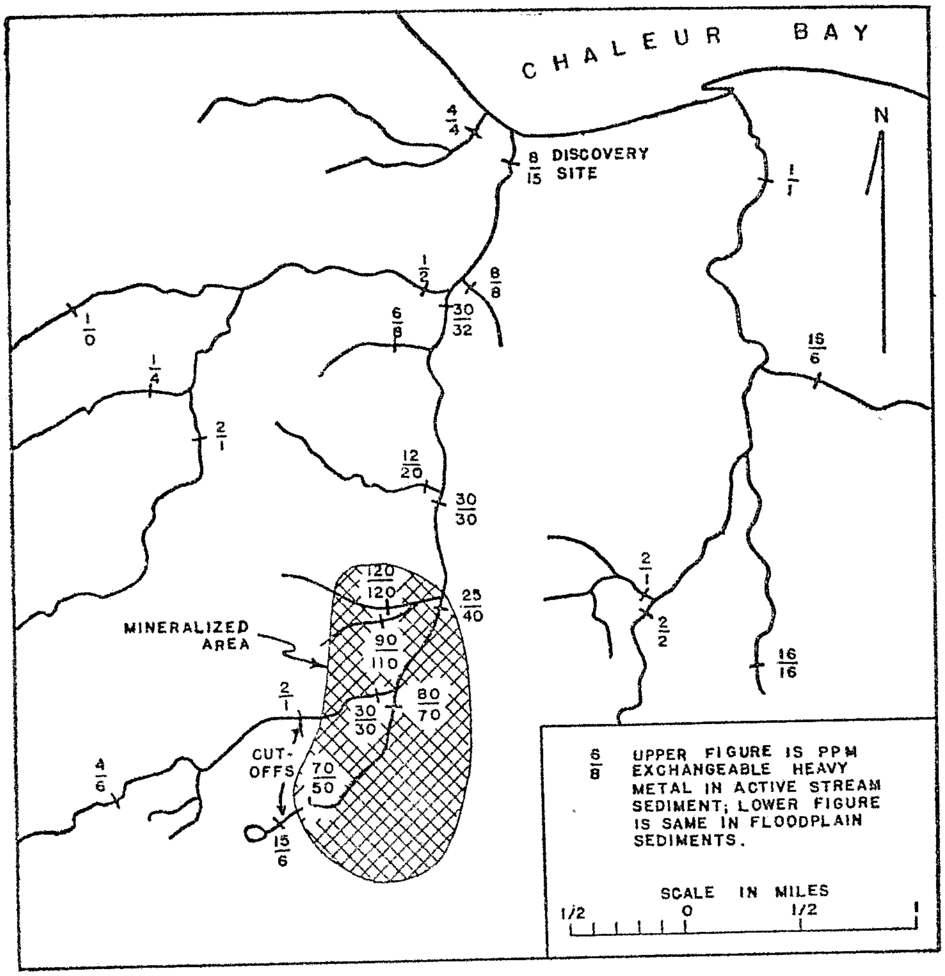

FIGURE 3. FOLLOW-UP OF GEOCHEMICAL STREAM ANOMALY AT NASH CREEK, NORTHERN NEW BRUNSWICK

In 1955, a considerable amount of geologic preselection of areas was exercised. In the first place, sampling was confined to the much smaller area enclosing the known deposits of the Bathurst Mining District. A review of the geologic setting of the known deposits of the district showed that, with only minor exceptions, no important deposits occur (1) in areas underlain by predominantly sedimentary rocks, (2) within bodies of intrusive rocks, or (3) in areas of low magnetic relief as shown on the areomagnetic map series of the Geological Survey of Canada. A composite map showing these unfavorable features so far as they were known was used as a guide in selecting areas for geochemical reconnaisesanc (see Fig. 5).

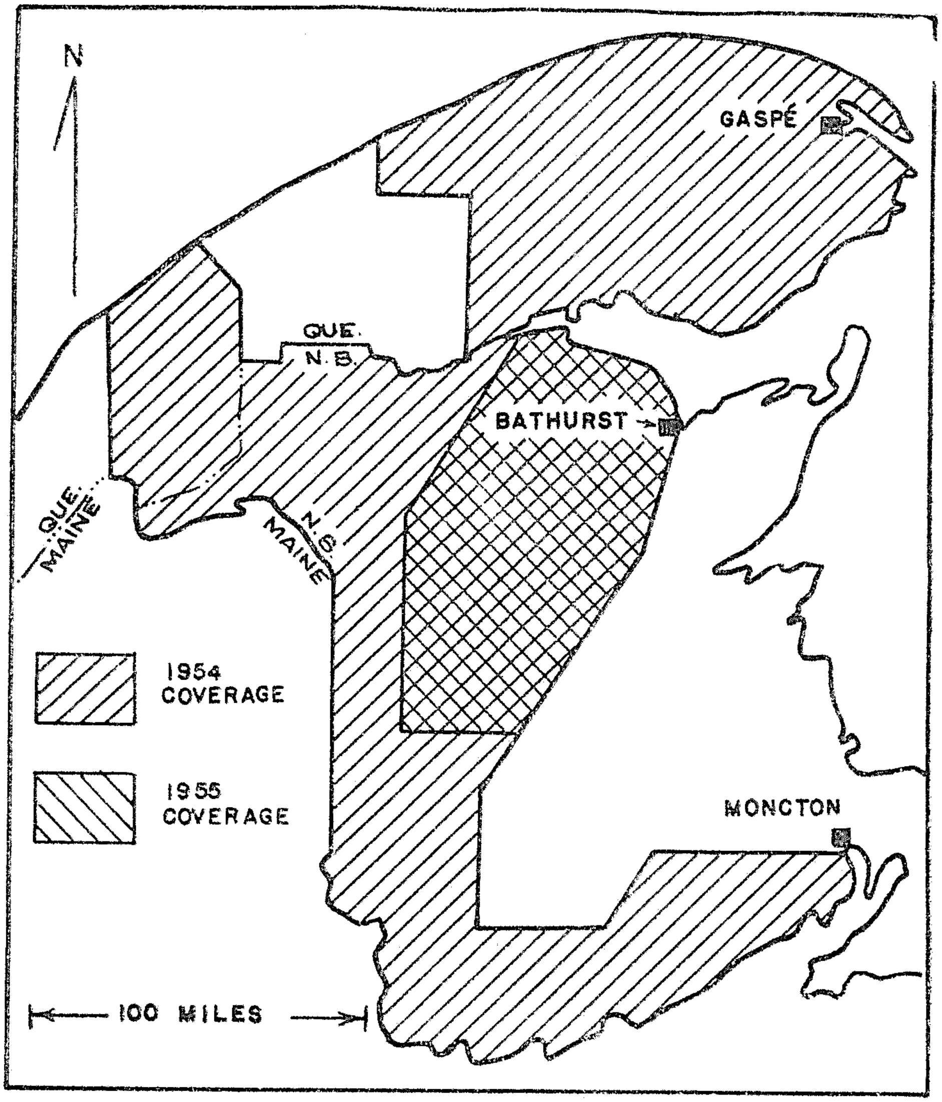

FIGURE 4. MAP OF NEW BRUNSWICK-GASPÉ AREA SHOWING GEOCHEMICAL RECONNAISSANCE COVERAGE

The operational statistics of the two season's work are summarized in Table 2. Personnel consisted of the four authors of this paper as senior staff, three to four junior men, one to two analysts, and an average of three local laborers. In both years, field work began early in May, and continued until early September.

The data of Table 2 show that in the second season's work, when the choice of areas was guided by considerations of geologic favorability rather than maximum coverage, the productivity in terms of recommended properties was higher than in 1954, even though only half as many sites were sampled and less than one-quarter the area was covered.

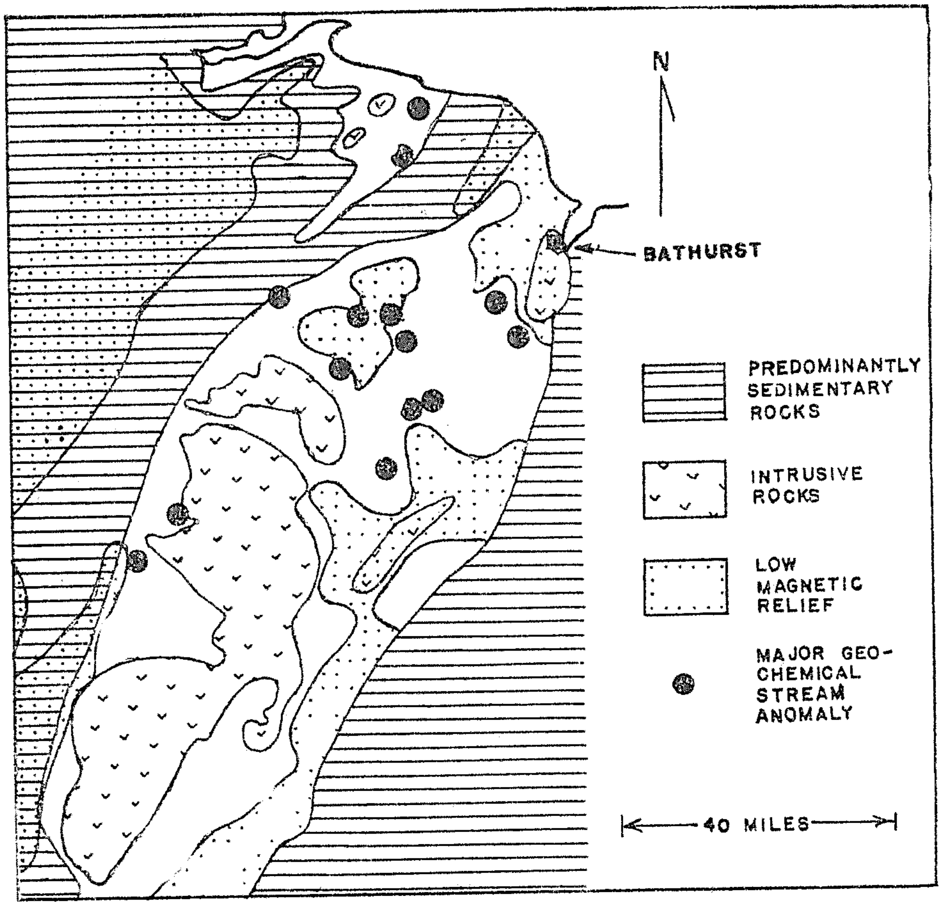

FIGURE 5. GEOLOGIC FAVORABILITY MAP OF BATHURST DISTRICT, NEW BRUNSWICK

RESULTS

GEOCHEMICAL RELIEF

One unexpected result of the reconnaissance work carried out during the 1954 season was the observation that certain broad areas showed a characteristic pattern of anomalies, or "geochemical relief", that is apparently related to mineralization. Three such patterns were identified (see Fig. 6):

1—Low geochemical relief, consisting of a featureless pattern in which the exchangeable heavy metal content of stream sediments rarely exceeds 5 ppm, is characteristic of northwest New Brunswick and adjacent parts of Quebec. This area is underlain by unmetamorphosed sedimentary rocks, and contains no known base-metal occurrences.

2—Moderate geochemical relief, featured by substantial numbers of small areas where stream sediments contain up to, but rarely more than, 20 ppm exchangeable heavy metals, is characteristic of southern and southwestern New Brunswick, and the Gaspé Peninsula exclusive of the central area. No generalizations can be made as to the geologic setting, as all variations in metamorphic grade, rock types, igneous activity, and structures are represented. Although small base-metal occurrences are known throughout these areas, no large deposits are known, with the possible exception of the Mount Pleasant deposit in southern New Brunswick.

3—High geochemical relief, featured by scattered localities where stream sediments containing over 40 ppm and as much as 200 ppm exchangeable heavy

TABLE 2

STATISTICAL SUMMARY

	1954	1955	Total
Reconnaissance Survey			
Area, square miles	27,000	6,000	27,000
Number of sample sites	3,266	1,671	4,937
Number of man-days, field *	184	131	315
Number of anomalies found	30	13	43
Follow-up Surveys			
Number of man-days *	230	61	291
Number of recommended properties	4	5	9
Analytical Work			
Number of samples	9,200	6,100	15.300
Number of man-days	305	224	529
Office Work, Administration			
Number of man-days	276	306	582
Equipment			
Trailer laboratory	1	1	
Canoes, boats	1	2	
Cars	3	3	

* Figures for number of man-days are for technical personnel only, exclusive of local labor hired as field assistants.

metal, is characteristic of two fairly well-defined areas, one in north-central New Brunswick and the other in central Gaspé Peninsula. Except for the occurrence of intrusive igneous rocks, the two areas have little in common geologically. Large ore deposits occur in both areas.

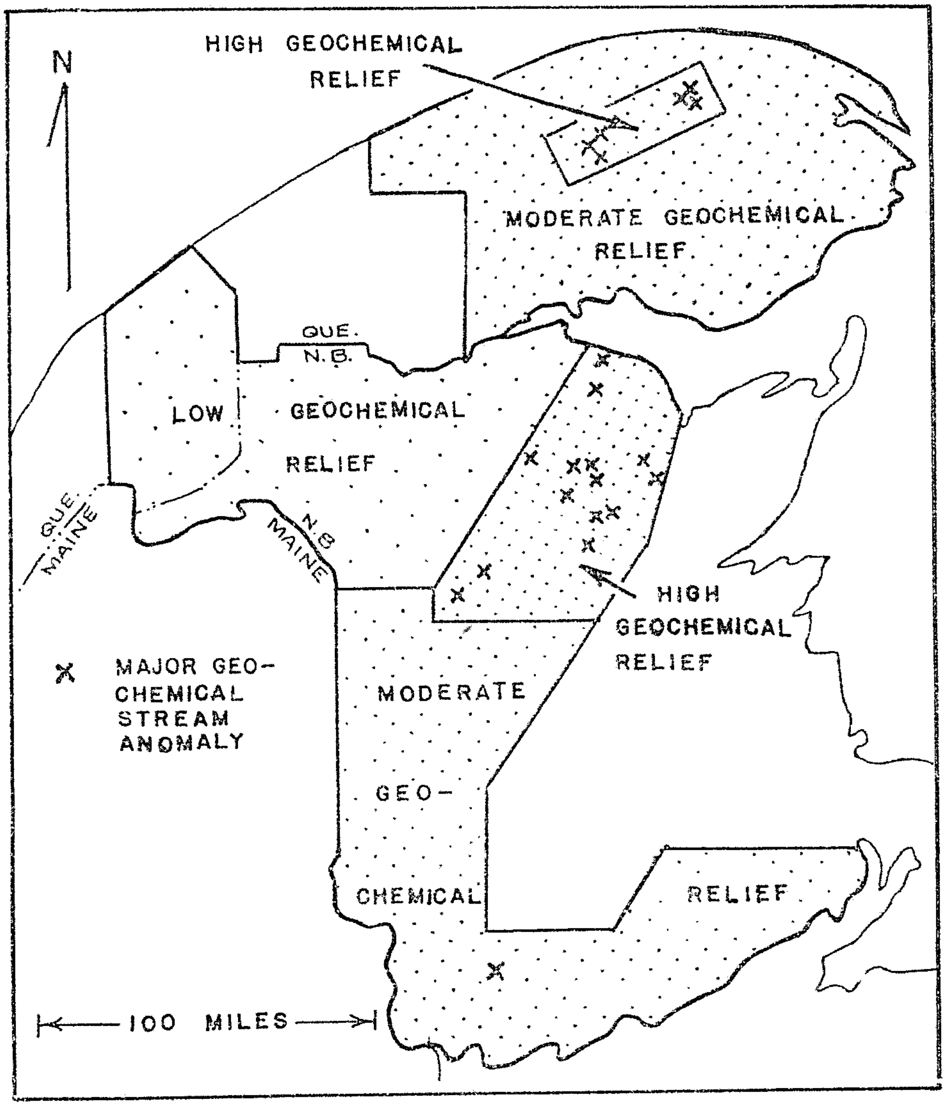

FIGURE 6. MAP OF NEW BRUNSWICK-GASPÉ AREA SHOWING RELATIVE GEOCHEMICAL RELIEF

The correlation between the occurrence of ore and the geochemical relief as brought out by the exchangeable heavy metal content of stream sediments, seems too close to be purely coincidental. When proved to be valid, this correlation would mean that in unexplored terrane, a stream sediment survey can be used as a primary method of delineating metallogenic provinces, where the chances of ore discovery are relatively good.

DISCOVERIES

The discovery of new ore deposits was, of course, the justification for the entire program. Table 3 summarizes the outstanding features of five of the nine properties recommended to the sponsoring company on the basis of the geochemical reconnaissance. Information on the other four is restricted, and cannot be released at the present time. Of the nine properties, exploration on only one, the Jacquet River prospect, has been adequate to provide a completely satisfactory explanation of the observed geochemical anomalies. None of the nine has yet reached the stage where a commercial body of ore can be blocked out. Detailed exploration work is continuing, however, so that eventually it may be possible to present the case histories of these properties in completed form.

On the more positive side, it can be stated that base-metal mineralization in the bedrock is associated with every geochemical anomaly that was found by this reconnaissance survey and that has been explored either previously or subsequently by diamond drilling.

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TABLE 3

DATA ON PROPERTIES ACQUIRED AS A RESULT OF GEOCHEMICAL RECONNAISSANCE

PROPERTY	GEOCHEMICAL INDICATIONS		GEOPHYSICAL INDICATIONS	GEOLOGY	MINERALIZATION
	Metals	Source Areas			
Charlotte Restigouche Co., New Brunswick	Zn Pb Cu	Distributed along 12,000 feet zone parallel to geologic structures	Strong electromagnetic indications suggestive of graphitic shear zones.	Altered pyroclastics and sedimentary rocks.	Fine-grained base-metal sulfides in one drill intersection; otherwise unknown.
Jacquet River Restigouche Co., New Brunswick	Zn Pb	At least three separate sources in zone 5 miles long.	Well-defined resistivity anomalies indicative of mineralized shear zones.	Rhyolite and rhyolitic pyroclastics.	Pyrite, sphalerite, galena and chalcopyrite in mineralized shear zones.
Lemieux Township Gaspe-Nord Co., Quebec	Zn Pb Cu	Restricted to three well-defined spring areas.	Not surveyed	Sedimentary rocks intruded by dikes of syenite.	Unknown.
Mount Pleasant Charlotte Co., New Brunswick	Cu Zn Pb	Distributed throughout area 2 miles long and 1 mile wide. Distributed principally along single 2800-foot zone.	Essentially featureless electromagnetic pattern.	Altered rhyolitic tuffs and breccias. Quartz-sericite schists.	Lenses of highgrade sphalerite; disseminated chalcopyrite, galena, arsenopyrite, fluorite, topaz.
O'Hearn's Brook Northumberland Co, New Brunswick	Zn Pb		Featureless electromagnetic. pattern.		Unknown.

GEOCHEMICAL PROSPECTING AS APPLIED BY THE ST. JOSEPH LEAD COMPANY

J. S. Brown and P. A. Meyer, Jr. *

ABSTRACT

The St. Joseph Lead Company has sampled soils as a guide to concealed deposits, chiefly of zinc and lead, since 1946. This has been done under widely varying conditions of soil, climate and geological structure, and has been supplemented in some cases by sampling surface water or ground water and vegetation. Illustrations are cited from southeastern Missouri, Pennsylvania, northern New York, southern Quebec and New Brunswick.

Analytical procedure has included use of the polarograph, and of various colorimetric methods (dithizone), the latter being preferred at present. Best results have been obtained in the laboratory. On-the-spot field methods, although useful, generally have not been wholly dependable.

Geological conditions may not always be favorable for the use of soil sampling. Deeply buried ore bodies, for instance, often seem to have no surface expression. However, where deposits do reach the present surface, even if concealed by appreciable amounts of overburden, they often yield good geochemical halos. Although no spectacular discoveries have been made thus far, the method has been significantly useful in numerous situations and is now an accepted part of the combined geophysical-geochemical exploration program.

INTRODUCTION

Geochemical prospecting by the sampling of soil for traces of valuable metals was first attempted by St. Joseph Lead Company in Pennsylvania in 1946. The senior author personally sampled an area around an old and inactive zinc prospect as detailed later. The locality was chosen because it was unglaciated and had a good depth of residual soil in which it was presumed that valuable metals might be concentrated in significant amounts. The chief problem at this time was the development of a practical method for determining accurately, indicative metals, primarily lead and zinc, where the amounts were well below the limits for commercial analysis. The samples were submitted to the laboratory of the Company's zinc smelter at Josephtown, Pennsylvania, and were analyzed under the direction of Chief Chemist Louis Cha. The method

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* *Respectively Chief Geologist and Geologist in Charge of Geophysical-Geochemical Unit.*

initially chosen was that of the polarograph. It was recognized that this probably woul not yield results of great absolute accuracy, but should give reproducible qualitative figures of comparative value, fairly rapidly and cheaply. Since the work experimental, samples were run on a fill-in basis at odd times and results were not available in many cases for several months.

Inasmuch as the results obtained did seem to have considerable significance, the program was extended to northern New York in the vicinity of the Company's Edwards and Balmat zinc mines even though this area had been glaciated fairly heavily. Owing to the severe winter climate, sampling was carried on for several years as a summer project and the laboratory work, at Josephtown, Pennsylvania, completed at anytime before the next season. This was reasonably satisfactory except that, where significant results were obtained, especially on isolated samples, it was difficult to relocate or identify the exact spot, since sampling usually was done by pacing traverse at fixed intervals (200 to 400 feet) without specific location markers for individual samples.

A small project also was carried out in the Wisconsin zinc fields in 1947. These samples were submitted to the Company's research laboratory at Bonne Terre, Missouri, under the direction of L. A. Rice. Here the samples were run by the dithizone colorimetric method, with occasional checks by polarograph. By 1950 it had been decided that the dithizone method generally was more rapid and accurate. All soil determinations thereafter were made at Bonne Terre by that method.

As the utility of this aid to prospecting became more apparent, it was evident that greater speed was desirable and that it would be particularly helpful if results, at least of qualitative value, could be obtained immediately, on the ground, sothat anomaous values could be checked and expanded as discovered without lag of time or loss of location. Accordingly, a geochemical laboratory and staff were set up in the geophysical unit under the junior author. Since 1952, all routine samples from the field have been run by this unit, which includes Meyer and 2 or 3 assistants. Considerable time also has been devoted to trying out field techniques and improving methods, according to published literature or otherwise, and to experiments with such phases as sampling water and vegetation. This program is not continuous but is carried on as circumstances require, and usually is more active in the summer season, particularly in Canadian areas. The staff, when not employed on geochemistry, devotes its time to geophysics. Summer programs often require additional temporary employees, usually students.

Spectroscopic methods have not been employed. No equipment for this is available and such occasional results as have been obtained from other laboratories suggest that the method is considerably more expensive and, so far as zinc is concerned, not equal in precision to the colorimetric methods.

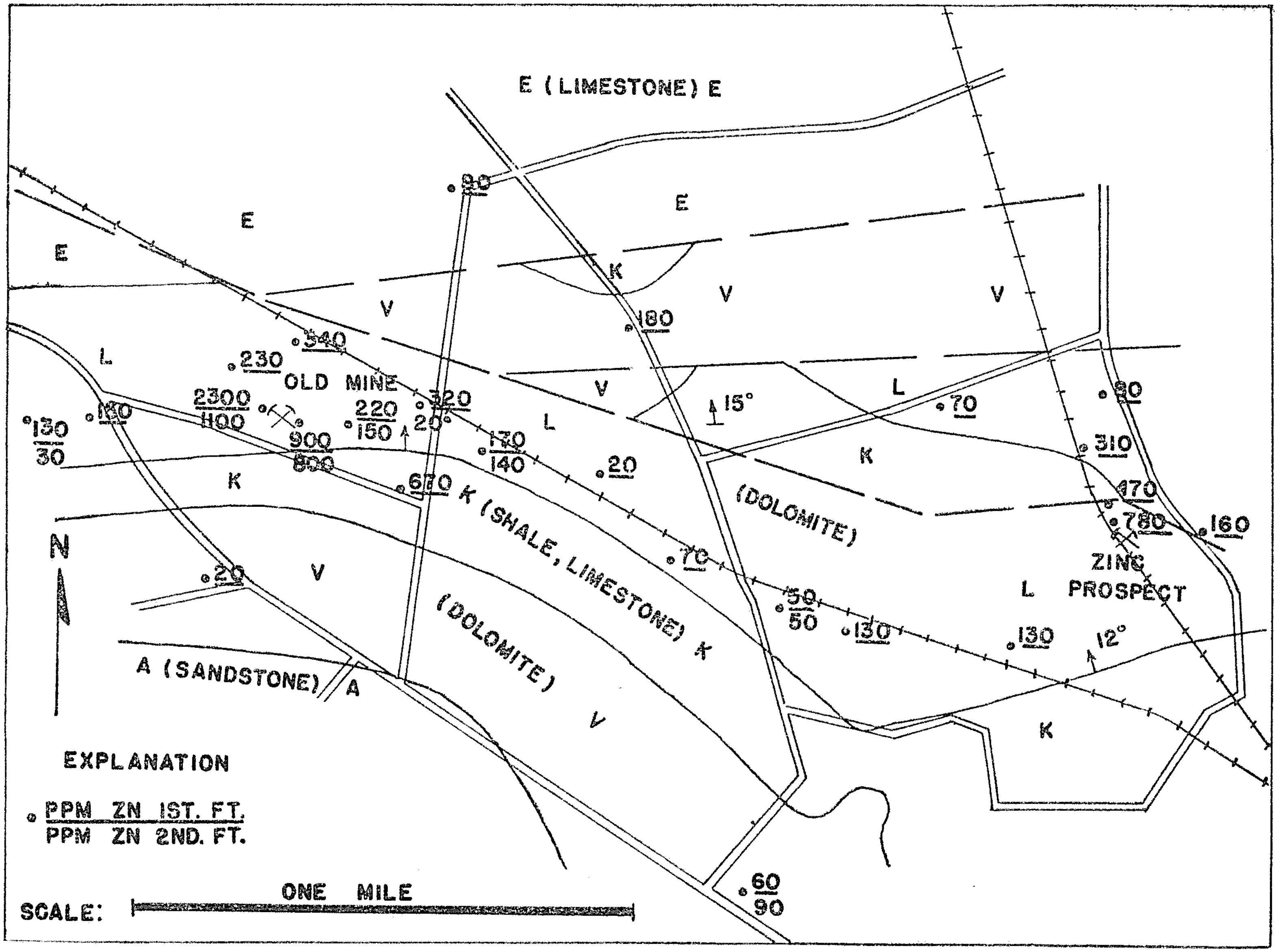

Fig. 1. Soil sampling in southern Pennsylvania.

ILLUSTRATIVE EXAMPLES OF GEOCHEMICAL SURVEYS

SOUTHERN PENNSYLVANIA

The results of a somewhat random sampling are shown in Figure 1. This seemed to demonstrate clearly that in this fairly deeply weathered and unglaciated area:

1.—A definite zinc concentration occurred in the soil near known prospects.

2.—This concentration generally was higher in the top foot of soil than in the next foot beneath, which was usually more of a clayey subsoil.

3.—The normal background was generally less than 100 ppm and apparently was not affected materially by the extensive use of fertilizers in this rich and intensely cultivated area.

4.—Occasional values from 100 to 300 ppm were obtained, but apparently economic significance would require a concentration of values near or above 1,000 ppm for any deposit extending upward to the present erosion surface.

EDWARDS-BALMAT, NEW YORK

The Edwards and Balmat zinc mines (Brown, J. S., 1936) are situated about 10 miles apart in a metamorphic limestone belt one to two miles wide. The area comprises low hills with some bedrock outcrop and a thin cover of soil more or less disturbed by glaciation but usually showing considerable kinship to the underlying bedrock. The hills are separated by small valleys and plains floored with stratified sand, silt or clay deposited in former glacial lakes. These sediments, of variable thickness, up to 100 feet or more, conceal soil-mantled bedrock very similar to that which is exposed above the old lake levels. The hillocky areas with limestone bedrock constitute good places for the use of soil sampling, wich usually shows significant patterns around known outcrops and producing areas. A typical map for the Balmat areas is presented in Figure 2. The area surrounding the Balmat mine and mill (No. 1, No. 2 Shafts) is too badly polluted by mine waste for the technique to be applicable but, away from this, soil sampling for zinc content definitely is useful. The previously unknown, though suspected outcrop of a good orebody near No. 3 shaft (not on Fig. 2) was pin-pointed by a single sample running 35,000 p.p.m. Zn ($3\frac{1}{2}\%$) on the original 200' grid. Check samples at close spacing gave results between 1,000 and 2,000 p.p.m. in several cases. These would have been sufficient to reveal the ore deposit had it not already been

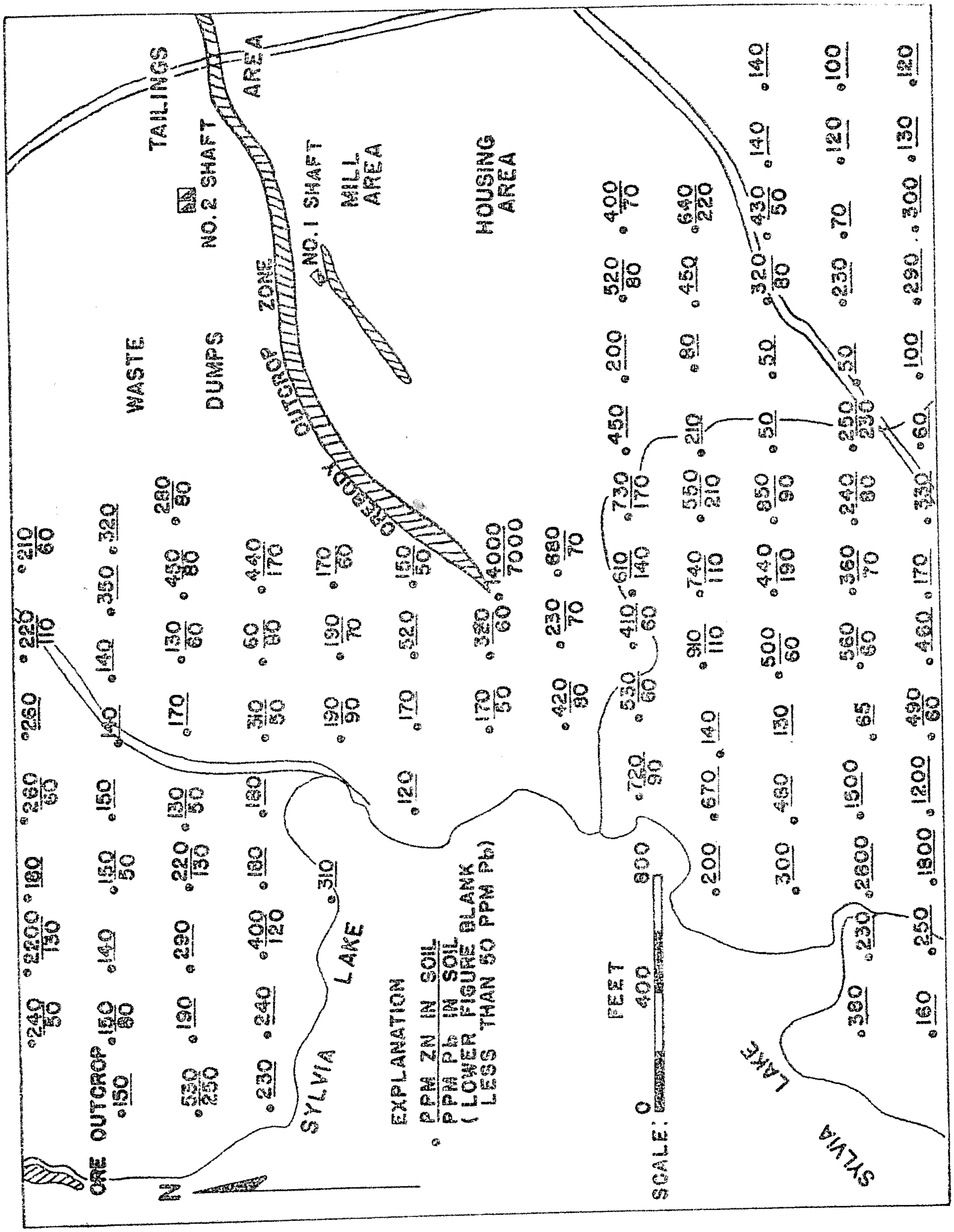

Fig. 2. Soil sampling near Balmatmine, New York.

discovered. As it was they did serve to localize its hidden outcrop in an area of heavy forest and soil cover. Samples at the south end of the net showing 1,000 to 3,000 p.p.m also led to the discovery of unsuspected, though apparently non-commercial, outcrops beneath thin soil. A number of other indications between No. 2 and No. 3 shafts still await testing. The problem of exploring areas of the alluvial sand, still and clay is more difficult. There is some suggestion that direct soil sampling may be effective at places where this cover is thin and underlying outcrops are near the surface (Hyatt). However, erroneous results may be caused by alluvial transport, as at Edwards, where a number of highs along the Oswegatchie river below the mine seem to be related mainly to a source at considerable distance (the Edwards mine).

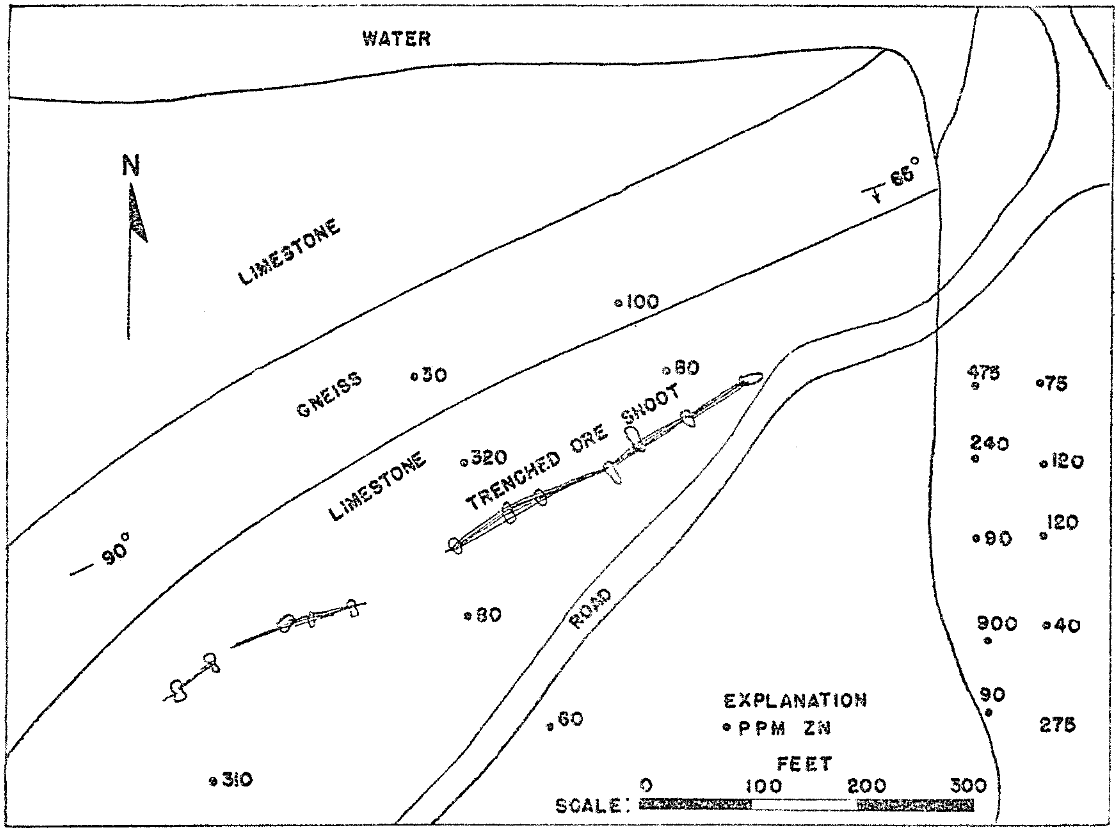

Fig. 3. Soil sampling in glaciated area, Québec.

Vegetation sampling has been tried over some of this terrain with indifferent success to date, as will be described by Meyer.

Lead association with Edwards-Balmat ore is so small in amount that it has not proved effective as an indication although erratic highs occasionally of probable significance can be obtained. The general background for lead is

10 to 30p.p.m. whereas that for zinc seems to be 50 to 200, and results are not generally given much weight under 1,000 p.p.m. Zn.

SOUTHERN QUEBEC

Conditions resembling those at Edwards-Balmat but with the difficulties intensified were encountered in exploring a number of zinc prospects in southwestern Quebec. Glaciation has been more intense and he soil cover over bedrock hillocks is thinner and less indigenous. Thus sampling at one prospect (Figure 3) showed little evidence of the strong mineralization even where it was covered by only 1 to 3 feet of soil. Checking of scattered moderate highs (500 p.p.m. Zn) east of the prospect did result in uncovering a very minor outcrop under a few inches of mossy soil. At another prospect in this area, a somewhat better correlation was obtained very near the outcrop but only in a very limited zone (Fig. 4).

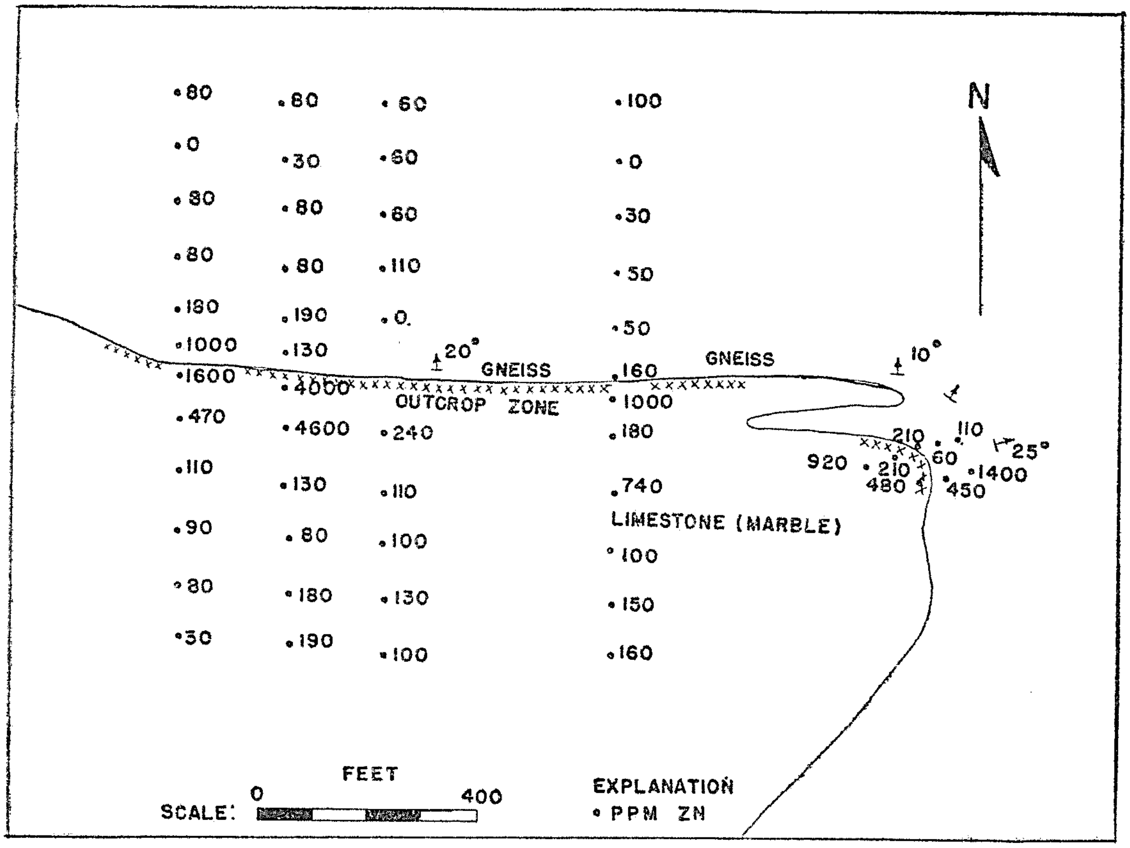

Fig. 4. Soil sampling at another area, Quebec.

Stratified glacial sediments (chiefly clay) are widespread in the valleys of this area, and surface sampling over them seems to be a fruitless venture.

NEW BRUNSWICK

The structural geology of New Brunswick seems favorable for geochemical prespecting because of steeply dipping formations, but since the province is covered with glacial drift preliminary experimental work seemed desirable.

Soil sampling was started in June 1953 with a traverse across the No. 6 orebody of Brunswick Mining and Smelting Corporation, Limited (Fig. 5).

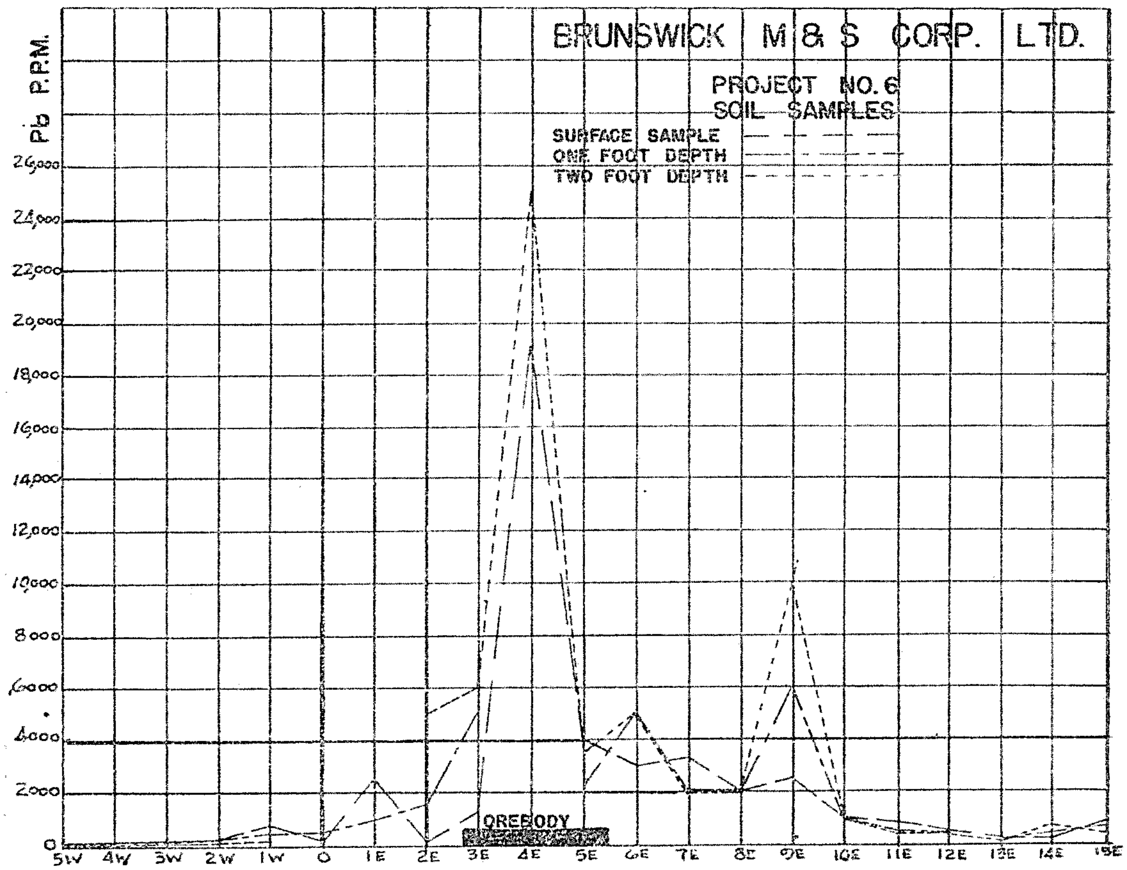

Fig. 5.—Soil sampling profile, No. 6 orebody, New Brunswick.

Three samples were taken at each location: one beneath the vegetation mat, the second at one foot, and the third at two feet in depth. Twig samples also were desired but unfortunately the area had already been slashed. Therefore, root samples of Balsam Fir were taken as a substitute.

Lead, which is considerably more abundant here than in northern New York, was found to be the best indicator because of its continuity and lack of mobility. A depth of two feet, where obtainable, proved to be the optimum for speed and reliability.

Because the first test showed promise, the area over the No. 12 orebody was covered in its entirety. This coverage yielded a striking picture which correlates well with the ore occurrence allowing for drainage and direction of glaciation. This anomalous case definitely is a result of the weathering of the orebody giving a residual halo in the overburden, modified by drainage, vegetation decay, and glaciation, with drainage playing the most important part in the dispersion. Background for lead was found to be 40 p.p.m. Any samples or areas that ran over 500 p.p.m. were given particular attention.

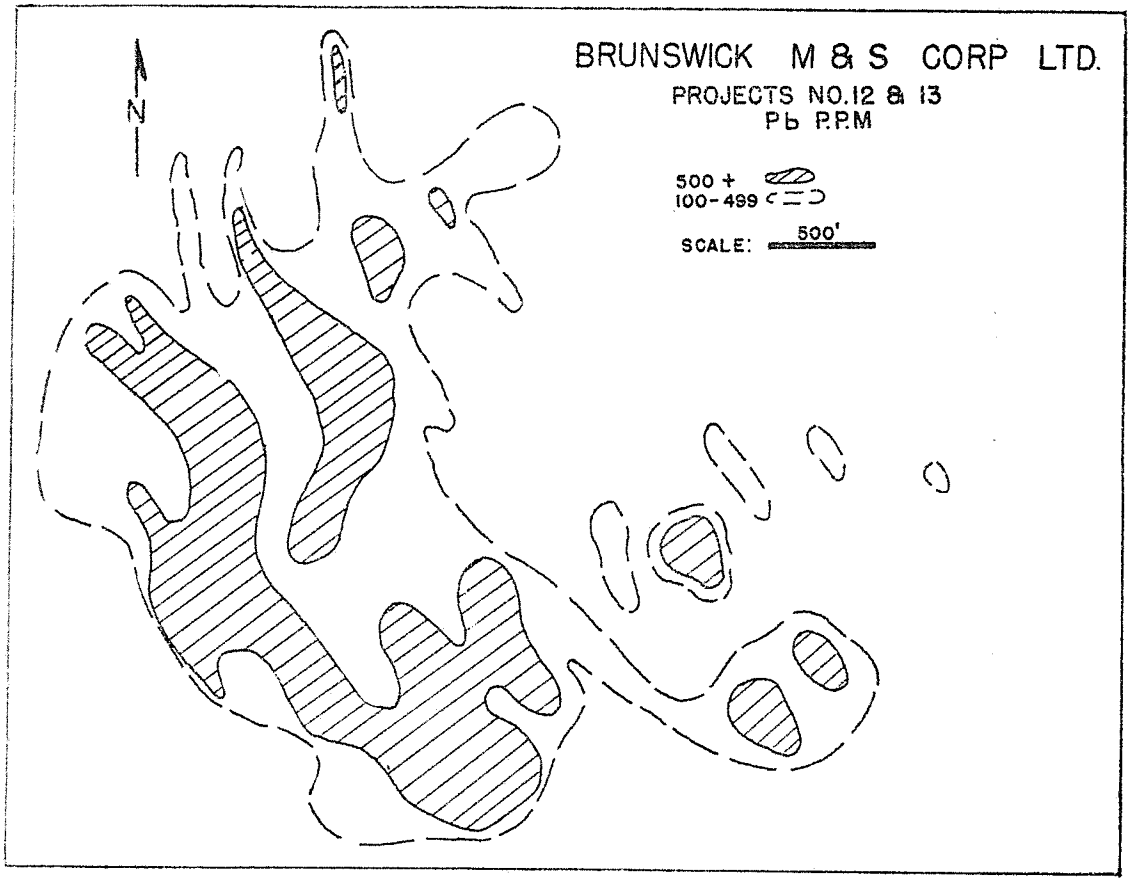

Fig. 6.—Soil sampling around No. 12 orebody, New Brunswick.

From the encouragement obtained during the 1953 field season, a program was set up to cover the electrical anomalies (both resistivity and E-M) on other claims in the 1954 season. Previously all samples were analyzed in the laboratory by the dithizone colorimetric method, but for this large project Bloom's Cold Extraction (1955) method was used. Six thousand samples were taken and tested in the field, of which 2,000 were checked in the laboratory. The cost of analysis in the laboratory was essentially equal to the cost of the in the field but the field costs included the normal field expenses.

It may be worth mentioning that an authentic looking anomaly (Fig. 7) not associated with an electrical anomaly was encountered which seemed important, but two holes were drilled and found to be barren. This must be attributed to some erratic condition not yet explained and shows that caution must be used in interpretation and that the method is not infallible. Conversely, ore could exist at depth without giving an anomaly so that the method is limited to near-surface deposits.

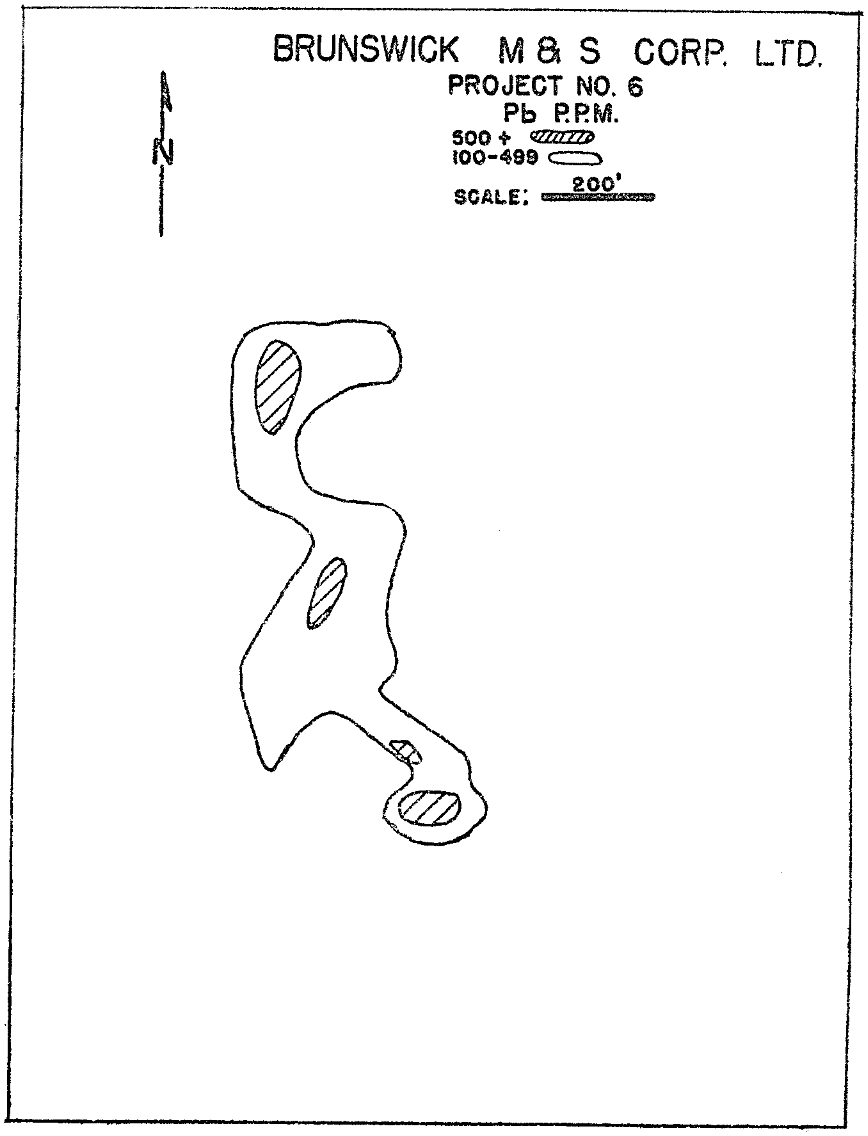

Fig. 7. False anomaly, near No. 6 orebody, New Brunswick.

SOUTHEASTERN MISSOURI

In contrast with the steeply dipping beds of New Brunswick, southeastern Missouri has flat-lying early paleozoic sediments covering a Precambrian erosional surface. The Bonneterre formation (Figure 8), where all the important economic lead-zinc deposits are found, is overlain by younger sediments attaining a thickness of 1,000 ± feet. Only in the central uplift does the Bonneterre crop out due erosion of the younger sediments. Geochemical prospectig is limited to this small area.

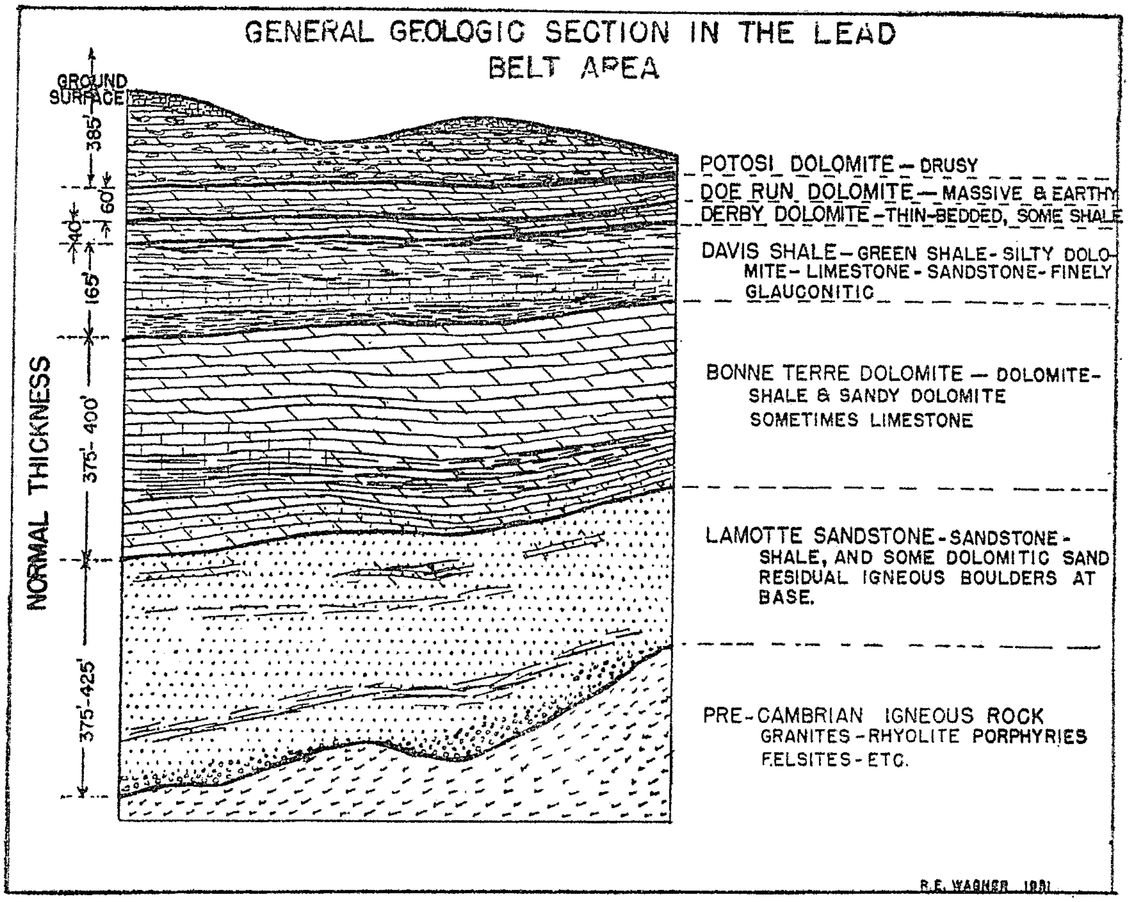

Fig. 8. Geological sections, Southeast Missouri lead district.

In January 1952, a geochemical laboratory was set up after study at the U.S.G.S. Geochemical Exploration Section laboratory in Denver, Colorado. Initial work was over areas of known mineralization varying in depth from the surface to 500 feet. These areas were covered by grid systems and traverses, taking samples at various distances from 100 to 500 feet, depending upon the area.

Samples originally were taken at a depth of one foot but these were found to be contaminated in some cases from the use of tailings as agricultural lime, so that thereafter a two-foot depth was used.

In conjunction with the soil program rock samples from drill cores of the formations also were analyzed in five-foot composites or by rock type intervals from the surface to the bottom of certain holes (Fig. 9).

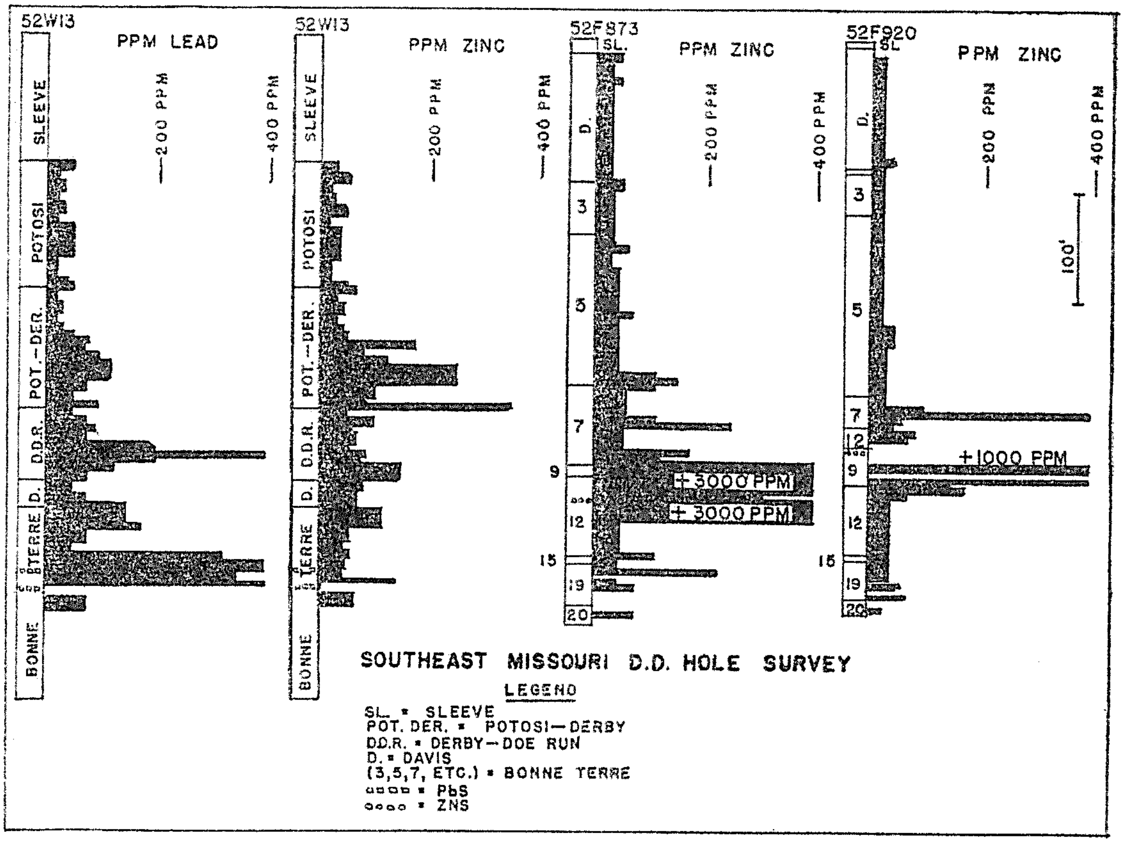

Fig. 9. Zinc-lead halos in Bonneterre formation, adjacent to ore, Southeast Missouri.

All samples were analyzed for lead zinc with the conclusion that any mineralization deeper than 100 feet could not be picked up by geochemical means. The abnormal amount of trace elements diminishes to background values quite rapidly above mineralized horizons and thus does not yield a very large primary halo above the ore zones.

In some areas of southeastern Missouri fault zones are mineralized in the higher formations. These can be picked up with a geochemical survey, but the deposits are small and spotty and do not seem to have a direct relationship to the mineralization in the Bonneterre horizon.

The best results from the surface sampling were obtained from the Mine La Motte area where "dirt lead" occurs. (Fig. 10). Here, the ore-bearing horizon is weathered and eroded and the sulfides are now residual material in the overburden.

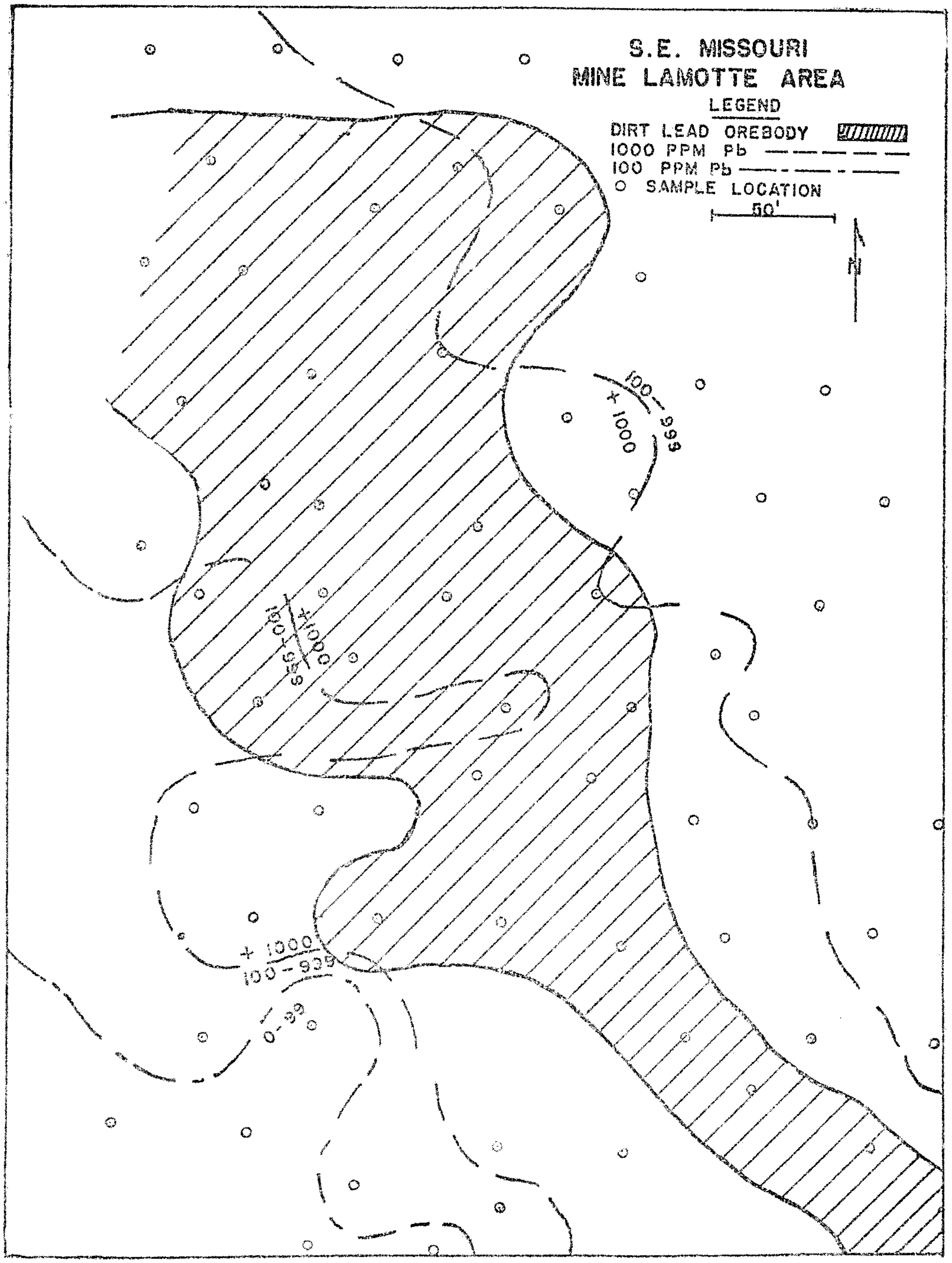

Fig. 10. Concentration of lead in industrial soil from lead orebody, Mine La Motte, Southeast Missouri.

Any type of geochemical or geophysical tool used in the Bonneterre outcrop area has to compete with a low drilling cost, and, therefore, no matter what methods are used economics always enters. It may be just as economical to drill without any prior work and be sure of barren or mineralized ground.

As most of the exploration work in southeastern Missouri is being done away from the central uplift area and the lead-bearing formations are deep, geochemical prospecting plays a very small part in the overall program.

Water Sampling

Experimental work has been carried out during the past year with this technique in southeastern Missouri; Balmat-Edwards, New York, and the Bathurst area, New Brunswick. The Huff (1948) method was used with minor modifications for greater sensitivity.

In all three areas the natural waterways were affected by contamination from the surface mining and milling operations. Therefore, a true picture of natural contamination from mineralization was not obtainable. It was found that the ionic content of the waters diminished rapidly in some areas but in others was sustained for a greater distance which could not be explained easily by dilution. At Balmat-Edwards, 400 ppb diminished to zero in two miles, while at Bathurst 600 ppb dimminished to. 6 ppb but still detectable at seven miles. Many factors can cause this and should be considered when sampling. Some of these causes are as follows: (a) type of formations the streams cross, (b) stream gradient, (cs) pH of the water, and (d) surface cover.

Vegetation Sampling

Experimental work with twings, needles, and roots both in New York and New Brunswick has given positive results over known mineralized areas, but caution must be used in sampling various species as their ability to absorb metallic ions varies widely.

Preliminary work done in New York over a zinc prospect pit with a foot or two of overburden gave the following results:

Species	*Background* (ppm Zn)	*Anomalous* (ppm Zn)
Gray Birch *(Betula populifolia)*	275	500
Sugar Maple *(Acer saccharum)*	20	175
Eastern Hemlock *(Tsuga canadensis)*	40	200

It is seen that the Gray Birch has a greater affinity for zinc than the other two species. This has been noted by others in various areas of the world.

Two profiles taken across a sand and gravel area of unknown *thickness* for exploration purposes are submitted for examination (Fig. 11). Neither profile could be sampled in its entirely fror one species, and this adds to the complication of interpretation. Although neither case shows an outstanding anomaly, there are slight highs that could be caused by mineralization in the bedrock or by contamination in the overburden as the overburden is glacial outwash. Further work will be done in this area.

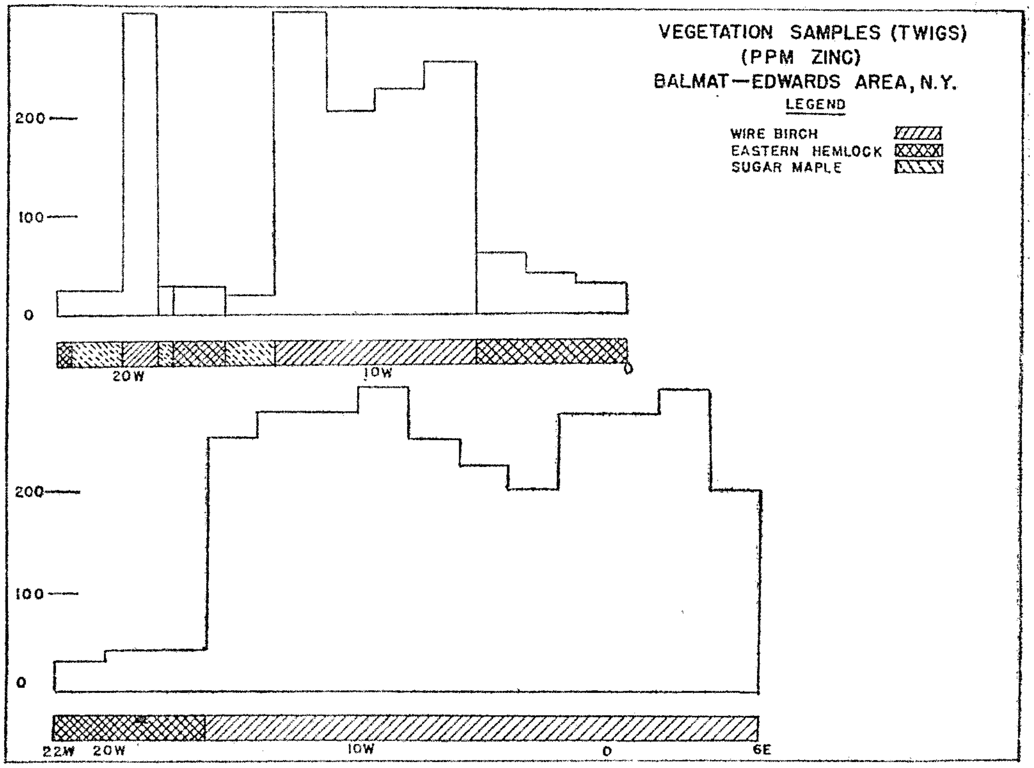

Fig. 11. Vegetation sampling near Balmat, New York.

Another item of interest (Fig. 12) is the profile obtained from the root samples of the Balsam fir across the Brunswick Mining and Smelting Corporation, Limited No. 6 orebody. This method of sampling could be used but ordinarily is unnecessary. Combined twigs and needles of the Balsam fir gave a positive anomaly over BM & S No. 12 orebody, showing its usefulness as a tool for possible use in winter when the ground has a cover of snow.

Field Techniques

Soil sampling has been done with a common wood bit welded on a shaft with a T-handle. Samples taken to the laboratory for analysis are put in small paper bags. In some cases, the sample location in the field has been marked with a doctor's tongue depressor, which can be found even several months later.

Vegetation samples were of twigs one or two years old with the approximate thickness of a pencil. In the case of conifers, both the needles and twigs were analyzed together.

It is our impression, with regard to water sampling, that samples tested by and transported for analysis. There should be less chance of contamination or absorption by the container if tests were made on location.

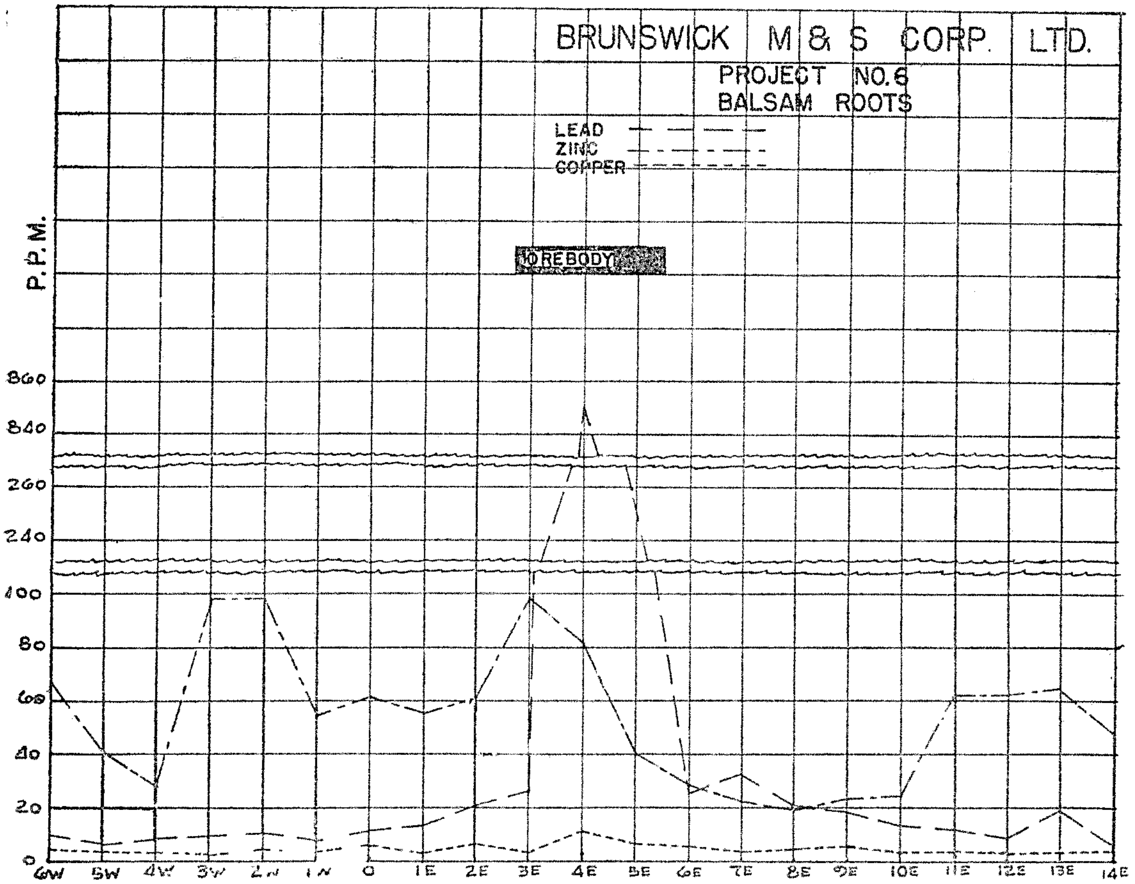

Fig. 12. Profile of voot sample of Balsam fin, near No. 6 orebody, New Brunswick.

The cold extraction method on soils should be used with caution, as there have been a few instances where definitely anomalous amounts of zinc and copper in the soil were not picked up by this method. This is to be expected in some areas and check analyses should be made in the laboratory whenever it is used in a new locality

SUMMARY

Although no major discoveries have been made by St. Joseph Lead Company using geochemical methods, and in places they may be useless or misleading, they are still considered well worthwhile in many situations and are used as a standard practice for exploration purposes in such areas. With any exploration tool, interpretation is of prime importance and geochemical methods are no exception. Although not infallible, the advantages outweigh the disadvantages and where suitable conditions exist for their application useful information usually is obtained.

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GEOCHEMICAL PROSPECTING FOR LEAD AT NAMOONA, NORTHERN TERRITORY, AUSTRALIA *

A. H. DEBNAM * *

ABSTRACT

The survey covered an area of 3 square miles, and two large lead anomalies in residual soils were discovered. Oone of these anomalies was thoroughly investigated by resampling at closer intervals. The optimum spacing of sampling traverses was found to be 400 feet. Deep samples gave more reliable results than shallow samples.

A comparison of th anomalies obtained by using the results from two different analytical methods revealed that they are almost identical.

At the time of writing this report, the geochemical prospecting had not been followed up by trenching or drilling, and so the results cannot be interpreted with any degree of certainly. However, it is unlikely that a large high-grade lead orebody exists at the prospect, as the intense anomalies are small in area. A weak anomaly extends for 6,000 feet along the strike of the sub-outcropping rocks, and is probably due to dispersed low-grade lead mineralization.

INTRODUCTION

The Namoona lead prospect was discovered in September, 1954. Its position on the Australian 4-mile map grid is shown on Fig. 1.

A preliminary geochemical survey was carried out during October, 1954, before the surface was disturbed by trenching. An extensive lead anomaly was disturbed by trenching. An extensive lead anomaly was revealed at the prospect. Trenching by bulldozer uncovered high-grade lead mineralization in the form of massive galena assaying 68% lead and 160 oz. silver per ton.

A second geochemical survey carried out in June and July, 1955, was designed to find possible extensions or recurrences of the mineralization.

Fig. 2 shows the area covered by the survey. The main grid extends in a north-westerly direction from the original prospect for a distance of 4 miles

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along the strike of the mineralized beds. Samples were also collected from a small area to the south-east of the original prospect.

The section between the main grid and the original prospect was thoroughly investigated by trenching and drilling during the 1954-55 wet season, but the results were disappointing. Only isolated concentrations of lead minerals were encountered. No geochemical prospecting was carried out in the trenched area.

The geochemical prospecting party consisted of the writer, two assistants for sampling, two assistants for laboratory testing, a cook, and a mechanic. The chemical analyses were carried out in a mobile laboratory built into a 14'6" caravan.

In all, 2,235 lead determinations were carried out on 1,747 soil samples, using dithizone as the colorimetric reagent. The analytical procedures were similar to those used at Mt. Isa in 1952 (Debnam, 1954), but the method of reporting and presenting the results was greatly improved.

DESCRIPTION AND GEOLOGY OF THE AREA

The Namoona area is, in general, flat with some low undulating hills and low but promnient ridges. The original prospect is located near the foot of the eastern slope of the highest ridge. This ridge breaks up into undulating hills to the south-east, and continues for only half a mile to the north-west. The flat ground is dissected by meandering creeks which flow north-east and form part of the South Alligator River drainage system.

Rainfall is about 40 inches per annum, and most of this falls between November and March. At times during this period all roads are impassable. For the remainder of the year cool, dry conditions prevail.

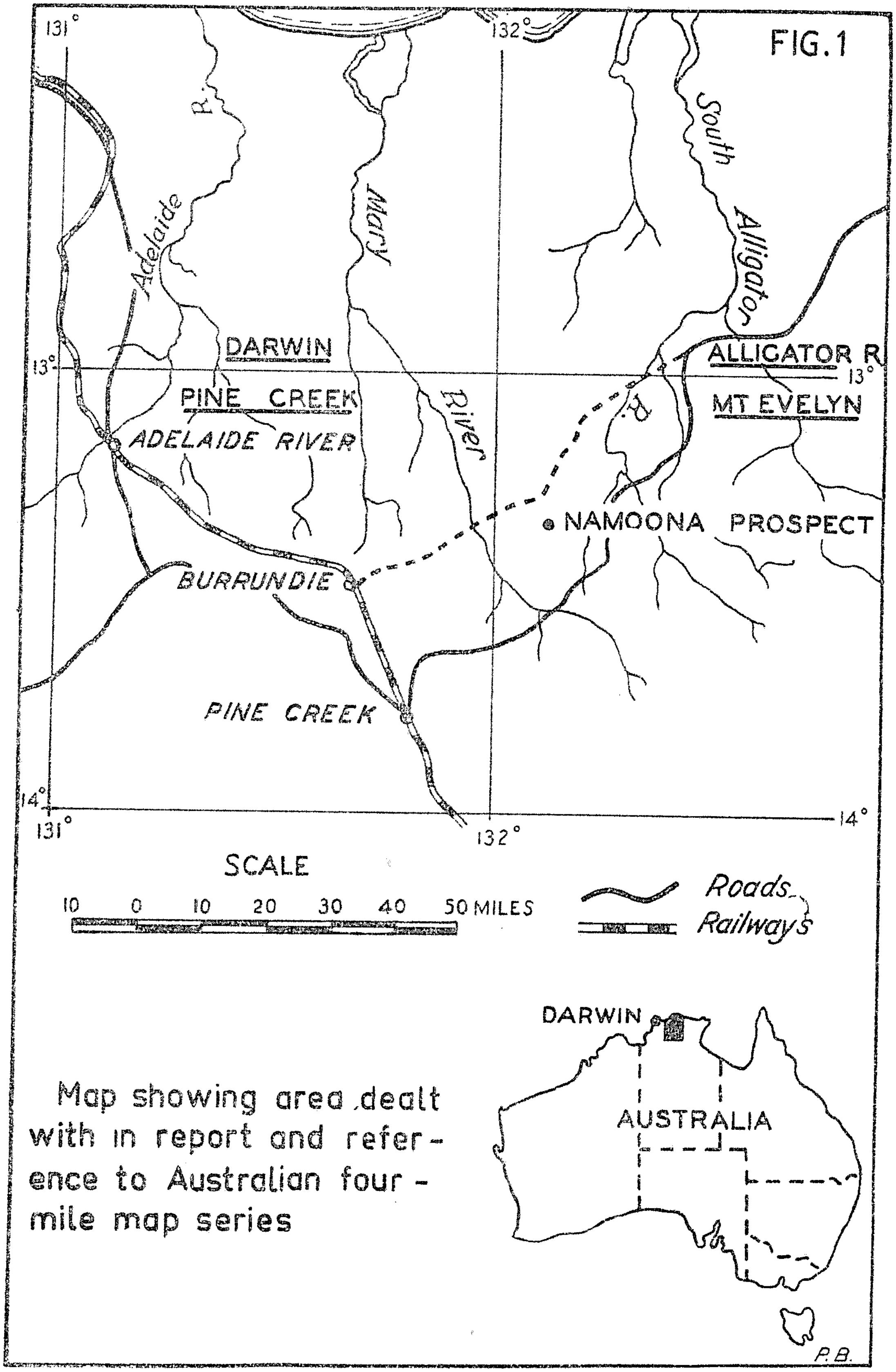
Vegetation is of savannah type. Trees grow to a height of 35 feet, and are mainly eucalypts (gums). Sorghum grass and spinifex are common.

The lead mineralization occurs in the Masson Formation which is of Lower Proterozoic age, and consists of siltstones, mudstones, greywackes, and quartz greywackes. The general strike is to the north-west. Granite outcrops about 5 miles west of Namoona.

At the original prospect the beds of the Masson Formation are flat lying with only minor folding, although elsewhere they are steeply dipping. The fine-grained massive galena occurs directly below the soil cover. Very little cerussite or anglesite is present, and the galena must have been protected from oxidation in an environment where oxidation normally reaches a depth of several hundred feet.

Soils in general are residual. The only alluvial soils occur in the vicinity of the meandering creeks. The alluvial soil is grey, and carries the typical tall sorghum grass.

FIG. 1



Map showing area dealt with in report and reference to Australian four-mile map series

SAMPLING AND TESTING PROCEDURES

The soil samples were collected at points on a grid which was laid out with compass and tape. On the original open grid these points were fixed at 200 feet intervals in traverses 400 feet apart. In anomalous areas the sampling density was first increased by collecting samples from traverses run midway between the original traverses, and finally from a 100 feet grid, if necessary.

Samples were collected at a depth of 24-30 inches, using hand-operated post-hole diggers. In the anomalous areas shallow samples were also collected at a depth of 6 inches with pick and shovel (see below). The fine fraction (-80 mesh) from approximately 1 lb. of soil was placed in a numbered paper bag and taken to the laboratory. Fifty deep samples or 200 shallow samples could be collected by two samplers in one day.

In the laboratory 5 grams of each sample were weighed on a rough balance and transferred to 250 ml. conical beaker; 60 ml. of 0.01 normal hydrochloric acid were added from a 500 ml. burette, and the mixture was swirled several times. If necessary, pH was adjusted to 3 with a small amount of normal hydrochloric acid, and then the mixture was allowed to settle for 30 minutes. Ten samples were treated in a batch, and 30 beakers in use simultaneously. One assistant weighed the samples, added the acid, and washed the equipment while another carried out the determinations.

The tests were carried out by decanting 30 ml. of clear solution into a 50 ml. stoppered graduated cylinder, and then adding 5 ml. of 0.001% dithizone solution (dithizone dissolved in carbon tetrachloride) and shaking for 2 minutes. At pH3 any copper present in the test solution will react with the dithizone to form the cherry-red copper dithizonate. If necessary more dithizone (0.01% solution) was added until all the copper had been removed from the test-solution; this condition is attained when a grey or purple-grey colour persists in the organic layer after shaking for 2 minutes. The carbon tetrachloride solution was then removed, either by decantation or in a separating funnel, before undertaking the lead test.

A fresh aliquot (5 ml.) of 0.001% dithizone was then added to the copper-free aqueous solution in a 50 ml. graduated cylinder. Two drops of concentrated ammonium hydroxide were added to increase pH to 8.5-9.5, and 0.5 ml. of 5% potassium cyanide solution was added to complex any zinc which might be present. These two solutions were added from 25 ml. burettes. The mixture was shaken for 10 seconds, and the amount of lead estimated by visually evaluating the intensity of the pink colour in the organic layer. If this colour is too intense to evaluate it is necessary to prepare a fresh copper-free test-solution, and a smaller aliquot (5 ml., 1 ml. or 0.2 m.) of this is tested until the final

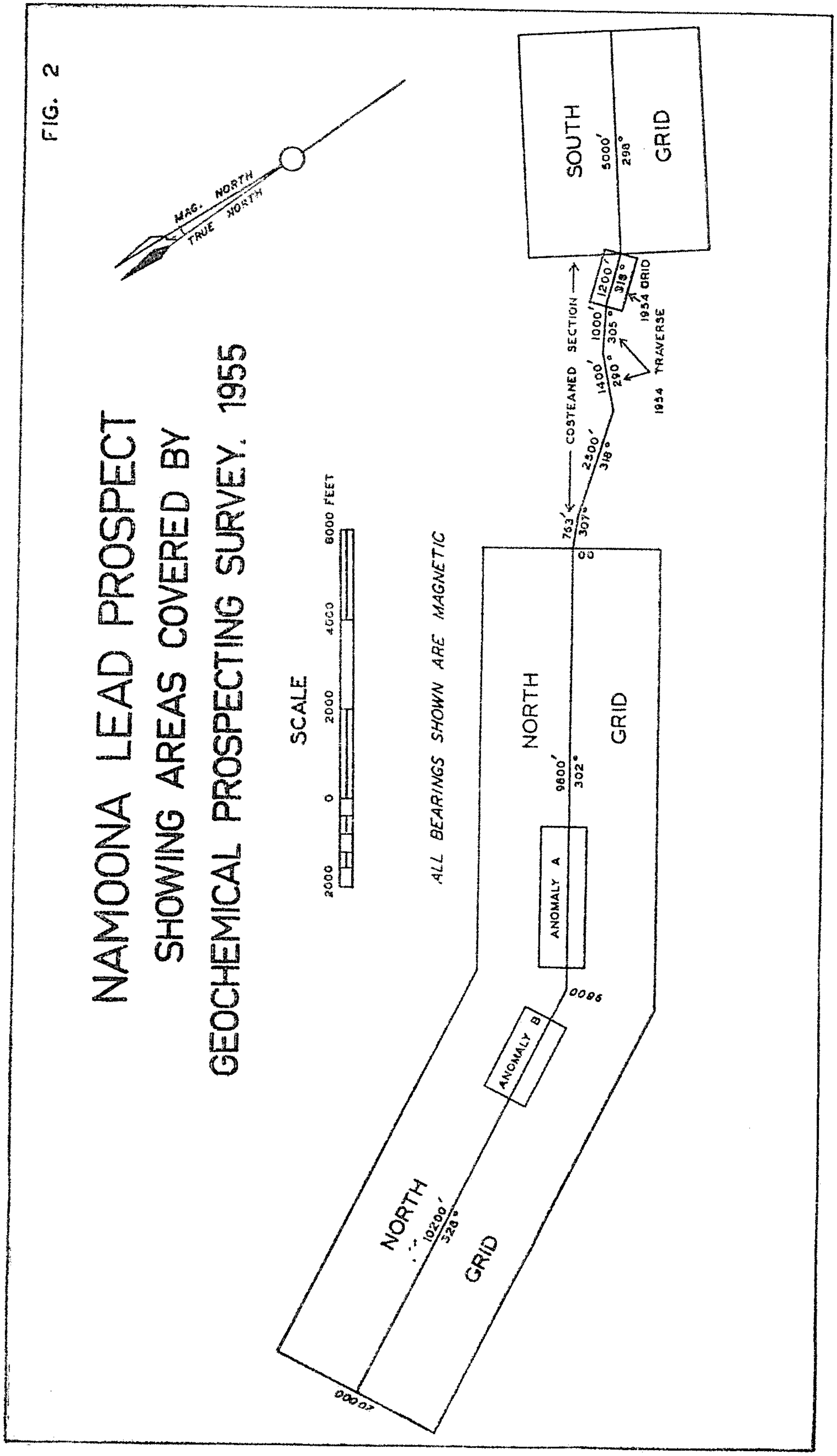


FIG. 2

NAMOONA LEAD PROSPECT
SHOWING AREAS COVERED BY
GEOCHEMICAL PROSPECTING SURVEY, 1955

colour in the organic layer is faint to medium pink. When taking smaller quantities of test solution the volume is brought up to 30 ml. with distilled water.

Table 1 gives the lead values as multiples of background for various intensities of the pink colour and amounts of test-solution. The multiples—of—background values have been grouped to give a range of anomalies with orders 1 to 7. The background value is arbitrary, and is taken as half the value of the lowest discernible positive test. It serves as a basis of comparison for the positive results.

Using the analytical procedure described, two assistants could test, on an average, 100 samples per day, provided that no difficulties were encountered.

TABLE 1

EVALUATION OF LEAD RESULTS

Aliquot of test solution (mls.)	Colour of organic phase	Multiple of background	Anomaly order	Range of background multiples
30	Colourless	1	0	1
30	Very faint pink	2	7	2-9
30	Faint pink	4		
30	Medium pink	7		
30	Intense pink	Greater than 10	6	10-29
5	Faint pink	20		
5	Medium pink	40	5	30-99
5	Intense pink	Greater than 60		
1	Faint pink	100	4	100-299
1	Medium pink	200		
1	Intense pink	Greater than 300	3	300-999
0.2	Faint pink	500		
0.2	Medium pink	1000	2	1000-2999
0.2	Intense pink	Greater than 1500		
1 drop	Faint pink	2000		
1 drop	Medium pink	4000	1	Greater than 3000
1 drop	Intense pink	Greater than 6000		

NAMOONA LEAD PROSPECT

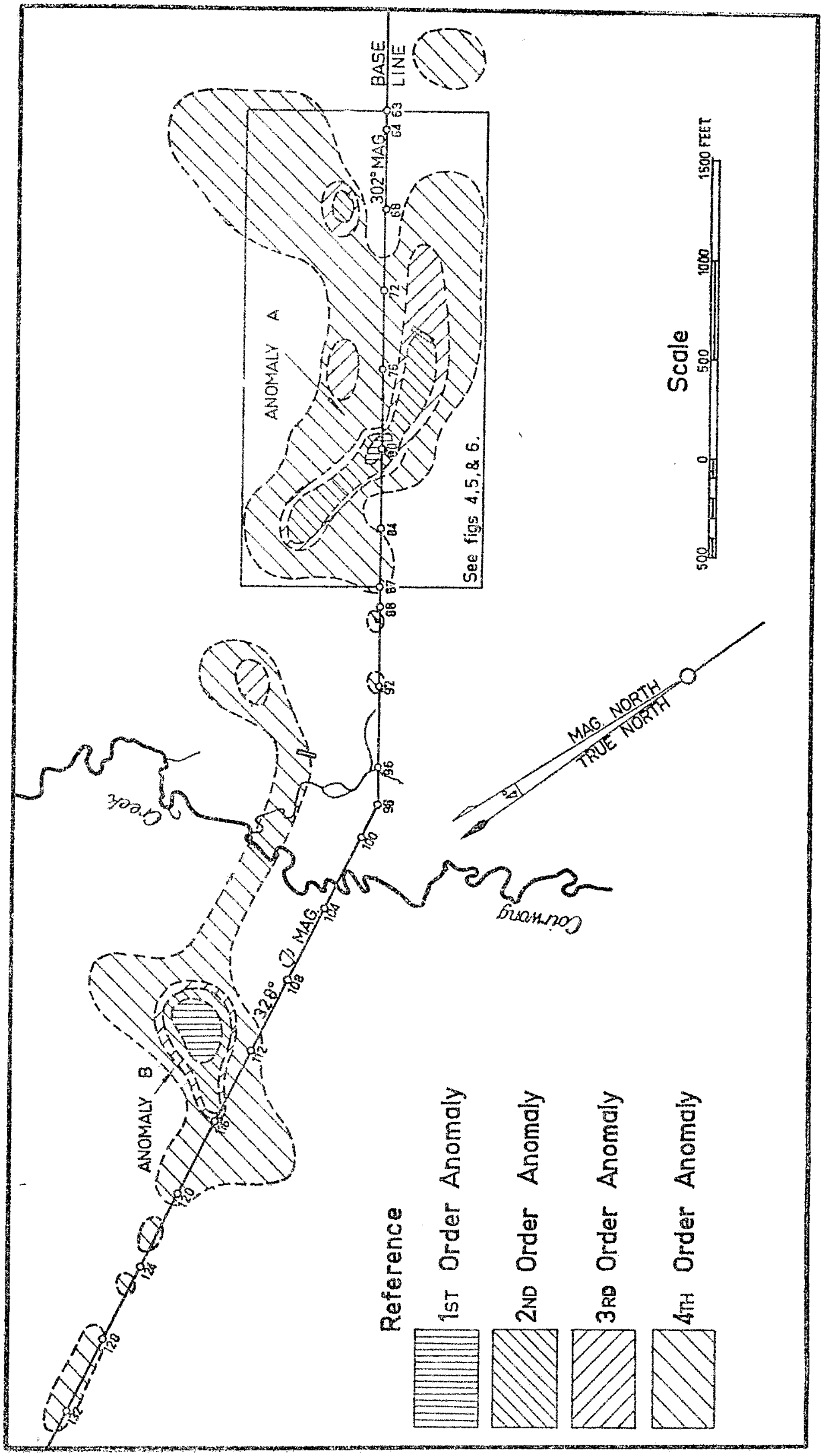
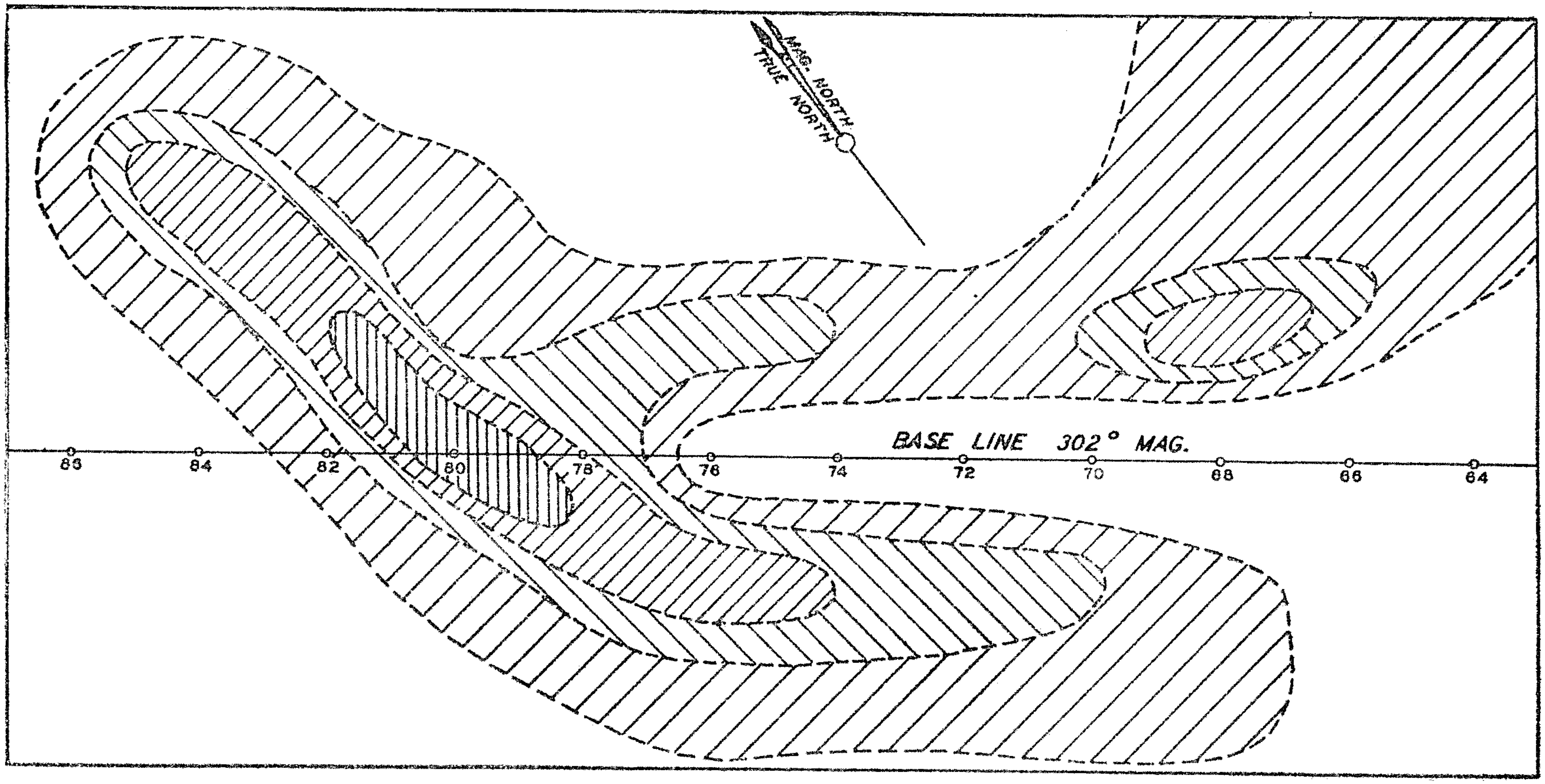


FIG 3 Lead Anomalies A and B



NAMOONA LEAD PROSPECT

FIG. 4A. Anomaly A, using results from traverses 64, 68, 72, 76 and 80. Cold dilute acid extraction of deep soil samples.

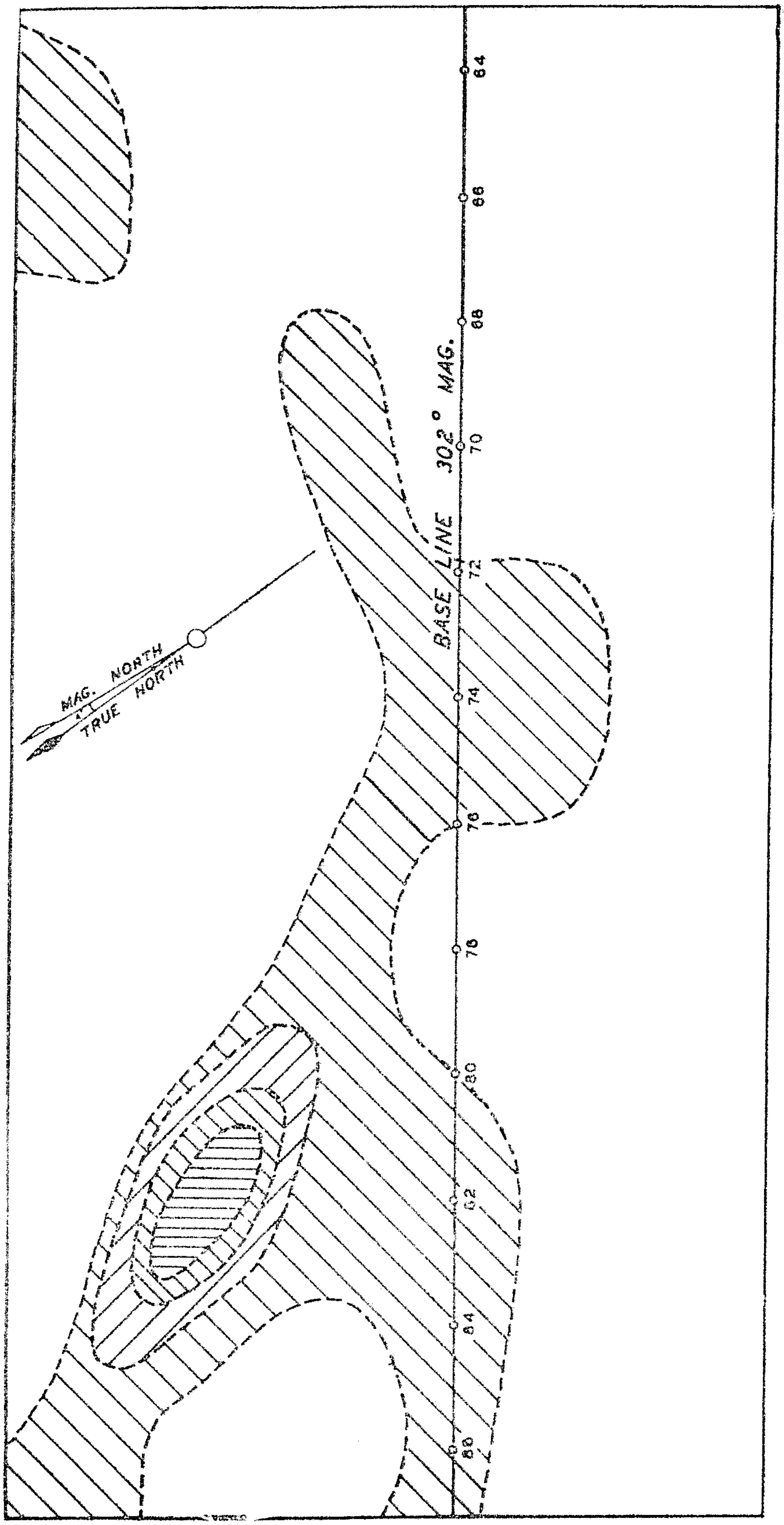


FIG. 4B. Anomaly A, using results from traverses 66, 70, 74, 78, 82 and 86. Cold dilute acid extraction of deep soil samples.

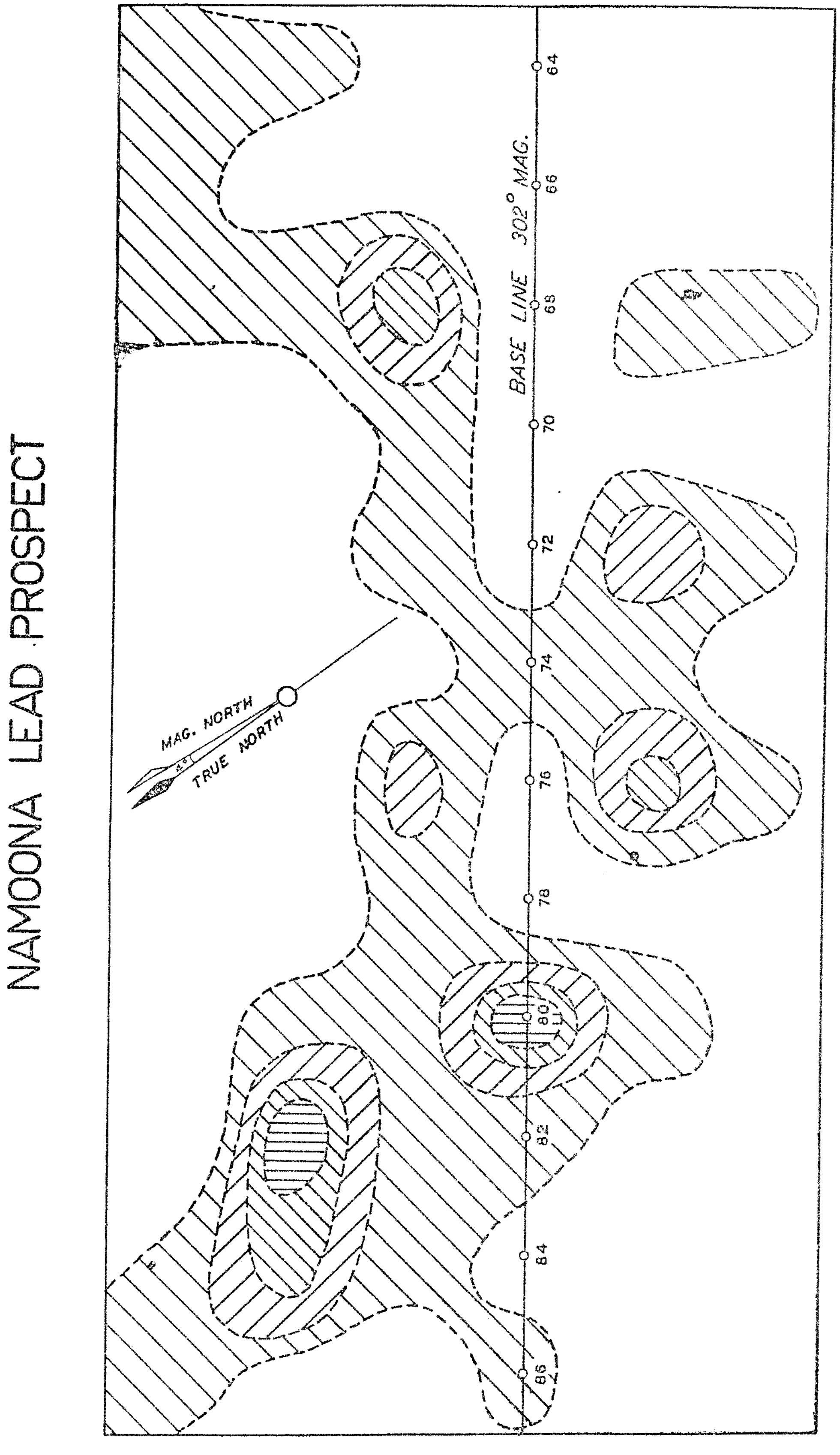


FIG. 5 A. Anomaly A, using results from all traverses. Cold dilute acid extraction of deep soil samples.

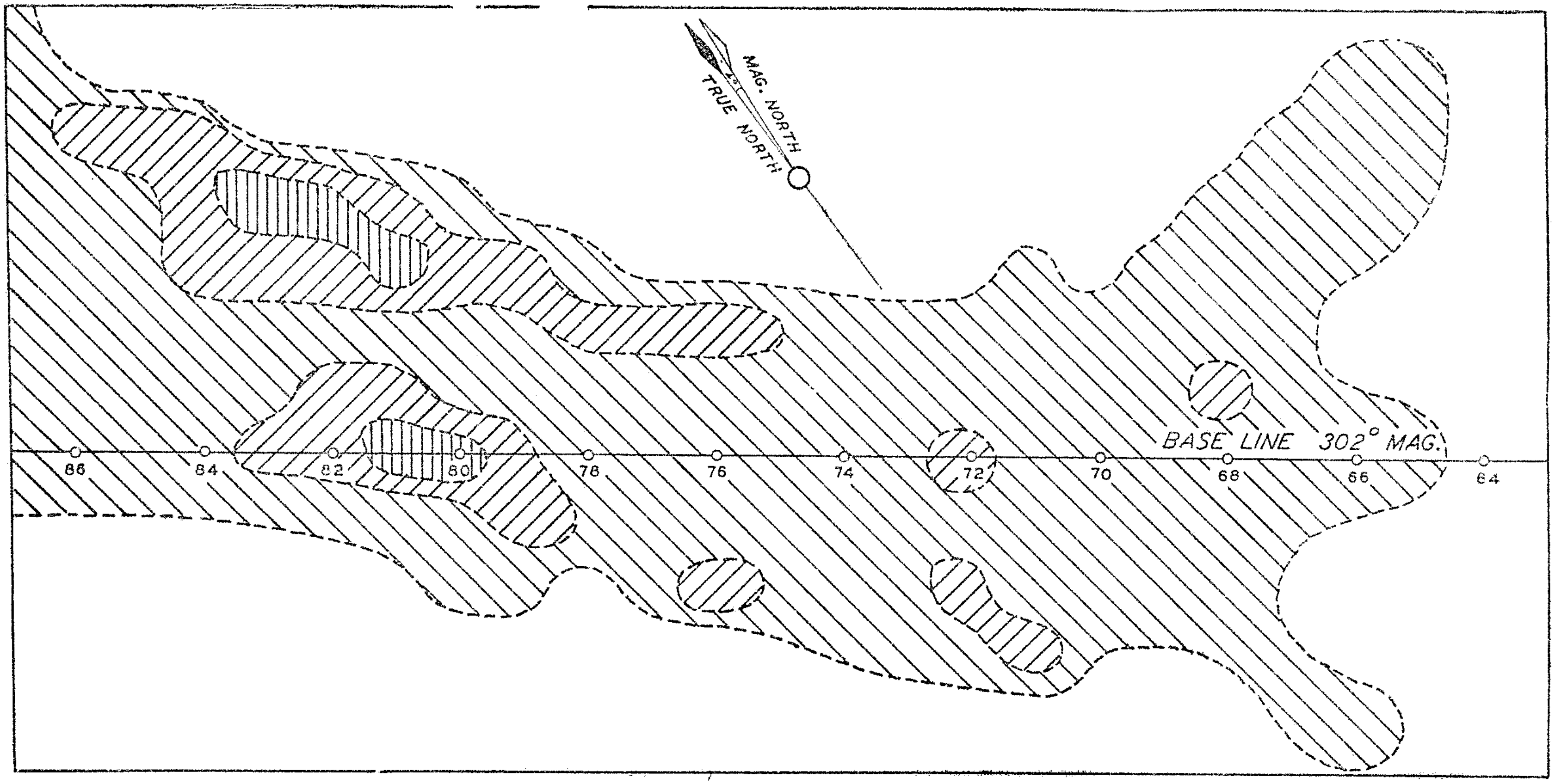


FIG. 5B. Anomaly A, using results from all traverses. Hot concentrated acid extraction of deep soil samples.

RESULTS

Only a small number of samples gave positive copper tests, and as they were scattered throughout the area no significance can be attached to them.

Two large lead anomalies were discovered. They are shown in Fig. 3, and their positions relative to the area sampled are shown in Fig. 3. Each anomaly has only small first order anomalies, but these grade into fourth order anomalies which cover an appreciable area. Only 1st, 2nd, 3rd and 4th order anomalies are shown on the figures.

Anomaly A was throughy investigated. Samples were collected at various depths, and many were subjected to two different methods of analysis. Those taken at a depth of 6 inches are called "shallow samples", and those from a depth of 24-30 inches are "deep samples". The analytical methods are the cold dilute acid extraction described in this paper, and the hot concentrated acid digestion as developed and used by the Geochemical Section of the U.S. Geological Survey.

Figures 4a and 4b show the anomalies obtained by plotting the results from the traverses numbered 64, 68, 72, 76, and 80 and from the alternate 66, 70, 74, 78, 82, and 86 traverses, respectively. A spacing of 400 feet between traverses appears to be the optimum for representative results under the conditions at Namoona as a 1st or 2nd order anomaly would certainly be detected. A spacing of 800 feet between traverses may not detect an anomaly better than 4th order. Using traverses 70, 78, and 86 shown on Fig. 4b only 4 results with 4th order anomaly intensity would be obtained.

In Fig. 5a the results shown in Figs 4a and 4b have been combined, and it demonstrates that sampling on a 200 feet grid pattern produces isolated strong anomalies without any decrease in size of the 4th order anomaly.

The results plotted in Figs. 4a, 4b, and 5a were obtained after treating deep samples with cold dilute acid. In Fig. 5b the results are those obtained after treating duplicates of the samples used in the compilation of Fig. 5a with hot concentrated acid. The 1st and 2nd order anomalies occur in the same positions on Fig. 5a, but they are more extensive. Furthermore, the 3rd order anomaly is larger than the 4th order anomaly on Fig. 5a. It is considered that the hot concentrated acid technique produces more realiable results, although a sharper and possibly more useful anomaly for locating the strongest mineralization, is obtained by using the cold dilute acid extraction.

The results for shallow sampling are shown in Fig. 6. The 1st, 2nd and 3rd order anomalies are very small. However, shallow sampling is much more expeditious than deep sampling, and it would be possible to cover a greater

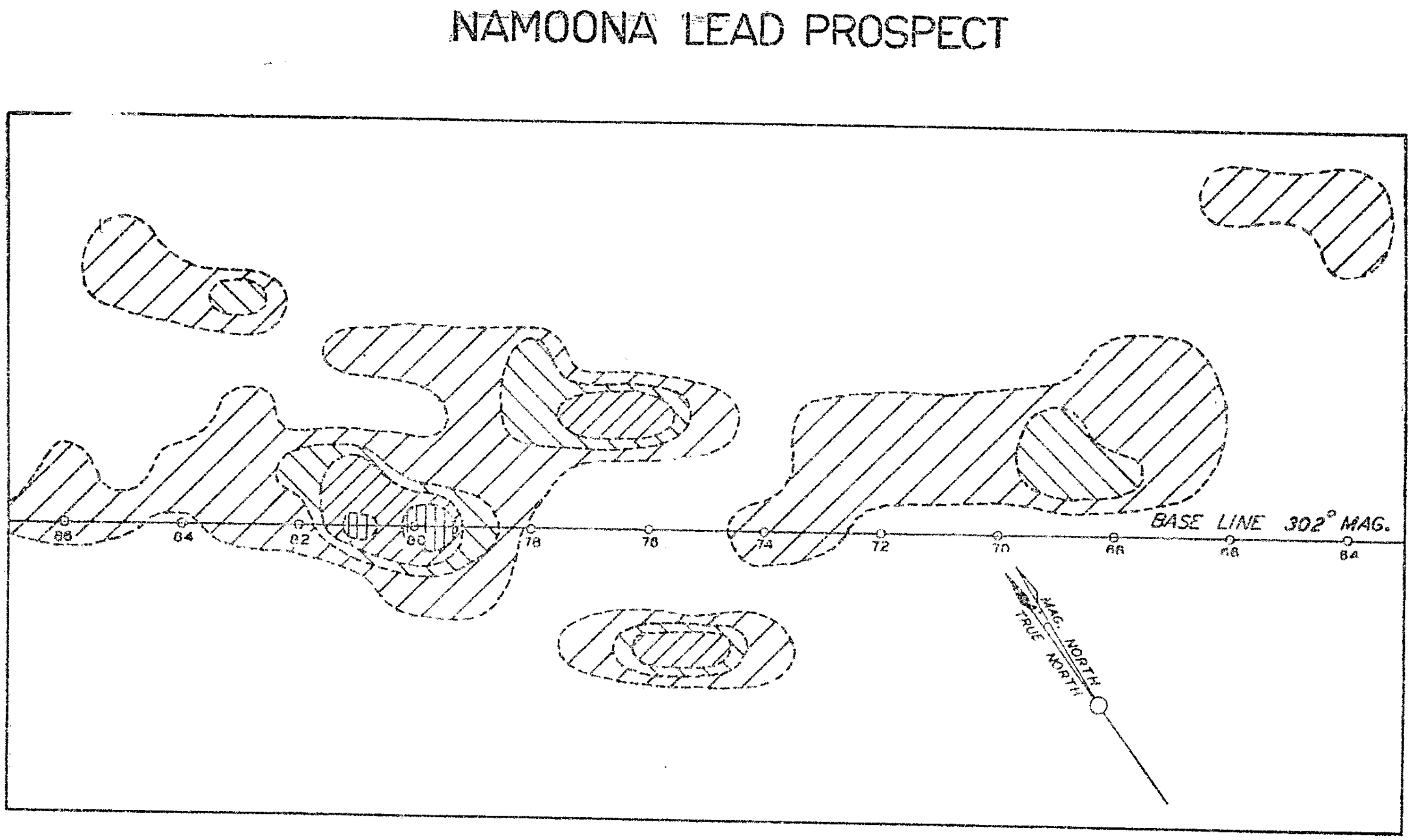


FIG. 6. Anomaly A, using results from samples collected at points on a one hundred foot grid. Cold dilute acid extraction of shallow soil samples.

SCALE

200 0 200 400 600 FEET

Reference ▥ 1ST Order Anomaly ▨ 2ND Order Anomaly ▧ 3RD Order Anomaly ▨ 4TH Order Anomaly area in the same time by collecting samples at 6 inch depth on a 100 foot grid than by sampling at a depth of 30 inches on a 200 foot grid.

Shallow sampling would be of greatest use in the Northern Territory towards the end of the dry season when deep sampling by hand-augering becomes impossible owing to the hardness of the soil through loss of moisture.

CONCLUSIONS

The two anomalies discovered in the course of the survey are of large dimensions, and it has been demonstrated that samples need not be collected at intervals of less than 400 feet between traverses and 200 feet in traverses.

Deep samples supply more reliable results than do shallow samples, but if deep sampling is impossible shallow samples will supply sufficent information provided they are collected from a close grid pattern.

Either hot concentrated acid digestion or cold dilute acid extraction of soil samples can be used.

The former gives more consistent results, whereas the latter produces a more distinct anomaly.

In the absence of subsurface testing of the anomalous areas it is not possible to properly assess the geochemical results. However, it is considered unlikely, on evidence provided by trenching and drilling in the area between the North and South Grids, that ore in payable quantity will be found in the area covered.

ACKNOWLEDGMENTS

The geochemical investigation described was undertaken as part of the programme of the Comonwealth Bureau of Mineral Resources, and the writer is indebted to the Director of the Bureau for permission to present this report. The co-operation of Consolidated Zinc Corporation Ltd., on whose leases the survey was carried out, is also appreciated.

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APPLICATIONS DES TECHNIQUES GÉOCHIMIQUES DE PROSPECTION, A LA RECHERCHE ET A L'ÉTUDE DES GÎTES URANIFERES EN FRANCE METROPOLITAINE

A. GRIMBERT

RESUMÉ

A la suite des résultats satisfaisants obtenus dans la recherche de méthodes de dosage adaptées au cas de l'uranium, la Direction des Recherches Minières du Commissariat à l'Energie Atomique a décidé, en Décembre 1954, d'utiliser, conjointement avec les méthodes classiques de prospection, les techniques géochimiques pour la recherche et l'étude des gîtes uranifères.

Ces applications pratiques ont été confiées à une Section de Géochimie dont l'organisation, les moyens en personnel et en matériel, ainsi que les méthodes de travail, font l'objet d'un exposé détaillé.

Quelques exemples de prospection, en France Métropolitaine, montrent la nature des problèmes posés (étude d'un gisement connu, recherche tactique sur des indices, recherche stratégique dans une région non prospectée), les méthodes utilisées pour les résoudre et les résultats qui ont été obtenus.

En conclusion, l'auteur souligne ce qu'apporte l'utilisation de la méthode géochimique de prospection tant au point de vue pratique de la recherche puis de l'étude des gîtes, qu'au point de vue économique où grâce è ses possibilités et à son prix de revient intéressant cette technique nouvelle peut rivaliser avantageusement avec celles utilisées jusqu'ici. Malgré leur but essentiellement pratique, ces recherches sont susceptibles d'apporter à la Géochimie théorique un nombre considérable de faits et d'observations du plus grand intérêt.

INTRODUCTION

Il ne s'agit pas d'exposer les principes de la prospection géochimique qui ont fait l'objet de nombreuses communications, mais d'indiquer, de façon détaillée, dans quelles conditions ces principes ont été mis en pratique, en France Métropolitaine, dans le cas particulier de l'uranium.

Je rappellerai tout d'abord les faits qui ont conduit le Commissariat à l'Energie Atomique à utiliser ces techniques nouveles dans la prospection des gites ufanifères.

I—HISTORIQUE

Au cours des années 1953 et 1954, M. Coulomb, du Service de Minéralogie du C. E. A., avait mis au point une méthode sélective de dosage de l'uranium en traces dans les sols.

L'efficacité de cette méthode analytique, rapide, sélective, peu onéreuse, répondant aux nécessités des analyses en grandes séries de la prospection géochimique, fut vérifiée au cours d'essais sur le terrain, avec l'aide de géologues du Service Central des Recherches Miniéres.

Les résultats satisfaisants obtenus ont conduit la Direction des Recherches et Exploitations Minières à créer, en Décembre 1954, une Section de Géochimie dont les buts ont été définis comme suit:

- contribuer, avec la géologie et la géophysique, à l'étude des indices uranifères en appliquant les principes et les techniques géochimiques.
- mettre au point une méthode de recherches permettant, dans des régions peu connues, la découverte de zones favorables à la prospection de l'uranium.

Les moyens suivants, en personnel et en matériel, furent mis à la disposition de la Section de Géochimie:

- 9 agents permanents: (1 ingénieur géologue, 2 prospecteurs, 5 chimistes, 3 aides chimistes) aidés par des manœuvres locaux pendant les opérations de terrain.
- 1 laboratoire fixe, au Centre de Chatillon, près de Paris.
- 2 camions laboratoires.
- 2 véhicules légers de liaison.
- le matériel de laboratoire et de terrain nécessaire au prélèvement et à l'analyse des échantillons.

La première tâche de la Section fut d'initier le personnel chimiste et prospecteur à ces techniques nouvelles; d'établir les caractéristiques du matériel à utiliser et de le faire construire; de mettre au point des méthodes de travail, tout en déterminant les possibilités et les conditions d'emploi de la prospectian géochimique de l'uranium en France métropolitaine.

Pour cela, des essais furent entrepris sur les auréoles de dispersion dans les sols, les eaux et les alluvions de certain gîte uranifères connus.

Dans les sols, ces essais permirent de constater que:

- la prospection géochimique ne laisse échapper aucune des anomalios valables découvertes par la radioprospection:

— elle présente, avec une grande sensibilité, l'avantage d'une sélectivité dont est dépourvue cette dernière méthode qui ne peut faire de distinction entre les rayonnements communs aux divers radio-éléments naturels,
— la grande mobilité de l'uranium provoque des anomalies géochimiques suffisamment étendues pour admettre le prélèvement d'échantillons suivant une large maille permettant une grande vitesse d'avancement;
— le meilleur moyen de faire des prélèments rapides à la profondeur deur désirés (jusqui à 1 m 50) est d'utiliser une tarière qui ne produit aucun dégât de surface, avantage appréciable dans les régions cultivées.

Dans ces conditions, il s'avère intéressant, dans un but tactique d'utiliser la prospection géochimique dans les sols, soit pour orienter rapidement la prospection détaillée à partir d'un indice, soit pour fournir des indications complémentaires sur un gisement lorsque les radioplans ne donnent que des renseignements incohérents ou nuls par suite d'un recouvrement important, ou parce que la minéralisation n'affleure pas.

Dans les eaux, d'autre part, l'utilisation des techniques géochimiques de prospection offre des possibilités considérables, dans le domaine stratégique, pour la recherche de zones favorables à la prospection détaillée, bien que la teneur des eaux de surface en uranium décroisse rapidement lorsqu'on s'éloigne de quelques kilomètres, en aval des gîtes uranifères.

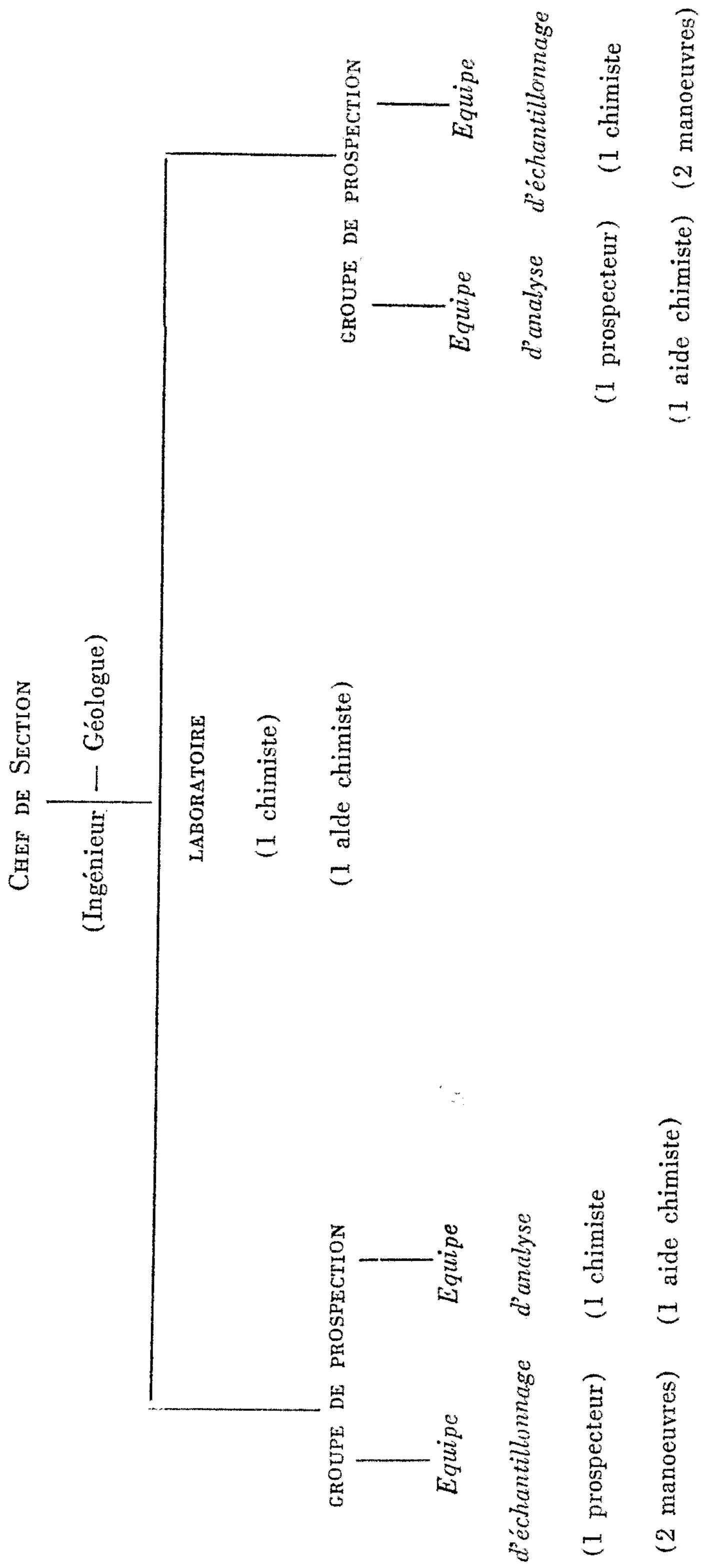
Dans certaines conditions, la prospection géochimique des *alluvions* peut également présenter de sérieux avantages et constituer une vérification des résultats obtenus dans les eaux.

Dans tous les cas, la synchronisation des opérations de prélèvement et d'analyse a permis d'orienter convenablement les recherches et s'est traduite par de meilleurs résultats dans des conditions économiques plus intéressantes.

Il a été également constaté qu'il est preférable d'utiliser un personnel *spécialisé,* soit pour des analyses, soit pour des prélèvements. En effet, si l'on confie la responsabilité des prélèvements à un prospecteur spécialiste de la prospection de l'uranium, il lui est possible, en parcourant le terrain à maille serrée, de faire des observations gélogiques ou géomorphologiques utiles, tandis que le personnel chimiste peut, tout en acquérant une grande dextérité manuelle, apporter certaines améliorations aux techniques analytiques utilisées.

II—ORGANISATION ET METHODES DE TRAVAIL

La Section de Géochimie a adopté l'organisation suivante pour obtenir une efficacité maximum avec un personnel réduit:


CHEF DE SECTION
(Ingénieur — Géologue)
GROUPE DE PROSPECTION
Equipe d'échantillonnage
(1 prospecteur)
(2 manoeuvres)
Equipe d'analyse
(1 chimiste
(1 aide chimiste)
LABORATOIRE
(1 chimiste)
(1 aide chimiste)
GROUPE DE PROSPECTION
Equipe d'analyse
(1 prospecteur)
(1 aide chimiste)
Equipe d'échantillonnage
(1 chimiste
(2 manoeuvres)

Chaque élément de la Section a une tâche bien définie dans les campagnes de prospection géochimique où l'on distingue:

— l'enquête préliminaire,
— la prospection de routine,
— l'interprétation des resultats.

A/ *L'Ingénieur - Géologue. Chef de Section* assure la direction du personnel de terrain et de laboratoire ainsi que la liaison avec la Direction et les autres services de recherches minières.

Il effectue les *enquêtes préliminaires* dont le but est de déterminer le meilleur moyen de résoudre les problèmes posés et de choisir les méthodes de prélèvement et d'analyse les mieux adaptées aux conditions locales.

Si la prospection géochimique dans les sols convient, on fait des prélèvements à différentes profondeurs suivant deux profils en croix ou perpendiculaires à la direction de la formation minéralisée, ou bien encore dans les directions parallèles ou normales aux lignes du relief, afin de définir: la profondeur des prélèvements; le réseau d'échantillonnage et, si besoin est, les modifications à apporter aux techniques habituelles.

Dans le cas l'études hydrogéochimiques, l'enquête préliminaire se limite à des essais à proximité de gîtes connus dans la région à étudier ou dans des régions voisines dont les conditions géologiques sont identiques. Des prélèvements, au hasard, dans les différentes formations de la région à prospector, servent à déterminer la teneur fondamentale regionale des eaux en uranium.

Dans les deux cas, les échantillons sont étudiés su laboratoire central.

L'interprétation des résultats est également faite par le Chef de Section en s'appuyant sur l'expérience acquise au cours des campagnes précédentes et tout en tenant compte de la topographie, de la géomorphologie, de l'hydrogéologie et des risques de pollution provoqués par les travaux miniers. Il fait appel aux connaissances des géologues locaux sur la géologie et la minéralogie de la région prospectée.

Lorsqui'il s'agit de sols, le travail de synthèse est effectué d'après les résultats reportés sur un plan au 1/2.000 (ce report constitue d'ailleurs une vérification, car des valeurs fortes isolées ne sont pas significatives) ; on détermine la teneur fondamentale locale, soit en se basant sur les résultats obtenus en dehors de la zone minéralisée, soit à l'aide d'une étude statistique portant sur la totalité des résultats. Les courbes d'anomalies sont tracées en prenant pour limite les valeurs supérieures à 2 fois, 4 fois, 8 fois, 16 fois, la teneur fondamentale.

Dans le cas de prospection hydrogéochemique, le report des résultats a lieu sur une carte géologique au 1/50.000 on 1/80.000.

B/ *Les Groupes de Prospection géochimique,* chargés des campagnes de routine comprennent: 1 équipe d'échantillonnage fornée par 1 prospecteur aidé de 2 manoeuvres locaux et 1 équipe d'analyse constituée par 1 technicien de laboratoire et 1 aidé.

Toutes les opérations de prospection: écantillonnage, préparation, analyse, sont effectuées entièrement sur le terrain avec entre elles le minimum de délai.

1º—*Dans le cas de sols, l'équipe d'échantillonnage* qui dispose d'un véhicule léger, se voit confier:

- — *le prélèvement d'échantillons* de 250 g. environ, qu'elle effectue à l'aide d'une tarière, dans les conditions fixées par l'enquête préliminaire (voir Annexe I la description détaillée de l'opération). En général, les prélèvements sont faite à 30 cm de profondeur suivant une maille carrée de 40 mètres
- — *la préparation,* qui consiste à sécher l'échantillon, à le broyer sommairement pour désagréger les parties argileuses durcies par le séchage et à le tamiser pour ne conserver que la poudre inférieure à 0.2 m/m (65 m2) qui est mise en sachets portant le nom de la campagne, la lettre de série et le nº de l'échantillon.

L'équipe d'analyse, effectue le dosage de l'uranium dans le domaine de la partie pour million, quels que soient les accompagnateurs, par fluorimètrie précédée d'une séparation chromatographique, avec une précision de ± 15% (voir Annexe II la description des manipulations analytiques).

Ces analyses sont faîtes à bord d'un camion laboratoire qui permet d'obtenir la même qualité de travail et la même rapidité d'exécution que dans un laboratoire fixe.

2º—*Dans le cas des eaux, l'équipe d'échantillonnage* peut être réduite à un seul prospecteur, si les conditions de terrain sont favorables. Il est chargé de prélèver des échantillons dans des bouteilles en polyèthylène de 1 litre 100.

Dans cette technique de prospection, on peut distinguer deux phases successives:

- — *la phase de dégrossissage,* qui recherchera un bassin plus uranifère que ses voisins par la détection des teneurs anormales en uranium dans les rivières moyenne importance et dans les ruisseaux collecteurs, à l'aide de prélèvements d'eau espacés de 1,5 à 2 km.
- — *la phase de détail,* qui localisera la zone intéressante par des prélèvements serrés, dans les eaux et les alluvions du ou des cours d'eau repérés précédemment ou bien encore dans les sols de leurs vallées.

Dans certains cas, il est intéressant d'étudier les variations de la teneur *des eaux souterraines en U aux* différents points où elles apparaissent (sources.

puits, suintements, etc....) pour essayer de préciser l'origine des anomalies.

Lorsque les conditions locales se prêtent difficilement à une radioprospection efficace, on peut envisager dans les sols une phase complémentaire de prospection géochimique qui permettrait de situer et de définir l'allure de la concentration uranifère repérée.

L'équipe d'analyse est responsable de la préparation et de l'analyse des échantillons.

Au cours de la préparation, l'eau prélevés s'éccule lentement à travers des résines anioniques échangeuses d'ions, contenues dans de petites ampoules pharmaceutiques.

Lorsque le camion-laboratoire n'est pas à proximaté du lieu de prélèvement, cette opération est effectuée par le prospecteur qui a prélevé les échantillons. Les ampoules de résine sont ensuite expédiées par poste dans des emballages spéciaux.

Le dosage de l'uranium (dans le domaine de la partie pour milliard) s'obtient par la méthode fluorimètrique (voir détail des manipulations analytiques Annexe II).

C/ *Le Laboratoire fixe,* installé au centre d'attache de la Section fonctionne avec 1 chimiste confirmé et 1 aide qui étudient les échantillons prélevés au cours des enquêtes préliminaires el contrôlent certaines analyses de terrain. Ils sont également chargés de la mise au point de techniques analytiques nouvelles.

III—EXEMPLES DE CAMPAGNES DE PROSPECTION GÉOCHIMIQUE

Malgré sa création récente, la Section de Géochimie a déjà apporté une intéressante contribution à la prospection de l'uranium en concourant avec les autres méthodes de recherches à des études de gisement, à des recherches tactiques sur des indices ou bien à des rcherches stratégiques dans des régions non encore prospectées. Par exemple:

A/. *L'étude du gisement de la Chapelle Largeau* (Vendée).

Cette campagne avait un double but:

a) Etudier les anomalies géochimiques dans les sols, afin de contribuer avec la géologie et la géophysique à la connaissance générale de la région.

b) Améliorer les techniques d'exécution de la prospection géochimique dans les sols.

La région au relief peu accentué, couverte de prairies naturelles et de cultures de ceréales, est située en Vendée (Ouest de la France) entre les vallées de la Sèvre Nantaise et de l'Ouin, à proximité de Mortagne sur Sèvre. Il s'agit de la bordure d'un massif granitique en contact franc avec des frmations métamorphiques du Paléozoïque.

La tectonique, de direction W-NW et NW, soulignée par des failles silicifiées, est connue avec assez de précision grâce à une étude géophysique de résistivité.

La minéralisation uranifère se présente sous forme de pechblende associée à de la pyrite dands une gangue siliceuse.

Outre le gisement, on connaît, —en relation avec la tectonique— un certain nombre d'indices découverte à l'aide des plans compteurs où la pechblende est associée à des produits d'altération (gummite — autunite).

Une étude préliminaire sur des indices uranifères avait donné des résultats positifs et n'avait montré aucune variation sensible de la teneur en U des sols résiduels en fonction de leur profondeur qui peut atteindre 1 mètre.

Les méthodes analytiques habituelles ayant donné des résultats convenables en présence des accompagnateurs suivants: Cu — Pb — Zn — Ni —, il était possible de passer à la phase suivante.

Au cours de la *prospection de routine*, 6,900 échantillons de sols furent prélevés à la maille de 20 m puis de 40 m. à 30 cm de profondeur, avec l'aide d'une tarière de 60 m/m.

La campagne fut exécutée en un peu moins de 3 mois par un groupe de prospection de la section de Géochimie.

La moyenne mensuelle fut de 2,400 prélèvements, en comprenant dans le calcules journées de repos et les delais d'installation.

Une *contribution à la connaissance générale* de la région a été apportée par l'étude des anomalies géochimiques reportées sur la carte ci-contre.

Les teneurs des sols en uranium varient de 1 à 210 ppm., la teneur fondamentale a été estimée à 4 ppm. et la première courbe entoure les valeurs supérieures à 8 ppm.

Seuls les anomalies étendues et les alignements d'anomalies plus réduites ont été retenus lorsqu' ils étaient situés en dehors de talwegs ou de zones déprimées.

L'anomalie n° 1, la plus importante en extension et en teneur, correspond au gisement principal où l'on connaît deux fractures minéralisées, de direction W-NW et N-S. L'anomalie géochimique s'étend également à la zone située entre les 2 filons, ce qui, permet de supposer que l'espace compris entre ceux-ci est également minéralisé. Dans cet intervalle, un grattage, sur une anomalie très localisée de 5 fois la teneur fondamentale, a mis à jour un filon minéralisé de 20 cm de puissance.

L'anomalie n° 2 est moins étendue que la précédente, mais sa bordure W, avec des teneurs en U assez élevées, peut présenter un certain intérêt par suite de sa coïncidence avec une anomalie de la résistivité.

L'anomalie n° 3, dont la teneur maximum ne dépasse pas 4 fois le fond, mérite de retenir l'attention par suite de sa situation à un noeud de failles repérées par la géophysique.

L'anomalie nº 4 correspond à des indices uranifères connus ayant fait l'objet de fouilles et de sondages. La partie aval de l'anomalie résulte vraisemblablement de la pollution provoqués par les travaux.

L'anomalie n° 5 est située dans une zone déprimée et marécageuse qui coïncide avec l'intersection de 2 zones faillées. Il est difficile de savoir si l'uranium contenu dans le sol provient d'une minéralisation sous-jacente, ou s'il résulte d'un transport en solution depuis une origine éloignée.

Il en est de même pour l'anomalie nº 6 qui, blen qu'elle corresponde à une anomalie géophysique de résistivité, peut résulter d'une pollution par les eaux ayant lessivé le mineral stocké sur le carreau de la mine.

Les autres anomalies, de moindre importance, s'alignent, en général, suivant la tectonique révélée par la géophysique et il est difficile de se prononcer sur leur valeur.

Outre les résultats pratiques, cette campagne de prospection géochimique dans les sols a permis un certain nombre de constatations ayant entraîné des améliorations de la technique de prospection:

— la campagne commencée à la maille de 20 m a été achevée à la maille de 40 m lorsque l'on s'est rendu compte que les concentrations uranifères d'une certaine importance créaient, dans les sols, des anomalies étendues qui ne pouvaient échapper à une prospection à la maille de 40 m. Des indices très prometteurs en surface n'ont parfois donné que des anomalies très limitées, et l'un d'entre eux, avec pechblende, qui par suite de son auréole peu développée, aurait pu échapper à la prospection à la maille de 40 m. s'est révélé de peu de valeur à la suite d'une campagne de sondages exécutée dernièrement.

La maille de 40 m présente donc l'avantage de faire un choix et de ne signaler que les anomalies dignes d'intérêt. A la suite de cette campagne, la maille de 40 m a été définitivement adoptée.

— la présence de minéralisation uranifère à l'échelle régionale se traduit par des anomalies géochemiques dans les points bas où se rassemblent les eaux (cuvettes, talwegs). Le prélèvement de sols, dans les zones déprimées, peut donc se révéler un moyen de reconnaissance stratégique intéressant d'autant plus que les analyses de sols sont actuellement 8 fois plus rapides et notablement plus précises que les analyses d'eau (domaine de la partie pour million au lieu de la partie pour milliard).

— les concentrations uranifères situées à flanc de vallée donnent des auréoles géochimiques très développées vers l'aval. Il serait donc possible de détecter la présence de ces concentrations par des prélèvements de sols espacés de 200 à 300 m. sur les flancs des vallées, juste au dessus des flats.

— la connaissance précise de la tectonique, grâce à la géophysique, aide à l'interprétation des anomalies géochimiques. Il serait donc intéressant de synchroniser les études géophysiques et géochimiques pour permettre à la fois une meilleure interprétation des résultats et une amélioration sensible du prix de revient de la prospection géochimique.

B/ *La recherche tactique sur les indices de Verneix* (Allier)

Le but de cette campagne était, à partir d'une anomalie de la radioactivité découverte en radioprospection, de diriger rapidement les recherches en cours et de déterminer l'extension de la zone intéressante.

En l'absence de travaux, il était également intéressant l'étudier les anomalies uranifères créées dans les eaux de surface et les eaux souterraines par cet indice.

La région étudiée est situés dans le centre de la France, dans le voisinage de Verneix, au N.E. de Montluçon (département de l'Allier), à l'Est de la vallée du Cher, dans une zone peu accidentés de granite et de granulite, passant à des gneiss et couverte de prairies naturalles.

La tectonique est localement mal connue en dehors des accidents régionaux dont la direction est E-NE, W-SW.

Le plan compteur à la maille de 2 m effectué sur l'anomalie connue était difficile à interprèter.

La minéralisation uranifère est constituée par de l'autunite disséminée dans la roche granulitique ou gneissique.

Une enquête préliminaire confirme l'existence d'anomalies géochimiques uranifères dans les sols résiduels avec des variations asses marquées de la teneur en U, en fonction de la profondeur pouvant atteindre 1 m 40. Qu'il y ait augmentation ou diminution de la teneur en U avec la profondeur, les prélèvements effectués à 30 cm de la surface présentaient une teneur supérience à la normale en cas d'anomalies géochimiques. Parmi les éléments decelés à l'analyse spectrographique des sols, l'uranium se révéla le plus intéressant à doser.

La campagne de routine fut entreprise immédiatement à la maille de 40 m puis resserrée á la maille de 20 m.
sur les anomalies pour essayer de préciser des alignements privilégiés.

3,500 échantillons, couvrant environ 300 hectares, furent prélevés à une profondeur moyenne de 30 on et analysés sur le terrain par un groupe de la Section de Géochimie.

Une étude statistique faite sur les teneurs en U qui varient de 1 à 300 ppm. a permis de fixer la teneur fondamentale régionale à 4.5 ppm. On n'a pas fait de différences entre les zones granitiques et gneissiques dont les limites exactes sont mal connues. Les résultats reportés sur la carte ci-contre révélent 2 anomalies principales:

—l'une orientés EW au Nord de Verneix, englobe les points radioactifs connus.

— l'autre E-NE, W-SW, au Sud de Verneix, était totalement inconnue.

A la suite de cette campagne, les recherches qui étaient dirigées vers l'Est, ont été orientées vers la NW et le SW. Les plans compteurs ont retrouvé des anomalies de radioactivité très localisées, dans l'anomalie géochimique située au Sud de Vernoix. Des travaux de fouilles et de grattages sont en cours.

Dans les eaux de surface, ces anomalies géochimiques se traduisent par des teneurs de 2 à 3 ppb. pour un fond de 0,4 ppb. Les résultats ont été plus spectaculaires dans les eaux souterraines collectées dans les puits de Verneix et des environs où des teneurs de 5 à 1.500 ppb. ont été enregistrées. On a obtenu les valeurs les plus élevées sur l'anomalie Sud et dans son voisainage immédiat.

En dehors de ces résultats pratiques, des constatations d'ordre technique ont pu être faites:

— la prospection géochimique dans les sols donne plus de renseignements que le plan-compteur,

— elle a une vitesse d'avancement supérieure pour un prix de revient équivalent.

— les prélèvements, resservés à la maille de 20 m sur les anomalies repérées à la maille de 40 m ont permis de préciser des zones de teneur maximum mais n'ont pas modifié leur allure générale,

— la prospection géochimique par les eaux de surface aurait permis de répérer ces anomalies et celles des eaux souterraines de les localiser.

C/ *Recherches stratégiques dans la région non prospectés du Sud d'Avallon* — (Yonne)

La région qui a fait l'objet de cette étude est situés à l'extrémité septentrionale du horst cristallin du Morvan, entre la vallée de la Loire, à l'Ouest, et la vallée de la Saône, à l'Est.

Elle est constituée par des granites, de la granulite, des microgranites, das rhyolites et des gneiss, qui ont tendance à former des unités structurales orientées suivant la direction hercynienne varisque.

Vers le Nord, des formations sédimentaires secondaires recouvrent le substratum qui apparaît dans le fond des vallées entaillant la converture.

L'enquête préliminaire menée sur un point uranifère connu, dans une région voisine, avait montré que la teneur en U d'un ruisseau coulant en aval quintuplaît au voisinage de la concentration uranifère pour redevenir presque normale à 1,5 km en aval.

La prospection de routine débuta par une phase de dégrossissage, sur les rivières et les risseaux collecteurs, au cours de laquelle 300 prélèvements d'eaux et d'alluvions, espacés de 1,5 à 2 kms, furent recueillis sur une surface de 1.200 Km2.

Cette première phase révèla, après vérification des valeurs anormales, l'existence de zones favorables, les unes dans les terrains cristallins, les autres en bordure des terrains sédimentaires, où la teneur des eaux en uranium était supérieure à 5 fois la teneur fondamentale régionale.

Les zones d'anomalies en terrain cristallin ont fait l'objet d'une prospection hydrogéochimique détaillée avec des prélèvements rapprochés en amont des points anormaux, ce qui a permis de localiser approximativement l'origine des anomalies.

Les analyses d'alluvions ont confirmé les résultats donnés par les eaux.

Les zones d'anomalies situées au voisinage des terrains sédimentaires, constitués par des niveaux calcaires gris bleu foncé, dans lesquels s'intercalent des lits de marnes grises, ont vraisemblablement ces formations pour origine. Il y aura lieu de les examiner en détail.

Cette campagne aura permis de diriger rapidement les équipes classiques de prospection (marteau et compteur Geiger) vers des régions qui semblent plus favorables que d'autres. Des recherches sont actuellement en cours.

Le groupe de prospection géochimique a pu améllierer ses techniques de prélèvements et d'analyses et faire quelques remarques d'orde pratique:

— la teneur en uranium des eaux ne semble pas avoir de rapport avec le pH qui varie de 6 à 8,

— les pluies, dans cette région où la pluvionmétric est d'environ 1,000 n'apportent pas de changements importants dans les résultats.

— les prélèvements d'eau à 1.500 m d'intervalle sur les ruisseaux collecteurs sont suffisants,

— il ne faut retenir pour anormales que les teneurs supérieures à 5 fois la teneur fondamentale régionale, mais des variations moindres dans des rivières importantes peuvent donner des indications utiles.

IV—RENDEMENT ET PRIX DE REVIENT

La prospection géochimique de l'uranium constitue un cas particulier de prospection géochimique car elle entre en concurrence avec la radioprospection par compteurs Geiger ou par scintillomètres.

L'utilisation de ces appareils, aussi bien sur le plan tactique, lorsqu'ils sont transportés par l'opérateur, que sur le plan stratégique, lorsqu'ils sont transportés à bord de véhicules automobiles ou d'avions, bénéficie d'une certaine expérience.

Pour rivaliser avantageusement avec la radioprospection, il a fallu d'abord montrer que la prospection géochimique était susceptible de rémédier aux déficiences des techniques de prospection utilisées jusqui'ici comme, par exemple: lorsque le recouvrement de sol est important où que le gisement n'affleure pas, lorsqu'il s'agit d'une reconnaissance dans des régions difficilement accessibles, où les voies de communication sont peu nombreuses.

Il a fallu ensuite démontrer que la vitesse d'avancement était satisfaisante pour un prix de revient acceptable.

Seul, le prix de revient résultant des dépenses occasionées par des opérations actives (topographie, échantillonnage, préparation, dosage) et des dépenses provenant de certaines opérations annexes de terrain (déplacement, frais de transport du matériel, etc....) y compris l'amortissement du matériel et des véhicules utilisés, a pu être calculé exactement.

A/ *Dans les sols*, le nombre de résultats quotidiens atteint 112, ce qui représente une surface d'environ 18 hectaras à la maille de 40 m.

Les analyses effectuées en double avec 2 essais à blanc et 2 étalons pour 12 analyses (32 mesures pour 12 résultats) par 1 technicien de laboratoire et son aide, correspondent à un rendement de 56 résultats homme/jour, sans tenir compte des analyses refaites pour non concordance des résultats ou mauvais groupement géoghaphique.

Les prélèvements, comprenant souvent un lever topographique sommaire et la préparation des échantillons, sont effectués par 2 manoeuvres et un prospecteur avec un rendement de 37 prélèvements homme/jour.

Le prix de revient du prélèvement et de la préparation d'un échantillon s'élève à 125 Fr.

Dans cette somme, le prix de la main d'œuvre entre pour 90%. Il est done possible de calculer approximativement le prix de revient de chaque opération en se basant sur le temps passé pour chacune d'elles:

— piquetage de terrain	20 %	soit	25 Fr.
— prélèvement à la tarière	35 %	soit	43 Fr.
— préparation des échantillons	30 %	soit	37 Fr.
— organisation-déplacements	15 %	soit	20 Fr.

L'analyse coûte 105 Fr — soit un prix de revient total de: prélèvement 125 Fr + analyse 105 Fr = 230 Fr par échantillon et une dépense de 1.450 Fr à l'hectare avec des prélèvements à la maille de 40 m.

Le prix de revient des opérations de prélèvement peut être abaissé de 20% par l'utilisation du piquetage mis en place par les "équipes de résistivité" de la prospection géophysique et nous généraliserons la mise sur pied d'équipes mixtes géophysique géochimique.

L'emploi de sachets de papier Kraft, séchés dans une étuve à bord de camion-laboratoire, est susceptible d'améliorer considérablement le rendement des opérations de préparation des échantillons.

Les opérations de prospection, que ce soit dans les sols ou dans les eaux, sont limitées par les analyses. Comme il n'est pas possible d'augmenter l'effectif du personnel opérant dans le camion-laboratoire on peut espérer doubler les cadences par la suppression des vérifications systématiques.

B/ *Dans les eaux*, la moyenne des résultats quotidiens n'atteint encore que 16, soit 25 à 30 km de cours d'eau dans la première phase de recherches.

Il est difficile d'indiquer un rendement pour la 2ème phase qui dépend des conditions particulières rencontrées.

La cadence des analyses limite celle des prélèvements et le prospecteur chargé de cette dernière opération effectue, en général, facilement 16 prélèvements d'eau par jour. Il prélève en même temps 16 échantillons d'alluvions aux mêmes points que les échantillons d'eau et un nombre variable d'échantillons de sols, si les conditions de terrain sont favorables.

Le rendement des préparations et des analyses d'échantillons d'eau (effectuées en double avec un essai à blanc et un étalon pour 6 analyses sur 2 échantillons pour chaque point de prélèvement, ce qui représente 32 mesures pour 6 résultats) est de 8 résultats homme/jour.

— Prix de revient du prélèvement	442 Fr
— Prix de revient des analyses	595 Fr
ce qui fait un total de	1,037 Fr

par résultat.

Au cours de la première phase (dégrossissage) d'une campagne hydrogéochimique sur une région de 720 Km2, par exemple, 143 échantillons ont été prélevés, y compris la vérification des points anormaux ce qui représente 1 échantillon pour 5 Km2 et une dépense de 207 Fr par Km2. Ce chiffre, bien entendu, varie suivant l'importance du réseau hydrographique.

Ces valeurs correspondent encore à une période de mise au point et des progrés sont réalisables.

V—CONCLUSION

La prospection géochimique de l'uranium en France est entrée dans le domaine des applications pratiques et figurera bientôt en bonne place dans l'arsenal des techniques de prospection.

Les résultats obtenus jusqui'ici ont montré que, malgré les conditions particulières qui lui étaient imposées, la prospection géochimique de l'uranium avait un avenir considérable dans la recherche puis dans l'étude des gisements uranifères, grâce à ses possibilités d'investigation en profondeur, à sa rapidité d'exécution et à son prix de revient avantageux. De plus, elle est susceptible de se révéler sans égale dans la reconnaissance des régions tropicales que nous abordons à présent.

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Nous apportons également notre contribution à la géochimie théorique en mettant à sa disposition des éléments d'observation sur le terrain des phénomènes de dispersion et de fixation de l'uranium dans les sols, et en lui fournissant un nombre considérable de résultats d'analyses qu'un laboratoire de recherches est incapable de réunir.

De plus, les campagnes de routine sont mises à profit pour effectuer des études n'ayant pas de put pratique immédiat, comme par exemple: sur les variations de la teneur des sols en uranium, en fonction de la profondeur; sur les variations de la teneur des caux en uranium en fonction de la pluviométrie; ou bien encore, sur la forme des anomalies provoquées par les cations accompagnateurs de l'uranium.

*

Mais l'utilisation de bonnes tecniques d'échantillonnage et d'analyses ne suffit pas et l'interpretation correcte des resultats obtenus constitue encore la principale difficulté. Il convient de la surmonter en développant notre expérience le plus rapidement possible par la mise en commun de toutes les connaissances recueillies dans ce domaine.

Pratiquement, ce but pourrait être atteint par des échanges d'informations techniques et scientifiques, par des stages auprés d'organismes spécialisés, par des réunions qui permettraient aux géologues spécialistes des recherches minières de confronter leurs connaissances dans le domaine nouveau de la géochimie appliquée.

V – PROGRAMS OF GOVERNMENTAL ORGANIZATIONS FOR CONTINUING WORK IN GEOCHEMICAL EXPLORATION

GEOCHEMICAL PROSPECTING BY THE GEOLOGICAL SURVEY OF NORWAY, 1954 - 1955

COMPILED BY P. PADGET,
WITH CONTRIBUTIONS FROM
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CHR. OFTEDAHL, S. SKJESEHK and
F. M. VOKES

ABSTRACT

Geochemical prospecting in various parts of Norway during the last two summers is described. Equipment, methods of working and field techniques are briefly mentioned. Emphasis is placed on the value of stream silt in detecting Cu, Zn and Pb mineralization. Several "case-histories" are given and the climatic and vegetative features of each evaluated. It is emphasized that the results and conclusions should be judged in the light of the recently glaciated nature of the terrain and the prevailing wintry conditions for about half the year.

INTRODUCTION

Since the summer of 1954 the Geological Survey of Norway has carried out geochemical prospecting along with current geological projects. The initial incentive to make use of the new and rapidly developing geochemical techniques was a programme of field mapping in the Precambrian of Finnmarksvidda, northern Norway. Here distances are considerable and exposures are often few. A rapid method of detecting possible ore bodies in covered ground was particularly sought.

The techniques have been applied elsewhere in northern Norway as well as at a few places in southern Norway.

METHOD OF WORKING

To carry out the purely chemical side of the work a small Austin "3 way" van (1,250 kg) was purchased and roof lights added. Laboratory equipment was installed and the whole left in charge of the chief chemist of the Survey, Mr. Brynjolf Bruun.

In the field, the van was stationed at places central to the area being surveyed. The prospecting work was devised by the geologists and to a large extent carried out by then along with field assistants.

All the work carried out so far has been concerned with detecting secondary dispersions. Attention has been mainly concentrated in and around areas where mineralization has been observed in the bed-rock. No new unexpected areas of mineralization have been found by geochemical methods.

Material examined has included stream waters, soils and to a limited extent vegetation. On the recommendation of H. E. Hawkes 0.1 gram samples of silt were taken from stream beds and the total heavy metal content (Zn, Cu, Pb) determined by the ammonium citrate —dithizone method (H. Bloom, 1953) on the spot.

This form of sampling is hereafter referred to as the "silt-method".

Individual projects are briefly described below. Geographical locations are shown in the key-map, Fig. 1.

1 FINNMARKSVIDDA (ABOUT 69°N)

Precambrian rocks here give rise to a moderate relief in which the main rivers are rather deeply entrenched. Otherwise drainage is often poor with areas of bog or fluvio-glacial sand and gravel, which effectively obscure the bed-rock from direct observation. Vegetation in these arctic latitudes is confined to dwarf birch on the drier ground and mosses and ling on the wetter parts.

1) *Water sampling.*—A number of tests were made on water from streams by the dithizone method. (Method of Huff, see in Lakin, Almond, Ward, 1952). It was thought that contrasted rock formations (quartzite, greenstone) might give different values. No significant differences were found however.

2) *Sulphide impregnated graphite schist.*—These occur at several places in the area and mainly contain pyrrhotite and pyrite but with chalcopyrite in small amounts locally. Values slightly over the background (50 ppm) were found by testing silt samples from streams (citrate-dithizone method). Systematic soil sampling on a net of points was carried out at one place, near a river called the Masijokka, where chalcopyrite is present. The soil has the typical podsol profile and samples were taken from different zones and tested by the method of Bloom and Crowe (1952) in the laboratory van. Higher values were locally obtained but it was not found possible to establish any definite dispersion pattern in the soil as a whole or in individual soil zones.

3) *Fidnatjokka.*—An important mapping horizon in the area is a fuchsite-bearing conglomerate. A bulk analysis showed 0.08% Cr at one place and the

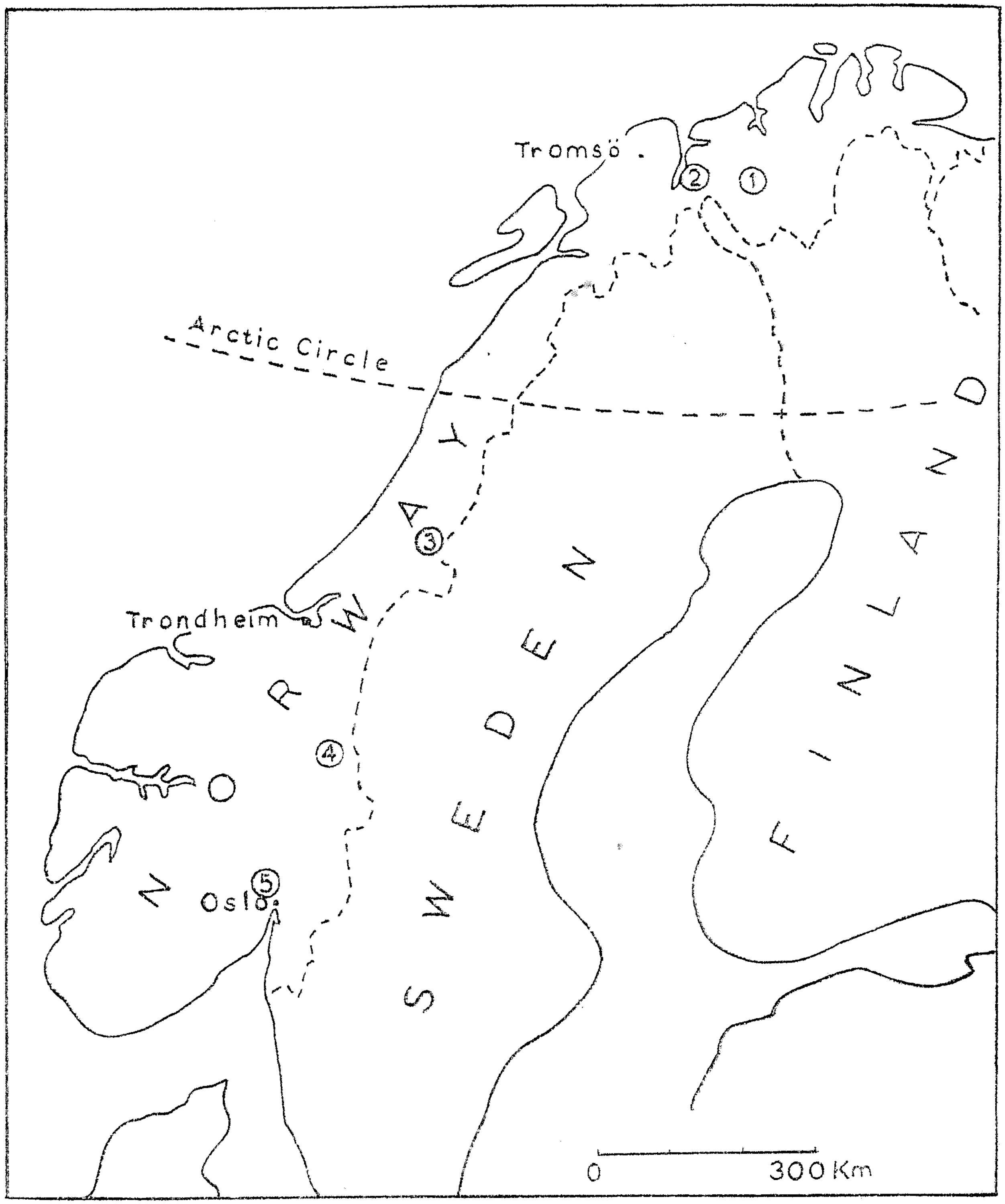

Fig. 1. Outline map of Norway showing location of individual geochemical projects. 1. Finnmarksvidda.—2. Birtavarre.—3. Joma.—4. North Österdal.—5. Grua.

element was tested for in a series of soil samples taken across the strike of the horizon. Depth to bed-rock 10 - 150 cms. Values slightly higher than the background were recorded.

Samples were tested in the laboratory van by methods based on those of Sandell (1950).

4) *Silt sampling.*—The technique of silt sampling was tried by each geological field party, carrying the necessary reagents and simple equipment in a knapsack. No distinctive anomalies were found in this way but routine sampling was carried out in 3 areas of known sulphide mineralization.

a) Cuojajokka.—A greenstone with a weak mineralization is exposed in the left bank of the Cuojajokka river. Mainly pyrrhotite but traces of chalcopyrite. No anomalies found, probably due to scarcity of Cu, Zn, Pb.

b) Davggejavre.—2 narrow zone (about 3-4 metres wide) of mineralization in schist. Mainly pyrrhotite and pyrite with traces of chalcopyrite some places. Higher values recorded on the strike of the zones.

c) Caskias.—Sulphide mineralization, mainly pyriteand chalcopyrite, is clearly visible in a greenstone formation over a distance of nearly 1 km. It is mainly in the form of an impregnation. The vegetation and soil cover is thin. Several streams cross the outcrop. Silt sampling showed higher values than normal, but about 1/2 km downstream from the mineralization only background values were recorded.

2.—BIRTAVARRE

The area lies 80 km ESE of Tromsö in latitude 69°N.

Mineralization in the area consists of thin plates of chalcopyrite-pyrrhotite ore concordant to the fairly flatlying schists forming part of the Caledonide mountain chain in northern Norway. Outcrops of the solid ore are rare; the "ore-zone" mostly expresses itself as a horizon of rust in the schists.

The region is a somewhat broken plateau 800 - 1,200 metres above sea-level. Chemical weathering is at a minimum and vegetation is confined to scattered lower-lying localities where it is mostly mosses, sparse grass and occasionally dwarf-birch.

Geochemical work comprised:

1.—Testing of overburden covering a known outcrop of an "ore-zone",

2.—Investigations of silt in the small rivers and streams draining the area.

1. *Overburden testing.*—An ore zone being investigated by diamond-drilling was known to sub-outcrop along a slope having a gradient of about 1:9. The slope is covered by 1 - 3 metres of glacial moraine composed of a yellow or

buff sandy matrix with erratics varying from pebble size to blocks upwards of one meter across. The slope is a north-facing one and snow lies most of the year on it. The resultant saturated morainemass is steadily creeping downhill under the influence of gravity and shows fine solifluction features. Vegetation is almost absent except for some moss and sparse grass on the drier parts.

Sampling took place across the supposed suboutcrop and downhill from it on a 25 metres grid, intermediate sample points being taken where desired. The samples of the sandy matrix were scooped from a depth of 10 – 20 cm using a small garden trowel. The heavy metal content was estimated on the spot by the citrate-dithizone method. Values up to 15 ppm against background values of 0 - 5 ppm were found in a zone parallel with the suboutcrop but displaced some metres downhill as a result of soil-creep. Values along the hillside were not constant but the highest occurred in an area which was later shown by drilling to coincide with the suboutcrop of an ore-shoot. A rust zone beneath overburden does not necessarily give an anomaly as it may be entirely due to weathering of pyrrhotite.

2. *Silt in streams.*—Several streams in an area 3 x 4 kms were investigated to test the dispersion from several known ore outcrops. They drain an area of bare schists or morainic debris. Most of their volume is derived from melting snow and they dwindle away in late summer. Silt was taken from between stones and tested by the citrate-dithizone method. The highest heavy metal values were found just downstream from old prospects where dumps of sulphide have lain and weathered for about 40 years. In such cases values up to 100 ppm were found, diminishing to about 20 ppm at distance of up to 1 km downstream. The work seems to indicate that an undisturbed outcrop of ore would not give rise to a detectable anomaly in stream silts.

3.—JOMA

The area is situated about 235 Km NE of Trondheim.

Sulphide mineralization in the Caledonide sequence here has long been known and current work by C. Oftedahl (in continuation of that of the late Steinar Foslie) is concerned with the mineralogy and origin of the ores. In certain areas the rocks are partly obscured from direct observation and in one of these, where a bog is present, systematic geochemical prospecting was carried out (1955).

The citrate method was employed on samples of silt taken at 50 m intervals alone streams crossing the area. It was found that a distinct anomaly could be traced where the values were appreciably higher (up to 180 ppm) than the background (0 - 30 ppm). This occurs in a zone up to 200 m wide and at least 2 1/2 km long, which curves parallel with the regional strike of the beds. It is assumed that it represents a secondary dispersion from a subsurface outcrop of a horizon of sulphide mineralization.

This is supported by the observations made in a small test-pit on the line of the anomaly as well as by a weak mineralization (0.38% Cu) in greenstones further along the strike.

In the same area weakly mineralized graphite schists also gave a geochemical anomaly.

Conclusions:

While helping to define the subsurface trace of a mineralized rock little can be stated regarding the amount or type of metal (Cu, Zn, or Pb) responsible for the anomaly.

In this connection the variation with grain-size of the sample is demonstrated below:

	Tota Cu % in silt	Total heavy metals (mainly Cu) Determined by dithizone-citrate methtod
<100 mesh (Tyler)	0,82	ca. 2000 ppm
>100 mesh (Tyler)	0,63	ca. 250 ppm

NORTH ÖSTERDAL

The area lies about 225 km from Oslo in a NNE direction near the Swedish border. Here the Engerdalen valley is floored by Precambrian rocks. Flat-lying Eocambrian-Cambrian quartzites rest on the Precambrian and outcrop in the valley sides. Considerable amounts of glacial drift (moraine) mantle the bed-rock (profile, Fig. 2).

At one place galena is disseminated in the lower part of the quartzite and its continuation at this horizon on both sides of the valley is suspected. Systematic sampling of silt in streams descending the valley sides from quartzite to Precambrian was carried out. A very abrupt rise in values was noted at the point where the lowermost quartzite layers crop out. The values are rather lower in cases where the outcrop is not visible due to a cover of moraine (curve, Fig. 2) but the results show that it is possible to follow such a mineralized zone in thickly covered bed-rock.

Further north lies Tufsingdal mine based on a small body of sulphides (Pb, Zn, Cu). The shaft is partly water-filled. Sampling of the silt of the streams showed increasing values in the direction of the mine. The anomaly (Fig. 3) is strongest over a flatter area which is somewhat swampy. It clearly stops short of the mine proper.

It is deduced that the anomaly (heavy, broken line in Fig. 3) is due to contamination of the stream-water by ground-water derived from the mine-shaft where chemical weathering is likely to be more active. The elongation of the anomaly and its rough coincidence with the drainage system is also interesting in this respect. The anomaly is clearly separated from the area of known mineralization.

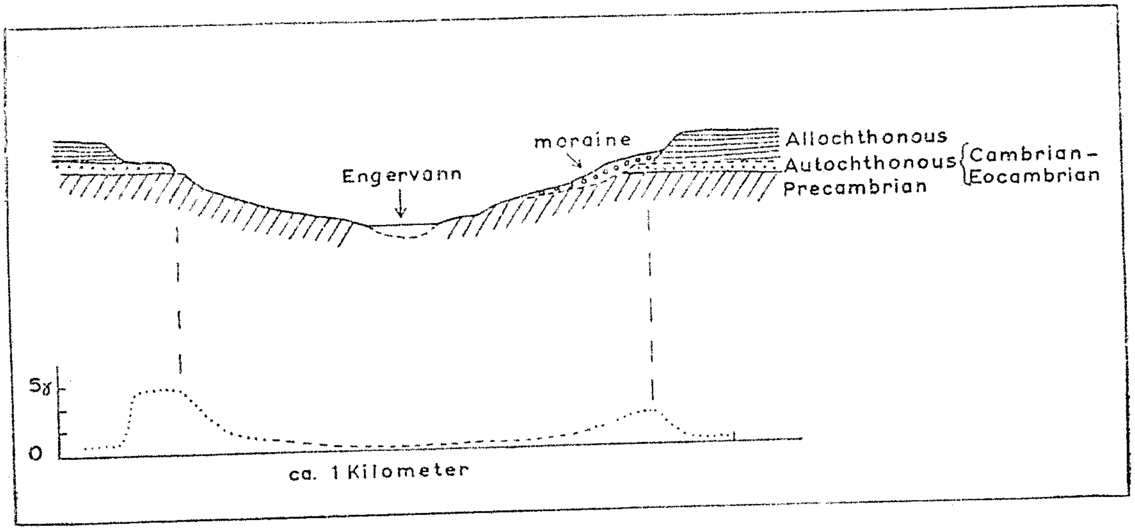

Fig. 2. Profile, somewhat diagrammatic) across the Engerdalen valley. Curve (below) shows geochemical values in silt taken from surface streams.

In the Tufsingdal area a mineralization also occurs at the Precambrian/Eocambrian-Cambrian border (heavy continuous line in fig. 3) as in Engerdal but the values are higher due to the presence of Zn and Cu in addition to Pb.

5. GRUA

The area lies 40 km north of Oslo. Cambro-Silurian sediments contain Cu, Zn, Pb sulphides in contact with granite. The area was examined and briefly described by V. M. Goldschmidt (1911). Several small mines were formerly in operation. The terrain is well wooded and drained by small streams.

Water samples were taken from streams close to Nysaeter mine, where zinc and copper minerals occur. Significant values were detected in the water, using the method of Huff (see in Lakin, Almond, Ward, 1952).

On the other hand water from a stream near Mutta mine, where lead sulphide is the dominant mineral, gave no significant values. This is apparently due to the relative insolubility of lead.

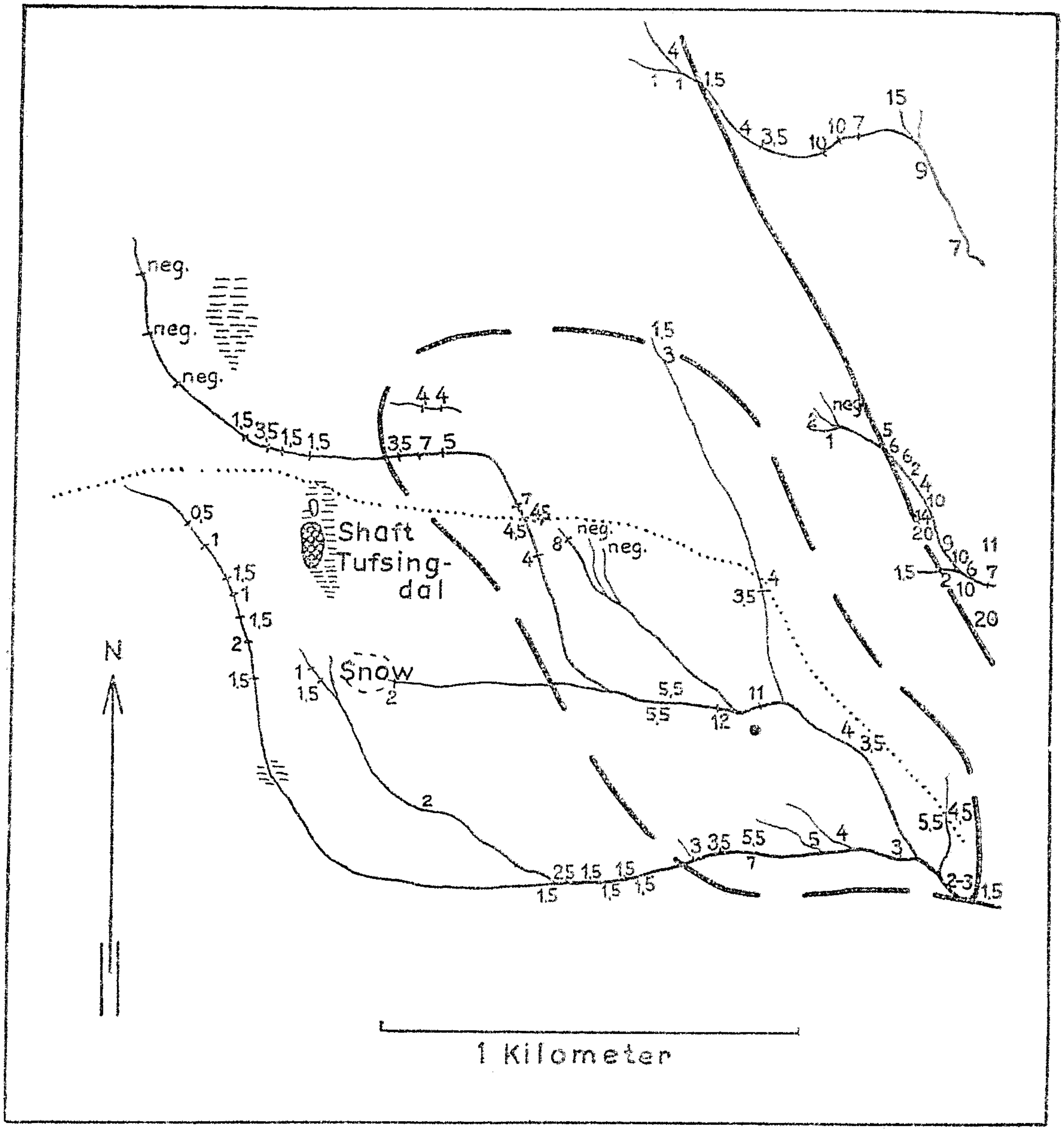

Fig. 3. Drainage system of the Tufsingdal mine area.

It was in this area that silt sampling was first tried. High values were at once obtained in the range 50 - 220 ppm. Variation was also noted between samples taken at any one place and this was shown to be dependent on the degree of grading. The presence of larger grains in the samples invariably caused a fall in values.

Soils were also sampled at points on short traverses across the presumed strike of an ore-bearing vein, 20 cm across, where exposed in a mine portal. Distinctly higher values were found in a zone probably corresponding with the strike of the ore. Soil cover was 2 - 3 metres.

CONCLUSIONS

1. *Silt sampling.*—Of the methods tried to date, that of sampling silt from stream beds and testing for total heavy metals (Cu, Zn, Pb) by the citrate-dihizone method has given the most satisfactory results. It is rapid, simple to carry out and sensitive to quite weak secondary dispersions. More uniform results are obtained when the sample is well graded to the silt size. The method can also be applied to soil if samples of suitable size and grading can be obtained.

Zn and Cu are normally more soluble than Pb (e.g. Grua, North Österdal) and are mainly responsible for the anomalies. The method has been most successful for indicating the distribution of a known ore horizon in covered ground (e.g. Joma, North Österdal). No completely new finds of ore have yet been made by using the method as a pure prospecting tool.

2. *Water sampling.*—Metal values are usually small and tend to vary from time to time and from place to place.

The above results should be judged in the light of present-day climate with wintry conditions over most of the country for 5 – 6 months of the year. Also the relatively recent disappearance of the Quaternary ice - sheets and thinness of the soil and overburden most places. Chemical weathering is therefore not in such an advanced stage.

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ADDENDUM

ADDITIONAL REMARKS CONCERNING GEOCHEMICAL PROSTECTING IN NORWAY

Geochemical prospecting for traces of "heavy metals" using the citrate-dithizone method has been continued by an N G U field-team this summer (1956). In particular, the method has been used in connection with *lead sulphide mineralization* occurring at or near the sub-Cambrian peneplane in south-central Norway.

Previously the investigations had been restricted to silt from streams flowing over known outcrops of the lead-bearing horizon, and marked "heavy metal" anomalies had been found, as described in the paper just read.

This summer's investigations showed that the anomalies in the *stream silts tested*, were due, not to lead, but to copper and zinc derived from the weather ing of the small quantities of chalcopyrite and sphalerite associated with the galena. On the other hand, *soils* (including those derived from glacial moraine) overling the lead-bearing zone gave marked anomalies due to *lead*, with only very subordinate copper and zinc. The lead-bearing horizon could be clearly followed along its strike, by determining the lead in the soil cover.

This seems to point crearly to a separation of lead and copper plus zinc from the same mineralized rock under weathering processes. Lead does not seem to be moved in solution into the stream waters and to be fixed in the stream sediments, but rather occurs residually in the soil over the mineralization. This could probably be related to the relative insolubility of the sulphate of lead, as compared with that of the other metals. Pyrite is present in small amounts in the mineralized rocks and overlying Cambrian shales and would give rise to weak sulphuric acid in the ground water under the processes of weathering. This would lead to the decomposition of the primary sulphides with the production of sulphase of copper, zinc and lead. The former, being highly soluble, would be carried by the ground-water flow into the streams, to be partially adsorbed by the silt in them, whereas the lead sulphate, would remain almost in situ or only be moved short distances in the soil or other cover.

Since we have not read of other instances of such separation, we should be very pleased to hear from others if they are able to report similar behaviour of lead, zinc and copper, or other metals. This summer's results by our field team show that more positive indications will be obtained by investigating the residual soil cover over areas geologically favourable for the occurrence of the lead mineralization than by investigating stream sediments.

LES RECHERCHES GÉOCHIMIQUES AU NIARI (A.E.F.) REALISÉES PAR LE BUREAU MINIER DE LA FRANCE D'OUTRE-MER

J. Nicolai * et J. Sens * *

RESUMÉ

Les alluvions sont systématiquement prélevées tous les 100 m environ dans les rivières prospectées, ce qui permet de localiser les zones où une étude de détail est nécessaire.

Celle-ci est effectué en récoltant des échantillons de sols tous les 20 m sur des profils distants de 50 m au moins.

Ces échantillons sont anlysés pour le cuivre et le zinc en employant une méthode colorimètrique utilisant des solutions de dithizone dans le tétrachlorure ou le white spirit.

Dans le secteur de N'Zala, la géologie de surface avait permis de repérer dans des grès des minéralisations en liaison avec des failles dont le prolongement fut déterminé par une prospection géophysique TURAM.

Une étude des sols a permis de constater une liaison entre ces accidents et la minéralisation, ainsi qu'un passage latéral d'une minéralisation à dominance plomb-zinc à une minéralisation à dominance cuivre.

D'autre part cela a permis d'observer una continuité entre deux secteurs minéralisés qui semblaient indépendants.

Une campagne de sondages est actuellement en cours et à montré l'existence de riches minéralisations provoquant les fortes anomalies géochimiques de surface.

INTRODUCTION

La géochimie du Cuivre, Plomb et Zinc a été mise au point en Afrique Equatoriale Française par le Bureau Minier de la France d'Outre-Mer (Mssion du Cuivre à Mindouli), au cours de l'année 1955.

Les méthodes analytiques et les techniques d'échantillonnage adoptées par la Royal School of Mines de Londres, nous ont été communiquées par le Dr. Tooms, adjoint du Dr. Webb, au cours d'une visite à Mindouli. Nous les appliquons pour la géochimie du Cuivre et du Zinc. Pour la recherche du

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* *Chef de mission.*

* * *Ingénieur-géologue.*

Plomb, nous préférons la méthode proposée par le Bureau de Recherches géologiques, géophysiques et Minières de Paris.

Le déroulement de la prospection géochimique est assuré par un géologue qui dirige les travaux, un chimiste, et un prospecteur chargé des travaux topographiques et de l'échantillonnage.

Nous exposerons successivement les méthodes de travail employées, puis les résultats obtenus en précisant les relations entre la géologie de surface, les anomalies géophysiques et les renseignements fournis par les sondages d'une part, et les anomalies géochimiques d'autre part.

I—ECHANTILLONNAGE ET TOPOGRAPHIE

Les échantillons prélevés sont de deux sortes:

— Echantillons d'alluvions

— Echantillons de sols.

ECHANTILLONNAGE DES ALLUVIONS:

Les échantillons d'alluvions sont prélevés systématiquement par les géologues et prospecteurs au cours des levés géologiques de rivières. L'espacement le plus souvent adopté entre les prises est de 100 à 120 m. Les alluvions sont prises *sous l'eau* et choisies les plus fines possible. L'échantillon, pesant 50 gr environ est enfermé dans un sac en papier Kraft fermé par une languette d'étain. L'emplacement de la prise est matérialisé par un piquet numéroté planté sur la berge.

La prospection géochimique des alluvions n'a qu'un caractère indicatif. Elle permet de localiser des zones anomales, sur lesquelles des études de détail, par analyses des sols, sont nécessaire.

ECHANTILLONNAGE DES SOLS:

L'échantillonnage sytématique des sols se fait aux noeuds d'un réseau qui peut être:

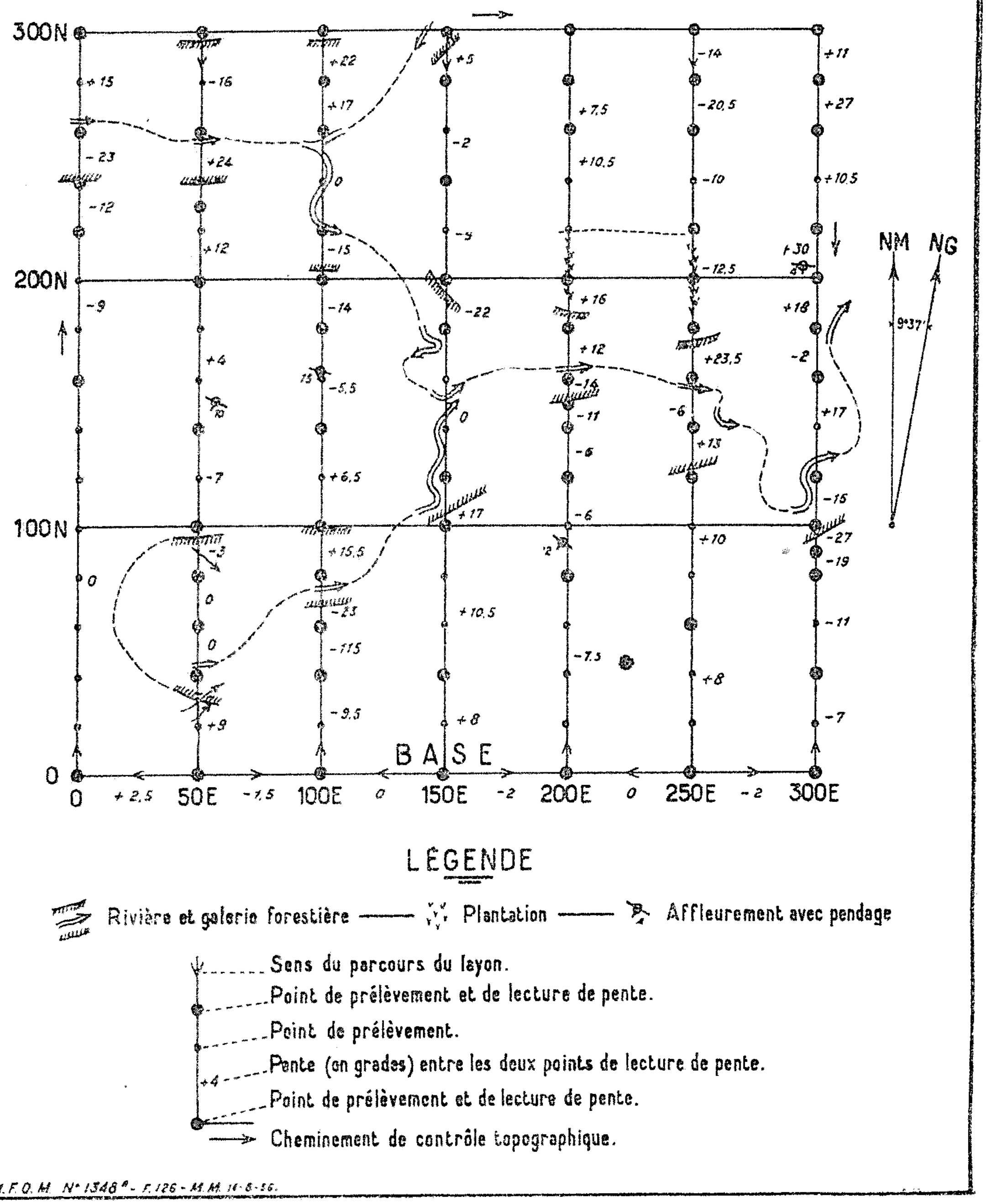
1º — à maille carrée de 40 m x 40 m, lorsqu'on ne connaît pas la direction d'allongement des minéralisations.

2º — à maille rectangulaire de 50 m x 20 m, le grand côté du rectangle étant parallèle à la direction d'allongement des minéralisations, lorsque celle-ci a été déterminée par l'etude géologique. C'est le cas le plus fréquent.

Les opérations topographiques et d'échantillonnage se déroulent de la façon suivante:

FIG. 1

CROQUIS DE PIQUETAGE AU 1/2.000.



a/ — *Tracé d'une base rectiligne,* parallèle à la direction d'allongement des minéralisations. Ce travail est effectué par un prospecteur Européen à la règle à éclimètre ou au tachéomètre. Un piquet numéroté est planté tous les 50 m (ou tous les 40 m suivant le réseau adopté).

b/ — *Ouverture de layons* perpendiculaires à la base, à partir des points piquetés. Ce travail est effectué par un topographe indigène et so néquipe (5 manoeuvres), à l'alidade et à la chaîne d'arpenteur. Un piquet numéroté est planté tous les 20 m (ou 40 m, suivant le réeau adopté) et un trou de 50 cm creusé à la matchette à chaque piquet. L'avancement journalier varie de 800 m à 2 Km suivant la difficulté du terrain.

c/ — *Prélèvement des échantillons et exécution d'un croquis de piquetage* par le prospecteur Européen. Un échantillon de 50 gr environ est prélevé sur la paroi de chaque trou, à 40 cm de profondeur, et enfermé dans un sac en papier Kraft, sur lequel on note les coordonnées du point de prélèvement (numéro du profil et distance à la base) et la nature du sol.

Le prospecteur dispose d'un plan où sont tracées des droites parallèles représentant, à l'échelle du 1/2.000, les layons et les points de prélèvements. Il note sur ce plan tous les renseignements d'ordre topographique (rivières, forêts, plantations, etc..., pente du terrain mesurée au clisimètre), et la position des affleurements par rapport aux points d'échantillonnage. (Voir Fig. 1).

Le rendement est de 200 prélèvements par jour.

d/ — *Levé topographique sommaire* destiné à vérifier la direction et le chaînage des layons et à obtenir une carte approchée. Pour cela, le prospecteur exécute un cheminement autour de la surface étudiée: partant de la base, il lève le premier layon tracé, les extrémités des layons suivants, puis le dernier layon, se refermant ainsi sur la base.

On peut alors dessiner le fond, topographique à l'échelle du 1/2.000 en courbes de niveau, sur lequel seront reportées ultérieurement les valeurs trouvées à l'analyse et les indications de la géologie, après étude des affleurements par le géologue.

II—PREPARATION ET ANALYSE DES ECHANTILLONS

Les surfaces prospectées étant situées en général à moins de 30 Km de Mindouli, il n'a pas paru utile d'installer des laboratoires sur le terrain. Les échantillons sont envoyés au centre pour être préparés et analysés.

PRÉPARATION DES ÉCHANTILLONS:

a/ — *Séchage:* Les échantillons sont séchés dans les sacs, au soleil ou sur une tôle chauffée.

b/ — *Broyage:* Il n'y a pas de broyage proprement dit. Mais les fractions argileuses agglomérées dans les sols sont disloquées dans un mortier de porcelaine.

c/ — *Tamisage:* Dans des tamis en nylon. La maille adoptés est de 80 ou 120 mesh, et doit être constante pour une zone déterminée.

MÉTHODES ANALYTIQUES:

Les procédés d'analyse que nous utilisons nous ayant été communiqués par le Dr. Webb (Royal School of Mines de Londres) ou par le BRGGM, nous ne les décrivons que sommairement:

Analyses d'alluvions: méthode par extraction à froid (Dr. Weeb)

Un volume donné de l'échantillon (1/4 cc) est mis dans un tube colorimétrique. On ajoute ensuite le réactif approprié au métal recherché en quantité voulue, puis 5 cc d'une solution de dithizone dans le white spirit. La teinte obtenue dans la phase organique apres agitation est comparée à une échelle de 10 tubes standars, préparés á partir de solution titrées de métal.

Les résultats, purement qualitatifs, sont donnés en "indices" de métal. L'indice attribué est le numéro du tube standard de même teinte que le tube où a été placé l'échantillon considéré.

Cette méthode permet le dosage rapide du cuivre et du zinc.

Le rendement est de 150 déterminations cuivre et zinc par homme-jour.

Analyses semi-quantitatives de sols pour le cuivre et le zinc (Dr. Webb)

L'analyse porte sur 100 mgr de l'échantillon, pesés à la balance de torsion. Ces 100 mgr sont attaqués dans un tube à essai par fusión au bisulfate de potassium et reprise par C1H normal.

L'essai colorimètrique est fait sur 1 cc de liqueur d'attaque. Les autres opérations sont analogues à celles des analyses d'alluvions. La dithizone est en solution dans le tétrachlorure de carbone.

Les résultats sont donnés en microgrammes de métal par gramme de sol ou parts par million (ppm), avec une erreur de ± 30%.

Rendement: 100 déterminations cuivre et zinc par homme-jour.

Analyses semi-quantitatives pour le plomb (BRGGM)

La méthode est analogue à la précédente. Seule l'attaque diffère: 100 mgr de l'échantillon sont attaqués par 1 cc d'eau régale, avec chauffage au bain-marie.

La dithizone est en solution dans le chloroforme.

III—PRESENTATION DES RESULTATS

PROSPECTION DES ALLUVIONS:

Sur la carte, on souligne d'un trait de couleur conventionelle les sections des rivières dont les alluvions ont des indices supèrieurs à 7 ou 8.

PROSPECTION DES SOLS:

On détermine localement les teneurs normales en métaux lourds dans les sols à l'ecart de toute minéralisation (back-ground)

La carte, établie au 1/2.000, porte alora des plages d'anomalies, dont les valeurs limites sont déterminées au début de l'interprétation.

APPLICATIONS ET RESULTATS OBTENUS

I—GÉOLOGIE - PÉDOLOGIE

Les secteurs propectés par géochimie jusqui'à ce jour sont situés sur l'esquisse géologique d'ensemble, Fig. 2.

GÉOLOGIE:

Les indices de minéralisation étudiés se présentent soit au voisinage du contact des séries schisto-calcaire et schisto-gréseuse (Mindouli, Boko-Songo), soit dans la série schisto-gréseuse (N'Zala).

Stratigraphie

La série stratigraphique est la suivante:

Série Schisto-gréseuse:

Inkisi (1): arkoses à galets. Transgressif sur les niveaux sous-jacents
M'Pioka et M'Fidi (P3 — P2 — P1 — Po): grès arkosiques et argilites.

Série Schisto-calcaire:

C5s: calcaires dolomitiques. A Boko-Songo, le sommet de l'étage est constitué par des marno-calcaires schisteux;

C5m: marnes noires bitumineuses

Les étages inférieurs ne nous intéssent pas pour la présente étude.

Tectonique

Les directions tectoniques principales sont:

— la direction combienne (N 70º E)
— la direction mayombienne (N 45 W)
— la direction méridiene (N-S)

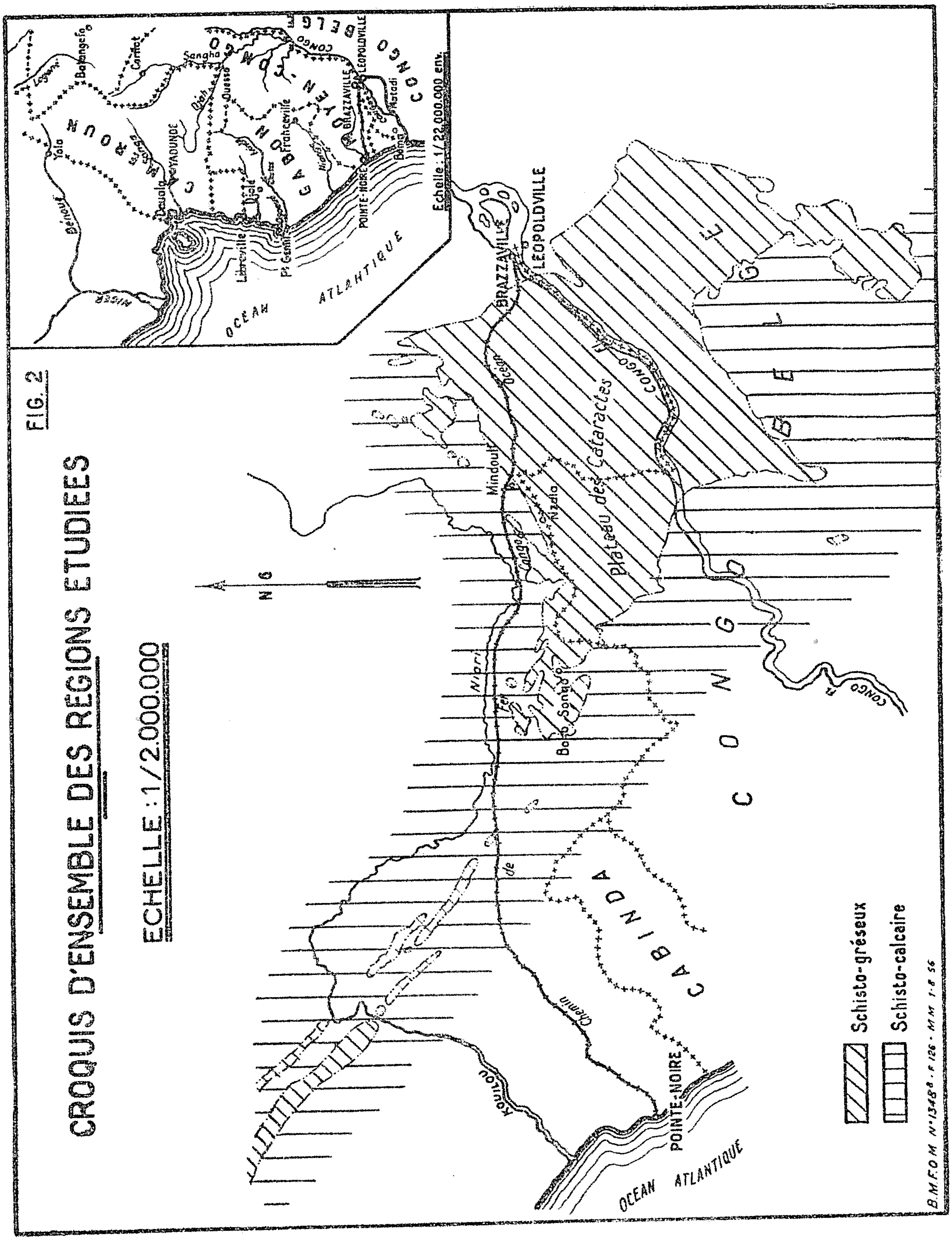


FIG. 2

CROQUIS D'ENSEMBLE DES REGIONS ETUDIEES

ECHELLE : 1/2.000.000

PÉDOLOGIE:

La détermination de la profondeur d'échantillonnage nécessite la connsissance des profils de sols. Dans les régions étudiées, nous avions affaire à des sols latéritiques développés sur des matériaux résiduels, ou l'on reconnait en général 3 horizons:

Horizon A: terre brun rouge à brun jaune, avec en surface un sous-horizon brun Ao, humique.

Horizon B: rouge nodulaire (quelques centimètres)

Horizon C: moucheté, nodulaire et à fragments de bed rock.

Sur les fortes pentes (bordure du Plateau des Cataractes), les horizons B et C ne sont pas développés.

Les échantillons doivent être pris dans le même horizon; c'est l'horizon A, le plus constant, qui a été choisi Les teneurs de la couche humique Ao étant, très irrégulières, les prises de sols sont effectuées juste en dessous, soit à une profondeur de 40 cm environ.

II—PROSPECTION GÉOCHIMIQUE DU SECTEUR DE MINDOULI

Géologie et minéralisations:

Le secteur étudié (voir Fig. 3) s'étend sur la région miniere de Mindouli. Il couvre une partie du plateau gréseux des Cataractes et le rebord de ce plateau, affecté par de nombreuses failles combiennes.

Les minéralisations se trouvent:

1º)—Dans les grès où certains niveaux sont imprégnés de pyrite, de sulfures de cuivre et de malachite.

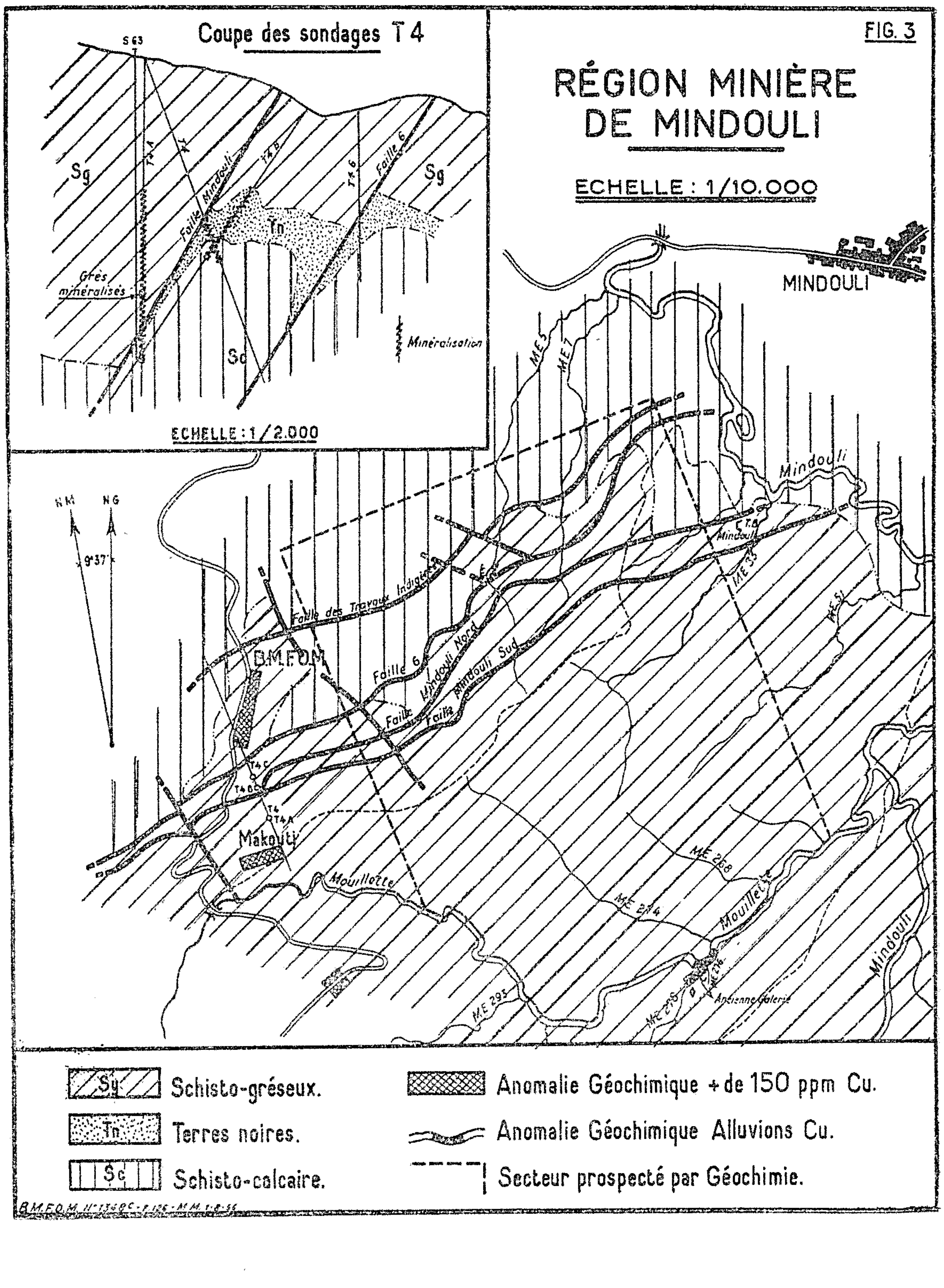
2º)—Au contact grès-calcaire, entre les failles bordières du plateau, où sont échelonnées des poches de terres noires cuivreuses et des calcaires minéralisés (sulfures et minéraux oxydés du cuivre.)

Prospection géochimique:

Sur la retombée et au pied du plateau ont été exécutés de très nombreux travaux miniers, indigènes, puis européens. Les anomalies geochimiques sont très fortes dands cette zone mais elles ne présentent aucun intérêt, car elles sont dues à des pollutions provenant des anciens travaux.

La prospection de surface, s'ttendant sur la plateau gréseux dépourvu d'affleurements, présentait à priori le plus d'intrét, mais aueune, anomalie digne d'intérêt n'est apparue. Il faut remarquer que l'echantillonnage du profil des sondages T4, T4A, T4B, T4C n'a révelé aueune anomalie sur ce profil, alors

FIG. 3


RÉGION MINIÈRE DE MINDOULI
ECHELLE : 1/10.000
Coupe des sondages T 4
ECHELLE : 1/2.000
S 63
Sg
Tn
Sc
Faille Mindouli
Faille 6
T4 A
T4 B
T4 6
Grès minéralisés
Minéralisation
MINDOULI
N M
N G
9°37'
Mindouli
Faille des Travaux Indigènes
Faille 6
Faille Mindouli Nord
Faille Mindouli Sud
B.M.F.O.M.
T4 C
T4 06
T4
T4 A
Makouti
Mouillotte
Mouillette
ME 5
ME 7
ME 33
ME 51
ME 268
ME 274
ME 293
ME 278
Ancienne Galerie
Sg Schisto-gréseux.
Tn Terres noires.
Sc Schisto-calcaire.
Anomalie Géochimique + de 150 ppm Cu.
Anomalie Géochimique Alluvions Cu.
Secteur prospecté par Géochimie.
B.M.F.O.M.

que des minéralisations existent à 50 m de profondeur (voir Fig. 3), sans doute profondément pour être décelées par la géochimie.

L'étude des alluvions du bassin de la Mouillette a mis en évidence de fortes teneurs en cuivre, sur 80 m en aval de l'affluent ME 278. Dans ce dernier, on trouve des grès minéralisés et des traces d'une ancienne galerie. L'étude des sols n'a mis en évidence que deux points moyennement anormaux en cuivre (160 et 300 ppm), au voisinage de l'affleurement et de la galerie.

Conclusions:

1º)—La géochimie n'a apporté aucune indication utile à l'étude de la région minière de Mindouli.

2º)—Au delà d'une certaine profondeur, les minéralisations ne donnent plus lieu à des anomalies géochimiques.

3º)—Certains indices peuvent donner lieu à des anomalies marquées dans les alluvions, très faibles dands les sols.

III—PROSPECTION GÉOCHIMIQUE DU SECTEUR DE BOKO-SONGO

A Boko-Songo comme à Mindouli, les études ont porté sur la bordure du plateau gréseux.

Résultats:

Les indices connus sont constitués par des croûtes de malachite dands les marno-calcaires du sommet du C5s.

Sur les 15 indices de cette sorte découverts, 14 n'ont donné lieu à aucune anomalie en alluvions. Des profils de sols exécutés sur le quinzième ont montré des teneurs en cuivre très fortement anomales dans les zones où les couches minéralisées étaient subaffleurantes, normales où il y avait un peu de recouvrement.

Deux ravins, prenant leur source au pied d'une petite falaise où affleurent les marno-calcaires, ont montré de très fortes teneurs en cuivre dans les alluvions. Dans les sols, une petite zone anomale est apparue au pied de la petite falaise. Aucune minéralisation n'était visible, mais l'analyse géochimique a révélé dans des échantillons prélevés dans la roche des teneurs de l'ordre de 300 ppm de cuivre.

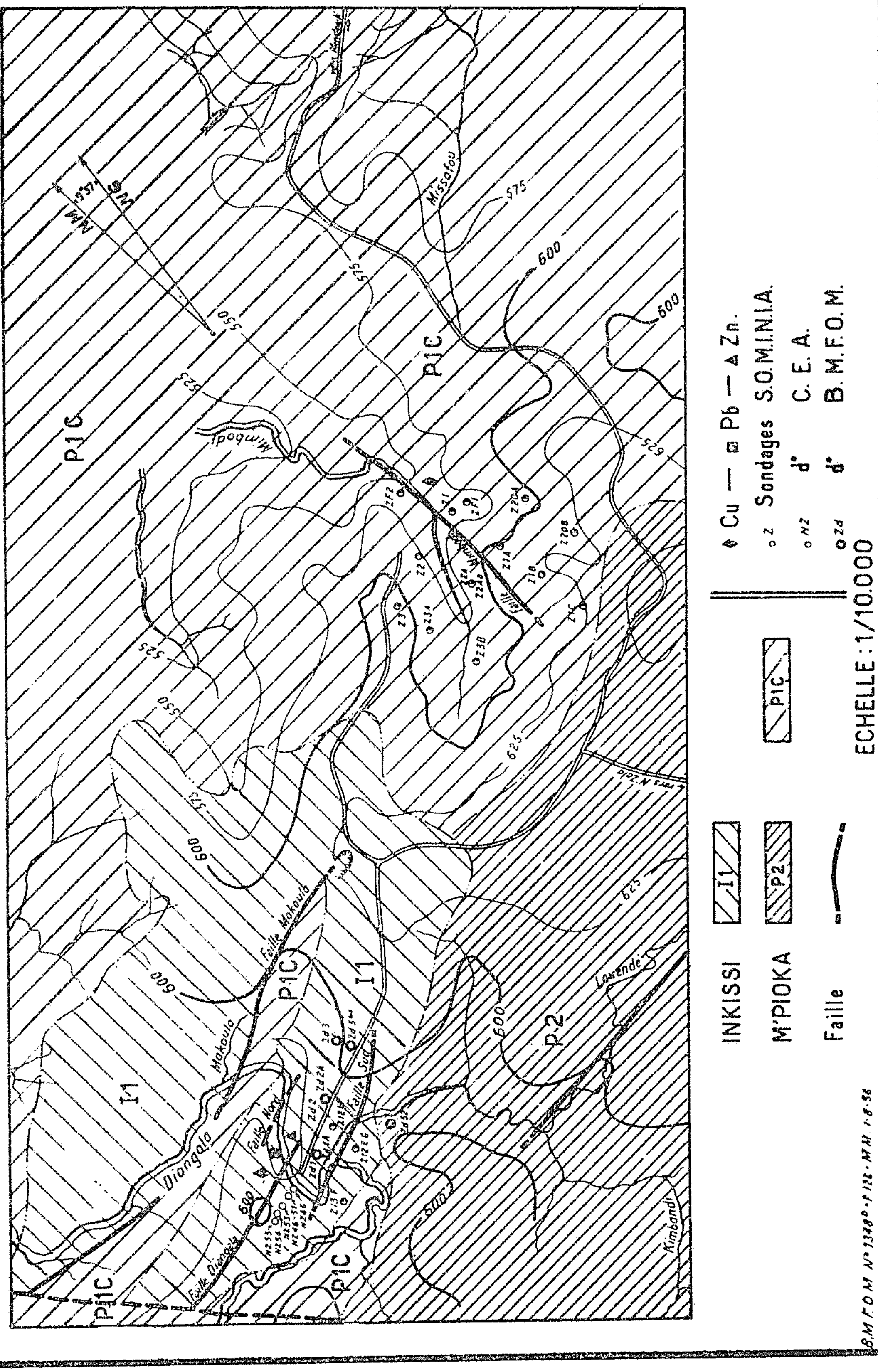
Conclusions:

1º)—Les couches de passage de schisto-calcaire au schisto-gréseux contiennent une faible minéralisation diffuse qui ne constitue pas un gisement intéresant.

FIG. 4

BASSIN DIANGALA-MIMBODI

CARTE GÉOLOGIQUE ET DES SONDAGES



B.M.F.O.M. N° 1348 D-P.122-M.H. 1-8-56

2º)—De très faibles teneurs en métaux lourds dans des roches (ne constituant pas un gîte) peuvent donner lieu à de fortes anomalies géochimiques dans les alluvions lorsque l'érosion est active.

IV—PROSPECTION GÉOCHIMIQUE DU DASSIN DE LA LOUTATOU

(Secteur de N'Zala)

La rivière Loutatou descend de la bordure du Plateau des Cataractes et coule sur les calcaires du C5s, puis sur les marnes du C5m.

La géochimie des alluvions a révélé de fortes anomalies, cuivre et zinc. L'étude des sols a permis de tracer des plages anomales (jusqui'à 1520 ppm de cuivre et 920 ppm de zinc) très irrégulières.

Des tranchées ont été creusées pour prélever des échantillons au contact du bed rock et dans la roche même.

Il semble qu'il y ait eu une forte concentration dans les sols à partir d'un bed rock faiblement minéralisé (100 à 300 ppm de cuivre et de zinc).

V—PROSPECTION GÉOCHIMIQUE DES BASSINS DE LA DIANGALA ET DE LA MIMBODI

(Secteur de N'Zala)

GÉOLOGIE ET MINÉRALISATIONS:

Les secteurs minéralisés des bassins de la Diangala et de la Mimbodi s'étendent sur les grès du plateau des cataractes. Les affleurements appartiennent au Plc et au P2, recouverts par endroits de lambeaux d'Inkisi discordant. (voir fig. 4).

1º)—*Indice de la Diangala:*

Il s'agit d'une zone broyée dans les arkoses de l'Inkisi, dite faille de la galerie, orientée N 60º E, avec un pendage SSE de 70º environ, minéralisée en blende, pyrite, galène et minéraux oxydés de cuivre.

Cette faille est encadrée, à 100 m au Sud et à 80 m. au Nord par deux zones fracturées de même direction, présentant les mêmes minéralisations (faille Nord et faille Sud).

2º)—*Indice de la Mimbodi:*

On peut voir dans la Mimbodi une faille Nord-Sud à pendage de l'ordre de 50º W, mais dont le rejet, sans doute faible, n'est pas déterminé.

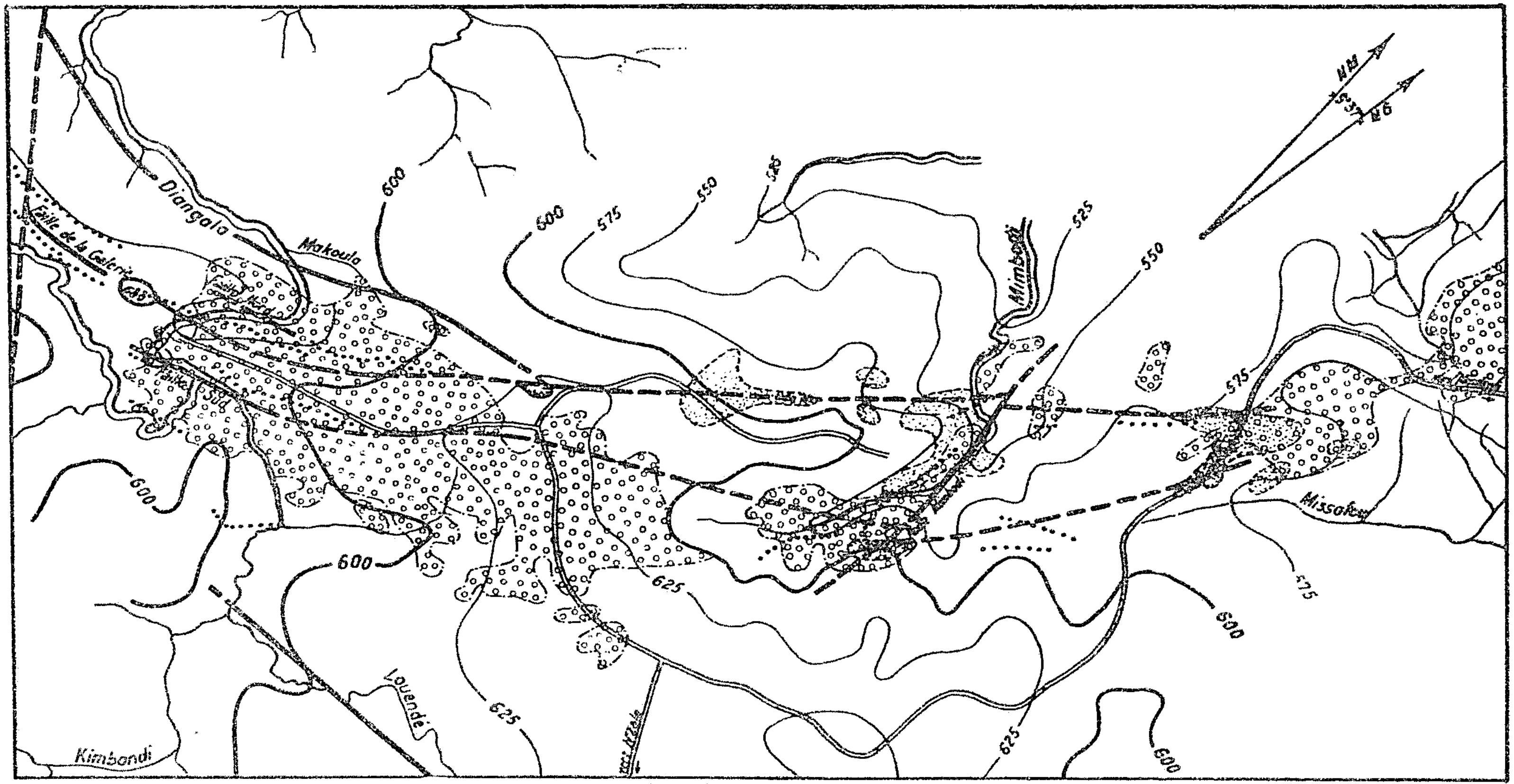
Au voisinage de cette faille, les grès minéralisés en chalcosine.

FIG. 5

BASSIN DIANGALA-MIMBODI

RESULTATS DE LA GEOPHYSIQUE ET DE LA GEOCHIMIE

INTERPRETATION STRUCTURALE



ECHELLE: 1/10.000

……… Conducteurs reconnus par Géophysique (Turam)

Anomalie cuivre (140 ppm et +)

——— Failles.

— — — Failles supposées.

Anomalie zinc (140 ppm et +)

B.M.F.O.M. N°1348E-F.126-M.M. 1-8-55

DONNÉS DES ANCIENS TRAVAUX ET DE LA GÉOPHYSIQUE (Figs. 4 et 5).

1º—*Secteur Diangala:*

L'indice de la Diangala étant radioactif, le Commissariat à l'Energei Atomique (C.E.A.) entreprit une galerie de reconnaissance sur la rive gauche de la rivière, qui s'avança d'une cinquantaine de mètres vers l'Ouest. 5 sondages furent exécutés, également sur la rive gauche de la Diangala. La minéralisation s'appauvrissait.

La Societé Minière du Niari (Sommia) reprit 'étude de la faille de la galerie et de la faille Sud. Trois sondages furent exécutés dont deux sur la rive droite de la Daingala, mais ils n'ont pas été poussés assez loin pour recouper les accidents.

Le Bureau Minier de la France d'Outre-Mer a fait exécuter une campagne électromagnétique Turam, la faille de la galerie et la faille Sud étaient marquées et prolongées vers l'Est par de fortes anomalies. Sur la rive gauche de la rivière, l'anomalie correspondant à la faille de la galerie cesse et est relayée plus à l'Ouest par deux lignes anomales.

2º)—*Secteur Mimbodi:*

Catorce ont été exécutés par Sommia. Plusieurs ont recoupé des grès minéralisés, mais ils n'ont permis de faire aucune interprétation d'ensemble cohérente du secteur.

La faille Nord-Sud donne lieu le long de sa partie visible à une anomalie Turam assez nette qui s'amortit ensuite rapidement vers le Nord et vers le Sud. D'autres anomalies, floues et sporadiques, sont orientées vers le Nord Est.

PROSPECTION GÉOCHIMIQUE DES ALLUVIONS

1º)—*Diangala:*

De fortes teneurs en cuivre et surtout en zinc apparaissent dans les alluvions, immédiatement en aval de la faille de la galerie et se prolongent sur plusieurs centaines de mètres.

2º)—*Mimbodi:*

Les anomalies cuivre et zinc s'étendent de l'indice jusqui'à 500 m en aval. En outre, il y a de fortes anomalies zinc, en amont de l'indice, jusqui'à la source de la rivière.

PROSPECTION GÉOCHIMIQUE DES SOLS (Fig. 5).

La surface couverte par la prospection géochimique englobait les parties minéralisées de la Diangala et de la Mimbodi. Les analyses étaient faites pour le cuivre et le zinc, quelques-unes pour de plomb.

Aucune anomalie géochimique notable ne prolonge la minéralisation de la Diangala vers l'Ouest.

Vers l'ENE, une anomalie zinc très forte (1400 ppm) va en décroissant jusque sur la ligne de crète qui sépare les bassins des deux rivières, en même temps que l'épaisseur du sol augmente. Elle présente deux lignes de tops qui semblent correspondre à la faille de la galerie et à la faille Sud ainsi qu'aux anomalies Turam tout en se prolongeant beaucoup plus loin que ces dernières.

En allant vers la Mimbodi, on voit apparaître, prolongeant l'axe d'anomalie zinc situé le plus au Nord (faille de la galerie), de fortes anomalies cuivre (300 ppm). Sur le prolongement de l'axe correspondant à la faille Sud reparaissant des anomalies zinc.

Enfin, la faille visible de la Mimbodi est marqué par des fortes anomalies cuivre et zinc orientées NS.

INTERPRÉTATION (Fig. 5)

Les axes d'anomalies décrits jalonneraient deux failles minéralisées:

— la faille de la galerie au Nord, minéralisée en plomb-zinc, puis en cuivre.

— la faille Sud, minéralisée en plomb-zinc.

Ces deux failles seraient décrechées légèrement vers le Sud par la faille de la Mimbodi. Elles se rejoignent probablement, en s'incurvant vers le Nord, au NE de la Mimbodi, vers la rivière Missafou, où reparaissent des anomalies cuivre et zinc).

Des sondages sont en cours sur la faille de la galerie. Ils ont déjà recoupé un filon de 2 m de juissance (minéralisation B.P.G. massive) ; au toit, les arkoses de l'Inkisi sont minéralisés en pyrite, galène et blende sur une grande épaisseur.

Conclusions:

1)—les fortes anomalies géochimiques sont en relation avec une riche minéralisation en cours de reconnaissance.

2)—la prospection géochimique a permis de suivre les accidents minéralisés et d'établir une continuité entre les deux secteurs Diangala et Mimbodi, considerés jusque là comme indépendants.

CONCLUSIONS GÉNÉRALES

De ces travaux, nous pouvons tirer deux conclusions générales:

1º)—La prospection géochimique a génénralement donné de bons résultats sur les grès. Il semble néanmoins nécessaire que la minéralisation soit assez riche et relativement proche de la surface du sol pour donner lieu à des anomalies. L'application de la méthode sur les calcaires nous avait été peu recommandée par le Dr. Webb: l'exemple de la Loutatou nous a renforcé dans cette opinion.

2º)—D'une façon générale, les indices de quelque importance donnent lieu à des anomalies géochimiques dans les alluvions, auxquelles se rattachent alors des anomalies dans les sols. Mais, quand l'érosion est active, des niveaux à minéralisation très faible, non visible et sans intérêt, peuvent provoquer de fortes anomalies dands les alluvions.

La géochimie nous aidera donc à rechercher par des analyses de sols les extensions des minéralisations découvertes au cours d l'étude géologique détaillée, plus qu'à repérer les indices par la prospection des alluvions.

RESEARCH IN APPLIED GEOCHEMISTRY AT IMPERIAL COLLEGE, LONDON

D. WILLIAMS *

Research initiated in 1949 was considerably expanded and re-organized in 1954 when the Geochemical Prospecting Research Centre was established in new laboratories. The principal aims of the Centre are to make critical investigations of known geochemical prospecting methods under a variety of conditions, to develop new techniques to meet different demands, and to carry out research on the fundamental principles involved in the formation and detection of geochemical dispersions and anomalies. Its organization consists essentially of three sections dealing with field investigations, routine analysis, and analytical research. Details are given concerning the cost of building, equipping and maintaining the laboratories, and the expenses defrayed in field work, mainly in Africa, together with an outline of recent and current research programmes.

Related research has included regional studies of the distribution of trace elements in specific ore minerals and the mobility of these elements during wallrock metasomatism.

INTRODUCTION

The principal purpose of this communication is to outline the aims, organization, activities and cost of establishing and maintaining a Geochemical Prospecting Research Centre in the Imperial College, in the hope that the information will be helpful to other organizations which may contemplate the setting up of an analogous Centre.

Research in geochemical exploration at the College was initiated in 1949 by Dr. J. S. Webb who, in collaboration with Dr. A.P. Millman (1950; Webb, J.S. and A.P. Millman, 1951) carried out a preliminary investigation of the distribution of heavy metals in natural waters and vegetation in areas of lead-zinc mineralization in Nigeria, West Africa. This was soon followed by a systematic comparative study of secondary geochemical dispersions in residual soils and plants related to suboutcropping tin-copper lodes in Cornwall (Millman, A.P., 1953), and by an experimental soil survey in Derbyshire which demonstrated the presence of a near-surface zinc anomaly presumably caused by primary 'leakage' dispersions above a lead-zinc vein in limestone buried

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* *Professor of Mining Geology, University of London.*

beneath 700 feet of sandstone and shale. Encouraged by the results of these surveys and mindful of American achievements in geochemical prospecting, Dr. Webb gladly accepted an invitation, sponsored by the Mutual Security Agency and the Department of Scientific and Industrial Research, to visit the United States in 1952 to acquire first-hand information on current analytical techniques, field procedures and general organization, as practised by the Geochemical Prospecting Unit of the U.S. Geological Survey. He returned more than ever convinced that the methods being successfully applied in temperate regions could be adapted for use in tropical areas, where the prevalence of extensive soil and forest cover seemed to offer great scope for mineral discoveries by the application of geochemical prospecting techniques (Webb, J.S., 1953). In consequence the research programme in applied geochemistry at Imperial College has been mainly concerned with its relevance to African territories in the British Commonwealth, though several investigations have also been carried out in lead-zinc areas of Great Britain.

The need for an organization in Britain, fashioned on the style of the American Geochemical Prospecting Unit, was discussed with representatives of the Colonial Geological Survey of Great Britain, the Department of Scientific and Industrial Research, and the mining industry, the sequel being the establishment in 1954 of a Geochemical Prospecting Research Centre in the Mining Geology Department of the Imperial College. Fortunately its birth coincided with the inception of the College expansion programme, and it was thus possible to accommodate the Research Centre in new Geochemistry laboratories within the Royal School of Mines (Fig. 1). The cost of building and equipping the laboratories, which are devoted to both Pure and Applied Geochemistry, was defrayed from a capital grant acquired through the medium of the University Grants Committee, financial sustenance for the Research Centre being currently provided largely from the Colonial Development and Welfare Central Allocation for Colonial Geological Surveys, and from the D.S.I.R.

The avowed aims of the Centre are threefold, namely: (i) the critical investigation of known geochemical prospecting methods under a variety of conditions, (ii) the development of new techniques to meet different demands, and (iii) research on the fundamental principles involved in the formation and detection of geochemical dispersions and anomalies.

ORGANIZATION OF THE RESEARCH CENTRE

Although the activities of the Geochemical Prospecting Research Centre are integrated with those of the adjacent Pure Geochemistry and Mining Geo-

ORGANIZATION CHART OF THE GEOCHEMICAL PROSPECTING RESEARCH CENTRE, IMPERIAL COLLEGE.

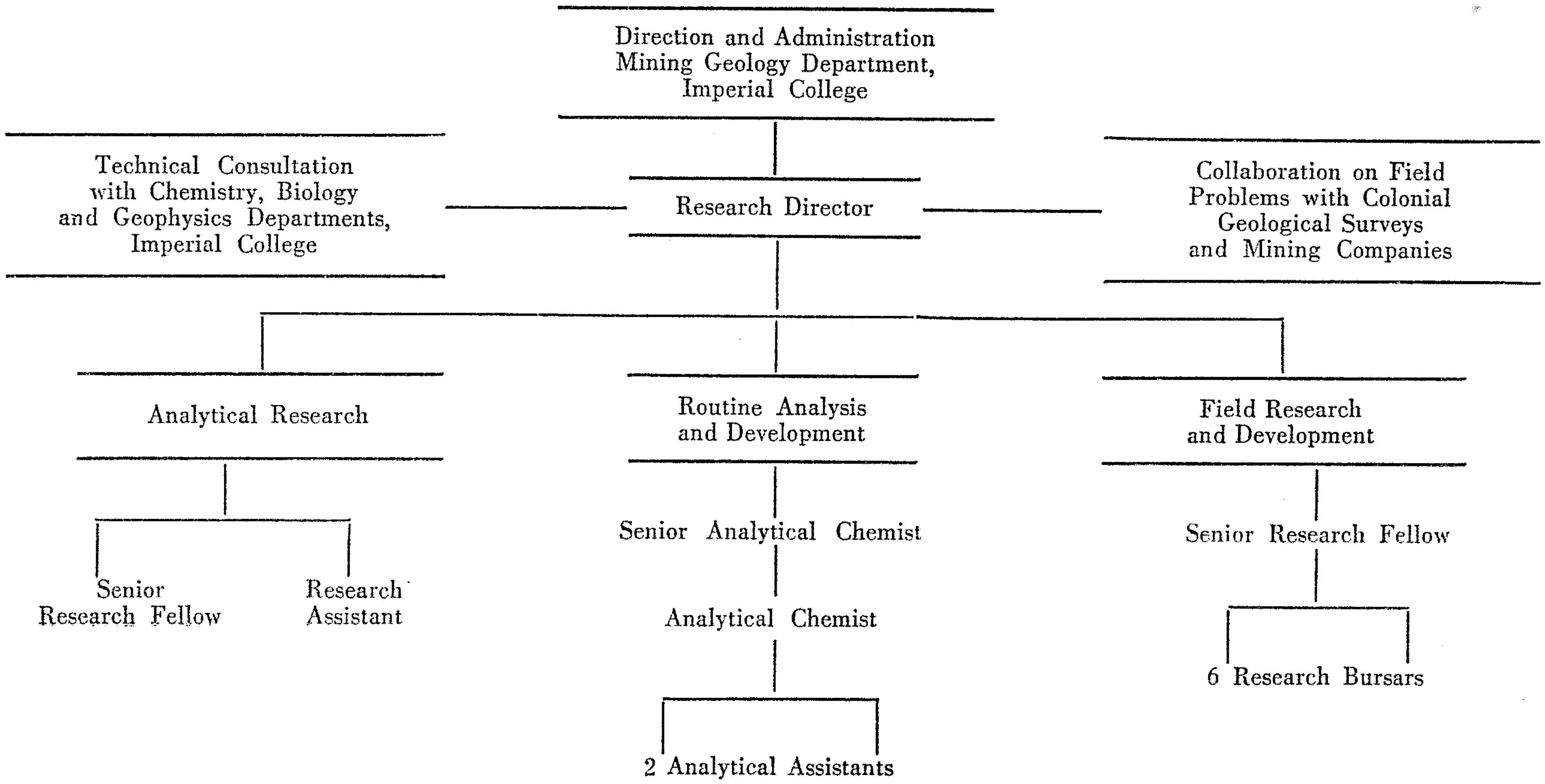

Figure 1.

logy Departments it is nevertheless possible to depict the general organization of the Centre in the following diagrammatic form:

The organization is composed essentially of three sections dealing with (i) field investigations, (ii) routine analysis, and (iii) analytical research.

Although the research programme is carried out under the author's aegis, its execution is intimately controlled and canalized by the Research Director, Dr. J.S. Webb, who collaborates on field problems with appropriate personnel of the Colonial Geological Surveys and mining companies, engages in technical consultations with allied departments in the Imperial College, and supervises the field, laboratory and secretarial activities of the Research Centre.

FIELD SECTION

This is primarily concerned with the critical investigation of various geochemical methods in selected field areas, with a view to developing techniques of practical value in local prospecting operations. Concurrently, fundamental research is undertaken whenever feasible in order to ensure a firm foundation for this work.

The selection of suitable areas for field study is best achieved in overseas territories with the cooperation and assistance of local Geological Surveys and interested mining organizations. These bodies are encouraged to supply information concerning the general geological setting of the mineralized region; local geological, topographical and other significant details; available field facilities; together with a set of preliminary soil samples for determining the range of metal concentrations that might be encountered and for establishing an analytical procedure appropriate to the material in question (Williams, D., 1955, pp. 53-55). If the information and analytical results appear to warrant any further action, the Research Director or his adjutant (a Senior Research Fellow) visit the area for field reconnaissance and the collection of additional samples, and to decide whether the proposed project offers sufficiently attractive new problems to justify research by a postgraduate bursar, or whether it seems unlikely to contribute significantly to the Research Centre's previous experience, in which case the local personnel may be encouraged to undertake a geochemical investigation with the advice and help of the Centre.

Should a bursar be assigned to the problem he undergoes such preparatory training as may be necessary in London in geochemical field methods and analytical techniques appropriate to conditions existing in the chosen area. Preliminary laboratory examinations are also carried out so as provisionally to determine what appear to be the optimum operational procedures. The bursar then proceeds overseas to make a critical study of the geology, to decide upon the most satisfactory geochemical prospecting methods and their limitations, and to evaluate the significance of systematically collected prospecting data. Field supervision is carried out by a senior member of the Research Centre as deemed necessary. Although sample control analyses are undertaken in the field, most of the samples are shipped to the Imperial College for analysis. At an appropriate stage in the field work the bursar may return to headquarters to carry out critical examinations requiring special laboratory facilities. A second visit to the field to check doubtful points and to collect supplementary data may be necessary before the bursar submits his final report, often in the form of a doctorate thesis.

In the event of field studies being undertaken in any given area the Colonial territory or mining company immediately concerned normally provides field and (where possible) laboratory facilities, transport, accommodaties and expenses incurred in the field in connection with an agreed working programme. For its part, the Imperial College distributes funds to cover the salaries of members of the Research Centre, their travelling expenses to and from the Colonial territories, and laboratory expenditure in London. Detailed accounts of the work done and results achieved are submitted to the relevant authorities on completion of the project. It must be emphasized, however, that although the research may demonstrate the most effective means of geochemical prospecting, consistent with cheap costs, it is certainly not the function of the Research Centre to pursue a programme of mineral exploration for Geological Surveys and mining companies.

Up to the present, emphasis has been laid on devising optimum methods of geochemical prospecting in selected areas, but in future it is anticipated that more attention than hitherto will be devoted to an elucidation of the fundamental processes involved in near-surface metal dispersions under a variety of field conditions. It is still intended, however, to concentrate particularly on the practical applications of geochemical techniques.

ROUTINE ANALYTICAL LABORATORIES

These are under the immediate control of a Senior Analytical Chemist, and deal with preliminary trial samples submitted by Geological Surveys and mining concerns, together with copious samples collected by bursars and their supervisors during the course of field investigations. An analytical chemist and two analytical assistants relieve the bursars of most of the burden of routine analysis so that they can concentrate on special problems pertaining to their research. Whenever possible the Routine Laboratories endeavour to improve and modify analytical methods to meet the requirements of immediate and future field investigations.

ANALYTICAL RESEARCH LABORATORY

This laboratory provides essential analytical procedures that have not been previously developed, and collaborates closely with the Routine Laboratories in improving existing techniques and in overcoming difficulties that commonly beset a procedure when applied under novel conditions, bearing constantly in mind the goal of rapid, simple and adequately accurate tests that can be applied in the field at a minimum cost. The research is conducted by a Senior Research Fellow and his assistant, under the supervision of Dr. A.J.E. Welch of the Chemistry Department of the Imperial College.

ACTIVITIES

FIELD INVESTIGATIONS

Much research has been carried out, both experimentally and commercially, in the United States and elsewhere on the development of geochemical prospecting methods in temperature regions. The new techniques have, however, hitherto received comparatively little attention in tropical areas, and consequently the research programme in applied geochemistry at the Imperial College has dealt mainly with their applications in African territories. A conspectus of this research in tropical terrain is presented to the Congress symposium by my colleague, Dr. J.S. Webb, and it will suffice therefore simply to enumerate here the various projects which been carried out by members of the Research Centre during the past six years, and particularly since 1953.

(a) *Secondary metal dispersions in soil.*

The greater part of the Centre's field work has been devoted to geochemical studies in areas where sub-outcropping mineral deposits are concealed by a mantle of soil. They include the following projects:

Copper-cobalt:	Northern Rhodesia, Uganda.
Copper:	Bechuanaland (preliminary studies).
Lead-zinc:	Nigeria, Tanganyika, South Africa; Great Britain.
Arsenic-antimony:	Southern Rhodesia, Sierra Leone.
Chromium:	Southern Rhodesia, Sierra Leone.
Tungsten-molybdenum:	Uganda, Sierra Leone.
Niobium:	Uganda (preliminary studies).

Tin:	Cornwall, England (preliminary studies).
Kimberlite and geological mapping:	Sierra Leone and elsewhere (preliminary studies).

(b) *Dispersion in drainage systems*

Considerable attention is being given to an evaluation of the applicability in tropical terrain of geochemical prospecting methods appropriate to regional mineral reconnaissance, involving the systematic analysis of stream water and/or the sediment of streams and swamps. Work of this nature has been conducted in the following areas:
Nigeria, Northern Rhodesia, Uganda, Sierra Leone.

(c) *Geochemical dispersion in plants*

Systematic sampling and analysis of plants growing in overburden in the vicinity of sub-outcropping mineral deposits, together with a comparison of the relative merits of plant and soil analysis, have been undertaken in several areas, notably:

Lead-zinc:	Nigeria.
Tin-Copper:	Cornwall, England.

(d) *Primary dispersions*

Geochemical dispersions formed during the period of mineralization by the passage of ore solutions into country rocks around the mineral deposit, have been investigated in a few areas, and the extent of the primary dispersion developes or haloes for individual elements in the same locality have also received some attention in the following cases:

Lead-zinc:	Derbyshire, where a near-surface zinc anomaly appears to be related to a blind lead-zinc vein 700 feet below ground level.
Copper:	Uganda, in wall-rocks of a copper-cobalt deposit.
Gold:	Southern Rhodesia, by determining the dispersion of accompanying arsenic in the vein wall-rocks.
Barite:	Devonshire, by studying the dispersion of associated base metals in wall rocks.
Fluorspar:	Durham, by investigating associated base metal dispersions in wall rocks.

ANALYTICAL RESEARCH

The development of new or improved field and laboratory techniques for trace analysis is the prime aim of a research chemist (Senior Research Fellow), and is also a frequent subject of study by bursars and staff in the Routine

Laboratories. Noteworthy among the results so far attained are a novel technique for determining tin in soils and new methods of estimating soluble copper in soils and alluvium and of chromium in soils. Several modifications have been introduced into techniques previously developed by other laboratories, including those for the determination of copper, lead and zinc in soils, sediments and rocks.

Descriptions of the procedures employed by the Geochemical Prospecting Research Centre have recently been published in a series of Technical Communications (Stanton, R.E. and H.A. Gilbert, 1956; Wood, G.A and R.E. Stanton, 1956; Solman, R.H.C., 1956.)

TRAINING

Although original investigations are the cardinal purpose of the Research Centre no opportunity is lost of instructing undergraduates and postgraduates of the Mining Geology Department of the College, members of Colonial Geological Surveys and interested staff of mining companies, in the principles and practice of geochemical prospecting. Moreover, from time to time two-week introductory courses, including lectures and laboratory demonstrations, are offered to British and foreign personnel concerned in modern techniques of mineral exploration, and the courses may be extended for the benefit of those wishing further training in special procedures. On occasions, too, individuals from particular Colonial Geological Surveys attend the Centre for training and subsequently return to the field for further experience alongside a bursar from the College engaged on a specific research project. Indeed, mutual collaboration between Government Surveys, mining companies, and the Centre is virtually a *sine qua non* of the Centre's principal activities.

COSTS

Although it is realized that the costs quoted for building equipping and maintaining the laboratories, and for carrying out field investigations, are largely peculiar to British conditions, they may nevertheless be useful to interested organizations in other countries.

Building and furnishing the laboratories depicted in Fig. 1, which were constructed as a new top story to the Royal School of Mines and are used about equally by the Departments of Pure Geochemistry and of Applied Geochemistry, cost approximately £75,000.

Capital equipment. Some of this equipment is used by both Departments, but it is estimated that the initial cost of equipping the Applied Geochemical Laboratories was roughly £10,000, made up as follows:

(a) *Sample Preparation*: including crushing machine, precision lathe, shaking machine, agate mortars, and sieves	600
(b) *Routine analysis:* Glassware and general equipment... (£1,300), 12 torsion balances, sample storage and records (£1,600), ovens, muffles, calculating machine, bench compressor, water baths, stills, refrigerator	
(c) *Analytical Research:* Glassware and general equipment... (£700), polarograph (£600), precision balance, platinum ware, centrifuge, 2 pH meters, electrochemical and microchemical equipment	1,800
(d) *Miscellaneous:* 2 petrological and 2 binocular microscopes and accessories	600
(e) *Field equipment*: field sampling and analytical equipment (£1,000), Land Rover van and accessories	2,000
	£10,000

A fully equipped spectrographic laboratory is readily available in the adjacent Pure Geochemistry rooms.

Annual Running Costs.—These may be conveniently ascribed to (a) staff manium, and characteristically low in indium, whereas in the higher-tempe-

Analytical Assistants, Research Assistant, Secretary	£6,900
Bursaries: 6 at £500 each	3,000
(b) *Travelling expenses*: 4 return flights to Africa by bursars, and 4 by Research Director and a Senior Research Fellow	2,000
Operational expenses: Field work (20 man-months at £150 per month, plus expendables, £3,500), maintance of laboratories in Imperial College (£1,000), secretarial costs (£250)	4,750
	£16,650

The foregoing notes include mention of the principal subjects of study undertaken by the Geochemical Prospecting Research Centre, but they are incomplete without reference to allied geochemical investigations carried out by the Mining Geology Department, quite apart from those within the purview of Pure Geochemistry.

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[1] Fryklund, V. C. and Fletcher, J. D. Geochemistry of Sphalerite from the Star Mine, Coeur d'Alene District, Idaho, *Econom. Geol.* Vol. 51, pp. 223-247.

TRACE ELEMENT STUDIES

A considerable amount of research has been done on the spectrographic determination of trace elements in specific economic minerals, ores and hydrothermally-altered wall rocks.

Detailed comparative studies have been made of the distribution of these elements in sulphides and gangue minerals from lead, zinc and barytes deposits in Britain, and in galena and sphalerite from massive sulphide ores in Portugal and Spain (Shazly, E. M. El, 1951). Despite recent expressions to the contrary[1] our studies of some of the commoner sulphides, notably sphalerite, indicate that their trace element content is related partly to their temperature of formation, although the recognition of regional or district variations in trace element assemblages emphasizes the prime importance of the metallogenetic province in affecting the distribution of these elements. It transpires that in certain districts in England and Wales where the ores were deposited at comparatively low temperatures, sphalerite is relatively rich in gallium and germanium, and characteristically low in indium, whereas in the higher-temperature blendes of other districts, including Cornwall and Liruei, Nigeria, the proportions of these elements is reversed. Zoning of trace elements sensitive to temperature variations has been noted around granite masses in Cornwall and Devon. For example, sphalerite from veins near the parent granites usually contains relatively large amounts of indium, manganese and tin, whilst the concentration of these elements in sphalerite tends to decrease at greater distances from the granite contacts; it is significant, too, that the low-temperature elements, gallium and germanium, are generally detected only in deposits situated many miles away from the intrusive bodies.

An investigation of trace elements in *cassiterite* and *stannite* (Venugopal, K., 1950) was undertaken as part of a programme of research to establish relationships between trace element assemblages and geological conditions during ore-genesis. On the basis of spectrochemical analysis of a large number of cassiterite specimens from most of the world's tinfields it is concluded that their trace element content is more dependent on the type of deposit and the nature of the ore-fluid than on the temperature of deposition of the tinstone. Thus, cassiterites from pegmatites contain relatively high amounts of niobium, tantalum, zirconium and manganese, whereas samples from greisens, quartz veins and sulphide ores carry less of these elements but more vanadium, indium, tungsten and gallium. In addition to differences in trace element content related to the origin of the cassiterite, regional traits were also observed; in specimens from Malaya, for example, beryllium is common, tantalum, titanium, and tungsten are present in moderate amounts, whilst niobium and zirconium occur only in small quantities. In the case of stannite also, regional variations were noted, traces of germanium and cobalt being typical of samples from Cornwall, whereas antimony is characteristic of stannites from New South Wales.

Wall-rock alteration.—Although the behaviour of major elements during the alteration of wall-rocks by hot mineralizing solutions has been studied in some detail in the past, comparatively little is known about the conduct of trace elements under similar conditions. Spectrographic and mineralogical research in the Department on suites of altered and unaltered igneous and sedimentary rocks from the Cornish tinfield and the pyrite mine of San Domingos in Portugal has established characteristic trace element assemblages for the granite wall-rock alteration zones in Cornwall, and for the various alteration types at San Domingos (6). Sericitization is found to be almost invariably associated with a large increase in rubidium and barium, whereas chloritization is always accompanied by a slight increase in manganese and cobalt together with a marked decrease in rubidium, barium, strontium and chromium. In the areas examined the induced trace element variations do not extend beyond the aureole of visible mineralogical alteration, and consequently do not enlarge the size of the target in the search for new orebodies. On the other hand, in areas of intense alteration where it is almost impossible to identify the original rocks by field or microscopical observations, they may often be recognized and mapped on the basis of their diagnostic trace element content.

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ESTUDIOS FUNDAMENTALES DE LA SUB-DIVISIÓN DE GEOQUÍMICA Y PETROLOGÍA DEL U.S. GEOLOGICAL SURVEY EN APOYO DE LA POLÍTICA NACIONAL DE LOS ESTADOS UNIDOS SOBRE MINERALES

E. INGERSON *

ABSTRACT

In 1946 the U.S. Geological Survey initiated a program of geochemical prospecting. By 1954 the techniques of this program had been thoroughly tested and were ready to be put in pratice by prospectors and mining companies. At present the U.S. Geological Survey has started a more fundamental program of research in support of the National Minerals Policy.

The current projects of the Geochemistry and Petrology Branch in the development of the program are the following:

1—*Chemical volcanology*

- a—Studies of the composition of volcanic exhalations and their relation to volcanic activity as well as to problems concerning the nature of the ore-forming fluids.

2—*Environment of ore deposition*

- a—Characteristics of the solutions; composition, temperature, pressure.
- b—Experimental studies of solubilities of metals in solutions similar to natural ones.

3—*Hydrothermal synthesis of minerals*

4—*Geologic thermometry*

- a—Studies of liquid inclusions.
- b—Studies of feldspars and carbonates.
- c—Studies of stable isotopes.

5—*Minor elements in ore-minerals*

- a—New sources of rare metals.
- b—Conditions of deposition deduced from minor element content.

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* *Publication authorized by the Director, U. S. Geological Survey.*

6—*Data of Geochemistry*

a—New revision of Clarke's classic compilation as a basis for further geochemical research.

7—*Studies of stable isotopes*

a—Better understanding of natural variations.
b—Geologic thermometry.
c—Sources, conditions of transport and deposition of the elements in various kinds of ore deposits.

8—*Determinations of geologic age*

a—Development and use of the following methods:
  (1) Isotopes of lead, uranium and thorium.
  (2) Zircon method.
  (3) Potassium-argon.
  (4) Strontium-rubidium.
  (5) Carbon 14.
b—Revision and improvement of the absolute geological time scale.

9—*Studies of laterization.*

a—Rock weathering in Hawaii.
b—Extension of studies to localities where laterites are more extensively developed, e.g., Puerto Rico, Cuba, Southeastern United States, etc.

10—*Analytical services*

a—For the service of this program and the related ones of other branches in the Geologic Division there are 45 laboratories in 5 different United States cites. The personnel of these laboratories is approximately 200 and they can make some 100,000 determinations per year on 40,000 samples.

INTRODUCCIÓN

En 1946 el U. S. Geological Survey inició un programa de carácter geoquímico para desarrollar nuevas técnicas y descubrir yacimientos minerales desconocidos y al mismo tiempo, tratar de localizar extensiones, si las hubiere, de los ya conocidos. Este programa tenía dos partes, más o menos independientes una de otra:

(1) Se creó un grupo de investigadores de laboratorio para perfeccionar métodos utilizables en el campo y para analizar muestras de rocas, aguas, plantas y tierras. Estas muestras podían ser proporcionadas únicamente por los geólogos del U. S. Geological Survey.

(2) Se crearon también brigadas de campo para definir las anomalías geoquímicas en los alrededores de los yacimientos metalíferos conocidos y buscar anomalías semejantes en otros lugares con objeto de localizar nuevos depósitos.

Ya en 1954 los métodos de este programa habían sido bien comprobados y estaban listos para ser puestos en práctica por exploradores (cateadores) privados y por compañías mineras. Actualmente el U. S. Geological Survey ha emprendido un programa mucho más definido y amplio a fin de apoyar la nueva Política Nacional sobre Minerales. Puesto que en los Estados Unidos todos o casi todos los yacimientos que afloran y que existen cerca de la superficie ya han sido descubiertos, hay necesidad de desarrollar ideas y métodos que sean completamente diferentes de los empleados hasta la fecha a fin de localizar nuevos depósitos importantes.

Esto quiere decir que para localizar yacimientos profundos que no tienen manifestaciones superficiales es preciso crear, estudiar y aplicar conocimientos que actualmente no se poseen sobre las leyes de la geoquímica. Algunos de estos yacimientos pueden encontrarse en cuencas rodeadas por montañas y debido a ello están cubiertos por capas de materiales de acarreo y desintegración, como aluviones, arena y rocas de todo tamaño que se han ido acumulando gradualmente a través del tiempo. Otros, por el contrario, se encuentran a grandes profundidades, contenidos en rocas ígneas o metamórficas.

Para llegar a obtener tales conocimientos, así como otros tipos de información útil a este programa, el U.S. Geological Survey ha emprendido una extensa serie de estudios de campo y laboratorio. Estos estudios incluyen: (1) la preparación de mapas geológicos de un gran número de cuadrángulos en varias partes del país; (2) la determinación de las propiedades físicas de rocas y minerales; (3) el mejoramiento de los métodos de exploración geofísica; (4) estudios de procesos sedimentarios; (5) continuación de los estudios de exploración geoquímica y (6) investigaciones sobre las leyes que originan los procesos geoquímicos, especialmente las que explican la localización de ciertos yacimientos minerales.

En estudios e investigaciones como los antes mencionados se basa la actual Política Nacional sobre Yacimientos Minerales. Por otra parte, hay dos programas adicionales en proyecto; uno referente a combustibles minerales y otro para aguas. Aun cuando todavía no se han aprobado los programas respectivos, es muy probable que estos planes comiencen a ponerse en práctica en el curso del próximo año fiscal.

Del programa antes indicado, relacionado con la política minera, le concierne únicamente a la Sub-División de Geoquímica y Petrología la parte de los estudios fundamentales en geoquímica. El resto es ejecutado por algunas de las otras Sub-Divisiones de la División Geológica del U. S. Geological Survey.

En apoyo al programa, la Sub-División de Geoquímica y Petrología tiene actualmente diez proyectos en ejecución. Algunos de los detalles de la organización, así como las operaciones, objetivos y planes para el futuro en el caso particular de cada uno de estos proyectos, son los siguientes:

VULCANOLOGÍA QUÍMICA

Uno de los métodos más adecuados para el estudio de las soluciones primarias es seguramente el proporcionado por la investigación de las emanaciones volcánicas. Estas, sin duda, pueden estar contaminadas con gases atmosféricos y agua subterránea, pero en ellas existen también componentes telúricos que proceden directamente del magma. De la identificación de estos componentes se pueden obtener nuevos conocimientos sobre el carácter de las soluciones magmáticas acuosas y existen publicados hasta la fecha gran número de análisis correspondientes a los gases volcánicos, aunque sólo unos cuantos revelan algunos detalles sobre la proporción de componentes juveniles. No hay seguridad de poder, con base en ellos, lograr cálculos exactos; sin embargo, es importante hacerlos, a fin de obtener datos sobre la naturaleza de las soluciones procedentes de magmas.

Además, hasta la fecha no se ha intentado determinar la constitución de los gases al salir del magma, o sea, de la lava. Todos los datos o informes que se tienen al respecto son el resultado de análisis hechos semanas, meses y hasta años después de haberse recogido las muestras de lava. Por lo tanto, estos no son análisis que correspondan a la realidad, pues con el tiempo transcurrido ha habido cambios en la composición que incluía tales gases en el momento de separarse de la lava.

En el observatorio volcanológico que se está construyendo en Hawaii será posible analizar, espectrográficamente, los gases tan pronto hayan escapado de la lava.

Durante una erupción puede observarse a simple vista que a escasos metros por encima de la fuente de lava estos gases sufren un cambio definido. Puede darse como ejemplo, una erupción cualquiera del volcán Kilauea. Cuando los vapores se separan de la fuente tienen un color rojizo, pero en contacto con el oxígeno del aire cambian rápidamente, hasta tomar un color blanco-azulado.

Si se pudiera colocar un espectrógrafo en un lado de una de estas fuentes, y proyectar por el otro lado una luz fuerte, de tal manera que ésta penetrara a través del gas rojizo, sería posible identificar los componentes del gas en el instante mismo en que éste se separa de la lava. Es probable que al principio los vapores existan en estado reducido y que contengan azufre en estado libre, como también sulfuro de hidrógeno, monóxido de carbono, ácido clorhídrico y otros compuestos reducidos. La oxidación causada por el contacto de los gases con el oxígeno atmosférico, además de otras reacciones, probablemente produzca bióxido de carbono, óxido de azufre y otros compuestos comúnmente encontrados en los análisis de exhalaciones volcánicas.

Si los hechos indicados anteriormente se desarrollan en el orden descrito, se podrían explicar las observaciones de Payne y Ballard (1940) sobre los cambios en la constitución de los vapores que emanaban de las grietas existentes en la localidad conocida con el nombre de Sulfur Bank, al norte del Kilauea, durante una de las erupciones del volcán Mauna Loa. Estos investigadores observaron que inmediatamente antes de una erupción y durante las primeras etapas de la misma, podía notarse la presencia de sulfuro de hidrógeno entre los componentes de los vapores. Si esta observación aislada pudiera confirmarse como regla general, ello nos proporcionaría un nuevo método para pronosticar las erupciones volcánicas. También es probable, sin embargo, que los cambios no sean exactamente los mismos en otros tipos de volcanes o en volcanes de otras regiones.

EL MEDIO ORIGINAL EN LA FORMACIÓN DE LOS YACIMIENTOS MINERALES

En los volcanes de Hawaii, así como en los casos de todos aquellos cuyas erupciones no impiden el trabajo de recolección directa de muestras de sus exhalaciones, se ha encontrado que emanan lavas conteniendo solamente cincuenta por ciento de sílice, o menos. De las rocas intrusivas cuyo contenido de sílice no sobrepasa lo antes indicado es difícil que se originen muchos depósitos metalíferos; estos yacimientos se derivan por lo general de rocas intrusivas que contienen más del sesenta por ciento de sílice.

Para tener un conocimiento más claro de la naturaleza de las soluciones que han originado los yacimientos minerales, es preciso estudiar los minerales que las constituyen, así como también efectuar el estudio de los minerales de las rocas ígneas de donde se derivaron las soluciones mineralizadoras. Casi todos los minerales encontrados en las vetas hidrotermales y en otros tipos de yacimientos de origen ígneo, así como en el caso de algunos minerales de las rocas ígneas mismas, contienen inclusiones líquidas. Los líquidos de estas inclusiones pueden tomarse como muestras de las soluciones originales. De estas soluciones, por el proceso de enfriamiento natural, se ha formado una cierta cantidad de materia mineral que se ha depositado en las paredes conteniendo las inclusiones. Debe tenerse en cuenta que los líquidos a que se ha hecho referencia no tienen, actualmente, la composición exacta de las soluciones originales. Los análisis de estas soluciones proporcionarán datos importantes acerca de su naturaleza no obstante que como se ha hecho notar antes, ya no tienen, precisamente, su composición original.

Al analizar los resultados obtenidos, correspondientes a las composiciones, determinadas mediante análisis como base de experimentación, proyectamos estudiar en el laboratorio los sistemas hidrotermales pertinentes, determinando la solubilidad de varios metales en las soluciones a fin de lograr aproximarnos cada vez más a la verdadera composición original de estos líquidos.

Aunque con los datos logrados no llegáramos a obtener las determinaciones exactas correspondientes a las composiciones originales, se obtendría por medio de ellos, sin embargo, a manera de poder calcular los límites de porcentaje entre los cuales deben haberse encontrado las composiciones originales. En este sentido nos referimos no solamente a las concentraciones de los aniones y cationes, sino también a las concentraciones de ión-hidrógeno (pH) y electrones (Eh). Además puede calcularse la temperatura (ver abajo, TERMOMETRÍA GEOLÓGICA) y conociendo ésta, es posible calcular también la presión.

Es probable que a través de estudios minuciosos sobre las estructuras cristalinas de los minerales de la mena podamos también obtener datos útiles acerca de las condiciones existentes en los yacimientos minerales durante su proceso de formación.

SÍNTESIS HIDROTERMAL DE LOS MINERALES

Los estudios mencionados, referentes a los sistemas hidrotermales, en los cuales se utilizan determinadas composiciones de soluciones naturales, formarán una parte importante de este proyecto de síntesis. Además de estudiar algunos sistemas completos, es necesario, sin embargo, estudiar también partes de otros sistemas.

Si pudiéramos estudiar de manera completa todos los sistemas pertinentes, tendríamos un conocimiento suficiente y de mucho valor sobre los minerales de los yacimientos metalíferos. Sin embargo, el estudio completo de un sistema hidrotermal entraña un proceso sumamente largo que demanda gran esfuerzo. Por eso, resulta más económico efectuar la síntesis de algunos minerales bajo diferentes condiciones de temperatura, presión y composición (incluyendo pH) a fin de calcular sus límites de estabilidad, sin que haya necesidad de estudiar el sistema completo.

TERMOMETRÍA GEOLÓGICA

El conocimiento de las temperaturas de formación de los minerales, los yacimientos metalíferos y las rocas, puede ayudarnos no solamente a solucionar problemas abstractos de geología teórica, sino también de geología económica, que tienen un significado muy práctico. Por ejemplo, en el caso de las rocas sedimentarias la temperatura de formación puede conducirnos a distinguir con precisión entre los yacimientos singenéticos y aquellos de origen hidrotermal. El conocimiento del origen de tales depósitos puede ayudarnos grandemente en la búsqueda, en otros lugares, de yacimientos minerales del mismo tipo. En un yacimiento de origen hidrotermal la secuencia de las temperaturas de formación proporciona datos respecto a la dirección del movimiento que han tomado las soluciones de las cuales se formaron los minerales existentes en las vetas conocidas. Tomando este conocimiento como base, se hace entonces posible la localización de las prolongaciones de un yacimiento dado.

Si se acepta la importancia de la temperatura en la formación de los minerales, etc., es también importante determinar la intensidad correspondiente a dicha temperatura en la formación de minerales en la Naturaleza.

Se han propuesto muchos métodos para ese objeto y la mayoría de ellos han sido puestos en práctica (Ingerson, 1955), pero de todos el U. S. Geological Survey actualmente utiliza únicamente tres:

(a) — El método basado en la investigación de inclusiones líquidas;
(b) — El método basado en el estudio de las composiciones correspondientes a los cristales de mezclas de formación equilibrada, y
(c) — El método basado en el estudio de las relaciones y razones isotópicas.

Para poder utilizar las inclusiones líquidas en la termometría geológica es preciso partir de varias suposiciones, suposiciones que parecen justificadas en la mayoría de los casos (Ingerson, 1947, 1955). Los resultados de este método pueden considerarse casi exactos, ya que el margen de error es tan sólo de unos cuantos grados centígrados, siempre y cuando sea posible calcular la presión durante la cristalización del mineral.

Las relaciones entre las temperaturas de formación de cristales producidos por mezclas, y sus composiciones dentro de varios sistemas (Ingerson, 1955) ya han sido estudiadas. Es natural que para determinar las temperaturas haya necesidad de utilizar un mayor número de minerales y por lo tanto, considerar un mayor número de sistemas.

Actualmente el U.S. Geological Survey ha puesto en práctica los siguientes métodos: (1) feldespatos, (2) óxidos de hierro y de titanio, (3) sulfuros de zinc y de hierro y (4) carbonatos de calcio o de magnesio.

Hasta la fecha las relaciones y razones isotópicas han sido utilizadas solamente para determinar temperaturas compartivamente bajas. Además, para obtener estas determinaciones se han estudiado nada más los isótopos relativamente livianos. En la actualidad el U.S. Geological Survey está aprovechando, con este objeto, los isótopos del hidrógeno (H^1/H^2), del boro (B^{10}/B^{11}), del carbono (C^{12}/C^{13}) y del oxígeno. Nuestra intención para el futuro es de experimentar con los isótopos del azufre (S^{32}/S^{34}), del calcio (Ca^{42}/Ca^{48}) y, posiblemente, con los del cloro (Cl^{35}/Cl^{37}).

ELEMENTOS SECUNDARIOS EN LOS MINERALES METÁLICOS

Este proyecto tiene un doble propósito:

1) Encontrar yacimientos nuevos de metales raros, cuyas trazas aparecen en los minerales metálicos que actualmente se explotan para extraer del metal principal que contiene cada uno de esos minerales;
2) Tomar el contenido de elementos secundarios como índice para la interpretación de las condiciones de formación de los minerales que los contienen.

Se ha logrado establecer que el indio y el galio se encuentran en la esfalerita. También se sabe que la fuente principal para la obtención del germanio y del cadmio es su extracción como subproducto derivado del beneficio del sulfuro de zinc. Además, una gran parte del oro que se obtiene hoy día, es extraído de sulfuros del tipo de la pirita y otros, donde se presenta como elemento secundario.

Probablemente haya otros minerales que contengan metales raros en cantidades suficientemente grandes y por lo tanto, susceptibles de ser utilizados económicamente, aunque sea en forma de subproductos, como fuentes de extracción de dichos metales. Por ejemplo, en la actualidad existe una gran demanda de ciertos elementos raros; dos de éstos, el niobio y el selenio, se encuentran en la forma indicada con anterioridad. Como parte de los aspectos que debe cubrir el proyecto en desarrollo, debe incluirse la búsqueda y análisis de tales substancias.

Sin embargo, los elementos secundarios en los minerales metálicos tienen un significado más general y quizás más importante, como índice de las condiciones bajo las cuales se forman dichos minerales metálicos. En especial, es posible determinar, de este modo, las temperaturas de formación. Necesitamos, sin embargo, como etapa previa, disponer de los resultados de experimentaciones sobre las composiciones apropiadas. Además, es necesario encontrar, en el mismo depósito, un mineral que también contenga el elemento secundario en equilibrio con el mineral que se está estudiando, a fin de que los datos correspondientes a las condiciones de formación tengan algún significado. Por ejemplo, en los estudios sobre la esfalerita (sistema ZnS-FeS) es preciso que haya pirrotita en el depósito, antes de que los análisis de la esfalerita puedan ser de valor en el cálculo de la temperatura de formación del yacimiento (Para otros ejemplos, ver arriba *Termometría Geológica* E. Ingerson, 1955).

REVISIÓN DE "THE DATA OF GEOCHEMISTRY", DE F. W. CLARKE

La última revisión de esta importantísima obra fue hecha en 1924. Desde entonces a la fecha se han publicado muchos datos nuevos, de tal modo que buena parte de los detalles de este volumen pueden considerarse ya anticuados.

Antes de emprender un vasto programa de investigaciones geoquímicas, será oportuno y de mucha utilidad tener al día un compendio de los datos químicos que se aplican a las ciencias terrestres.

En la nueva edición habrá catorce capítulos, escritos por unos treinta y cuatro autores; de ellos veintiuno trabajan en el U. S. Geological Survey; diez en distintas universidades de los Estados Unidos y los tres restantes son de otros países.

Se espera tener completos todos los manuscritos antes del término del presente año fiscal. Se pretende también, que la publicación de este volumen, en la serie denominada "Profesional Papers" del U. S. Geological Survey, se efectúe antes del primero de julio de 1959.

ESTUDIOS SOBRE ISÓTOPOS ESTABLES

El estudio de la distribución de los isótopos estables de los elementos en la Naturaleza constituye un nuevo y poderoso método que actualmente está siendo desarrollado para atacar problemas específicos de geología y geoquímica. Innumerables son las aplicaciones que pueden hacerse, pero muy pocas las que todavía han sido llevadas a cabo con respecto a problemas concernientes a los recursos minerales (Ingerson, 1953).

Antes de atacar tales problemas, se debe tener un mejor entendimiento de cómo se producen las variaciones de abundancia isotópica de los diversos elementos en la Naturaleza. Este conocimiento puede adquirirse mediante: (1) estudios teóricos; (2) determinaciones más detalladas y más extensas de las variaciones mismas y (3) investigaciones de laboratorio de procesos geoquímicos mediante el uso, como trazadores *(tracers)* de isótopos radioactivos o elementos enriquecidos en uno u otro isótopo estable.

Mientras más se sepa acerca de las condiciones de formación de los yacimientos minerales, más fácil será encontrar nuevos yacimientos del mismo tipo.

Los estudios isotópicos pueden aportar datos de mucha importancia acerca de la temperatura y presión que prevalecieron durante la cristalización de los minerales de la mena, acerca de la fuente de procedencia de los elementos, sobre la dirección del movimiento de las soluciones, etc. Este conocimiento puede utilizarse asimismo, en la búsqueda de otros yacimientos metalíferos.

Por ejemplo, los depósitos de plomo y zinc en el Valle del Mississippi se encuentran en calizas de edad paleozoica y hasta ahora, no se sabe, a ciencia cierta, cuál es la procedencia del plomo y zinc de dichos yacimientos, como tampoco de las soluciones que los depositaron en forma de galena y esfalerita, respectivamente. En consecuencia, no se sabe si sería más provechosa la exploración de las capas que están debajo de los yacimientos ya conocidos o bien si es mejor explorar, de preferencia, las capas que a uno y otro lado de los yacimientos metalíferos. En cambio, si se pudiera establecer, por medio de razones isotópicas, que las soluciones fueron hidrotermales, es decir, que los minerales se formaron a temperaturas mayores de cien grados centígrados y si se supera también, por el mismo método, que las soluciones ascendieron más o menos verticalmente, entonces se confirmarían las buenas posibilidades de que se encuentren nuevos yacimientos plumbo-zincíferos a profundidades mayores, en capas más antiguas.

Si por el contrario, se llegara a determinar que la temperatura de las soluciones originales se aproximaba a la temperatura ambiente actual y que dichas soluciones fluyeron lateralmente, entonces se estaría en condiciones de buscar nuevos yacimientos en capas de la misma edad, no muy lejos de la superficie.

Pasando a otro ejemplo, en algunas de las cuencas del suroeste de los Estados Unidos y en los salares de los Andes cuyo origen es incierto, existen yacimientos de boratos. La composición isotópica del agua de hidratación de estos boratos depende de la composición isotópica del agua en las soluciones que dieron origen a la cristalización.

Por haber estado expuestas a largos períodos de evaporación, las aguas de las cuencas áridas contienen una proporción más alta de isótopos pesados que las aguas subterráneas que corren a lo largo de los flancos de las cuencas. Por lo tanto, los boratos, que son productos exclusivamente derivados de los procesos de evaporación, contendrán agua de cristalización más pesada que la que contienen los mismos boratos formados por agua subterránea en los flancos de las cuencas. Si se pudiera hacer esta distinción, se sabría con certidumbre si la búsqueda de tales boratos debe efectuarse en los fondos de las cuencas o en sus flancos.

Se piensa utilizar, en un futuro inmediato, las razones de los siguientes pares de isótopos para hacer interpretaciones de los tipos expuestos más arriba: H/D, B^{10}/B^{11}, C^{12}/C^{13}, O^{16}/O^{18}, S^{32}/S^{34} y Cu^{63}/Cu^{65}.

DETERMINACIÓN DE LAS EDADES GEOLÓGICAS

La relación entre la edad de un yacimiento y la de las rocas que lo contienen puede ser importantísima en la exploración. Supongamos, por ejemplo, que existe un yacimiento de uraninita en una formación arenosa, cuya edad geológica ha sido determinada. Conociendo la edad geológica sabemos, automáticamente, dentro de ciertos límites, la edad cronológica de estas formaciones. Si la uraninita tiene una edad cronológica significativamente mayor que las rocas que la circundan, aquélla es de origen detrítico, o sea, residuo de rocas más antiguas. Por lo tanto, para encontrar nuevos yacimientos semejantes, se debe buscar, en capas de la misma edad, playas antiguas de mar, mantos de acumulaciones fragmentarias y arenosas y barras u otros lugares donde pudieran haberse concentrado minerales pesados en los sedimentos originales.

Si la uraninita y las rocas sedimentarias tienen la misma edad, es probable que la uraninita haya sido formada por agua de percolación. En este caso, para localizar otros yacimientos, se debe averiguar dónde están las estructuras que señalen la localización de los canales o cursos de agua en los sedimentos, tales como lechos de río, lentes de arena debajo de esquistos arcillosos, estratificación entrecruzada, etc. En este caso, es probable que también se encuentren otros yacimientos en rocas de la misma edad.

Pero, si la uraninita se ha formado en las rocas después de su diagénesis, cuando éstas ya estaban cubiertas por capas más recientes, entonces se encontrarán indicaciones de cómo se originó dicho mineral, no solamente por lo que respecta a la temperatura de cristalización de los minerales de valor económico sino también en lo tocante a la menor edad del yacimiento en relación a la edad de las rocas encajonantes.

En este caso es muy probable que haya otros yacimientos, o bien prolongaciones de los que se encuentran cerca de la superficie, a profundidades mayores y en rocas de diversa edad. Los yacimientos de uranio en el Colorado Plateau ilustran lo expuesto más arriba, con la excepción de que en éstos últimos la uraninita se encuentra en muy pequeñas cantidades debido a que dicho mineral se ha ido oxidando gradualmente. En la actualidad los minerales de valor económico son carnotita, uranofana, torbernita, autinita, etc. Sin embargo, bajo su zona de oxidación los yacimientos contienen minerales primarios tales como uraninita, cofinita, óxidos de vanadio, etc.

Los métodos que están utilizándose en la determinación de las edades geológicas empleando ejemplos de aplicaciones reales o sugeridas, o que se van a utilizar dentro de poco tiempo, son los siguientes:

1) Isótopos del plomo, del uranio y del torio (Kulp, Bate y Broecker, 1954): ver arriba el ejemplo ya mencionado, referente a las edades de los yacimientos radioactivos y sus rocas encajonantes.

2) El método del zircón, o método de Larsen (Larsen, Keevil y Harrison, 1952), puede ser usado casi con cualquiera roca ígnea que contenga zircón primario. Este método no proporciona resultados exactos, debido a que no incluye mediciones para la determinación de los isótopos del plomo, pero sí da correctamente, en la mayoría de los casos, las edades relativas. Este método es muy útil, ya que con él pueden alcanzarse los resultados deseados mucho más rápidamente que con los métodos que requieren mediciones isotópicas.

3) y 4) Los métodos con potasio-argón (Wasserburg, 1954) y con rubidio-estroncio (Ahrens, 1954) son relativamente nuevos. Ambos presentan dificultades analíticas, pero ofrecen muchas posibilidades para el futuro. Toda roca que contenga potasio contiene rubidio, ya que ambos se encuentran asociados; el potasio se aprecia en muchos tipos de rocas y minerales. Estos métodos pueden ser usados para determinar la edad de las rocas sedimentarias que contienen minerales potásicos (arcilla, por ejemplo) que se cristalizaron, sobre todo, en la época en que se produjo la formación de las rocas. Estos métodos pueden usarse también para fijar la edad de las rocas ígneas y metamórficas que contienen feldespatos y micas potásicas. Los métodos indicados son todavía de mayor utilidad en el estudio de rocas muy antiguas, ya que los dos elementos radioactivos mencionados anteriormente tienen largos períodos de vida media ($T_{Rb} = 6.0 \times 10^{10}$ años; $T_K = 1.3 \times 10^9$ años).

5) y 6) El C^{14}, o sea el radio-carbono (Libby, 1955a) y el tritio (Libby, 1955b), se producen en la atmósfera por acción de los rayos cósmicos sobre el N^{14}. Ambos tienen una vida tan corta ($T_C14 = 5{,}800$ años; $T_H3 = 12.5$ años) que impide su uso en problemas concernientes a la localización del mineral económicamente valioso. Son útiles, sin embargo, en la solución de otros tipos de problemas geológicos.

El uso principal del carbono 14 en geología es el de averiguar cuál ha sido la secuencia en los avances y retrocesos de los hielos durante el último período glacial y los cambios habidos, en los depósitos glaciales después del último retroceso de los hielos. Sin embargo, es posible que este método sea también útil en el estudio de las aguas subterráneas. Si dichas aguas fluyen por estratos acuíferos a una velocidad suficientemente lenta, el método del radiocarbono puede ser, tal vez, de gran utilidad en los problemas relativos a la determinación de la edad del agua subterránea y para indicar la velocidad y dirección que sigue en su movimiento.

Se ha sugerido que posiblemente el tritio pueda ser utilizado del mismo modo, para estudiar problemas del agua subterránea. Estas aplicaciones del C^{14} y H^3 no han sido puestas en práctica hasta la fecha.

Mediante el empleo de todos los métodos indicados trataremos de precisar, con mayor exactitud, la escala de las edades geológicas. Se sabe que las rocas del Cámbrico Inferior tienen una edad de aproximadamente quinientos millones de años y que la Era Paleozoica terminó hace más o menos doscientos millones de años. Se debe tener muy en cuenta que existen muchos problemas geológicos para cuya solución necesitamos una escala de edades más precisa que la que actualmente se usa.

Solamente en casos excepcionales se puede fijar con precisión la edad estratigráfica de las rocas ígneas. Estas rocas en general contienen minerales primarios del uranio y del torio y son del tipo de las pegmatitas, diques, lacolitos y otras formas de intrusiones. Hasta la fecha los métodos del plomo-uranio y del plomo-torio son los que se han usado casi exclusivamente en la determinación de sus edades geológicas, pero considerando que las edades estratigráficas de esta rocas no se conocen con exactitud, las edades cronológicas son, por lo tanto, inciertas.

Si se pudieran utilizar los métodos del potasio-argón y del rubidio-estroncio para determinar de manera directa las edades de las rocas sedimentarias, así como de las de rocas ígneas y metamórficas que no contengan minerales uraníferos, entonces sería posible precisar de manera más exacta la escala de las edades geológicas, especialmente en lo que se refiere a los Períodos Precámbrico y Paleozoico.

ESTUDIOS DE LATERITIZACIÓN

Las lateritas se explotan primordialmente para extraer hierro y aluminio, pero en este tipo de yacimientos se sabe que se encuentran concentrados varios otros elementos, tales como níquel, niobio, galio, vanadio y manganeso. En el estudio de los procesos de lateritización se piensa determinar cuáles son los otros elementos que se encuentran concentrados en las lateritas y que probablemente se pueden extraer en forma de subproductos.

No hay duda que las lateritas cubren a otros tipos de yacimientos, especialmente en los trópicos, donde sus extensiones son más grandes que en otras áreas. Por lo tanto, otro factor importante en las lateritas consiste en que por medio de ellas y a través de métodos geoquímicos y geofísicos, será posible localizar los yacimientos que se encuentren abajo de sus capas.

Durante el año fiscal en curso se ha iniciado el estudio de los procesos de lateritización en Hawaii, donde esencialmente existe un solo tipo de roca: basalto, que está descomponiéndose y transformándose gracias a los efectos producidos por diversas condiciones climáticas. La simplificación del problema, como se presenta en Hawaii, hará posible entender más fácilmente los principios que rigen a los procesos de lateritización.

Estos estudios se extenderán inmediatamente después a áreas más complejas, donde haya varios tipos de rocas y donde las lateritas sean más extensas y más potentes, es decir, donde se encuentren mayormente desarrolladas, tales como las que se localizan en la región occidental de Puerto Rico, o en las regiones donde se ubican las lateritas niquelíferas de Cuba y Oregón, o a las lateritas que originaron los yacimientos de bauxita de la parte sureste de los Estados Unidos, etc.

Para entender mejor los cambios mineralógicos de la lateritización se está estudiando en el laboratorio las condiciones de estabilidad de los minerales en las rocas originales (especialmente los feldespatos), las de los productos intermedios (tales como la sericita) y las de los minerales de las lateritas mismas (arcillas, óxidos e hidróxidos).

SERVICIOS ANALÍTICOS

Para el desarrollo adecuado de un programa de geoquímica y exploración en busca de yacimientos minerales, es necesario disponer de los medios adecuados a fin de poder hacer toda clase de análisis. Estos análisis deben llevarse a cabo no sólo en lo que toca a los proyectos anteriormente mencionados, sino también a todos los demás proyectos de la División Geológica.

A fin de efectuar tales análisis con el objeto de desarrollar adecuadamente el programa propio del U. S. Geological Survey y en beneficio de los estudios en cooperación con la Comisión de Energía Atómica, así como en apoyo del trabajo correspondiente a la nueva política minera, se tiene en Washington, D. C., en Beltsville, Maryland, en Denver, Colorado, y Claremont y Menlo Park, California, las siguientes clases de laboratorios, con aproximadamente las capacidades anuales expresadas a continuación.

Tipos de laboratorio	*No.*	*Personas*	*Muestras*	*Determinaciones*
Químicos	10	78	10,000	28,000
Espectográficos	3	16	8,000	40,000
Radiométricos	2	10	10,000	12,000
Fluorescencia de rayos-x	2	3	5,000	5,000
Rayos-x	6	12	3,000	7,000
Láminas delgadas y superficies pulidas	(4)a	(10)a	(18,000)a	——
Mineralogía	8	36	1,500	4,000
Petrología	7	25	500	2,000
De isótopos (incluyendo edades geológicas)	6	18	1,000	1,000
Termometría geológica	1	2	1,000	1,000
TOTALES	45	200	40,000	100,000

(a) No está apreciado en totales, puesto que en estas muestras no se han hecho determinaciones.

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Congreso
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SYMPOSIUM DE EXPLORACION GEOQUIMICA — Tomo III

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