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# EXPLORE

Newsletter for the Association of Exploration Geochemists

THE ASSOCIATION OF EXPLORATION GEOCHEMISTS 1970 1995 EXPLORATION ENVIRONMENT

NUMBER 97 OCTOBER 1997


## PRESIDENT'S MESSAGE

*David Garnett*

Scientists are both producers and consumers of information. Free interchange of ideas, discoveries and methods is essential if a science is to grow and evolve, and if its participants are to benefit from the efforts and insights of others. One of the roles of the Association of Exploration Geochemists (AEG) is to encourage dissemination of information relevant to exploration geochemistry and The Journal of Geochemical Exploration (JGE) has been one of the most important outlets for that knowledge. It is sponsored by the AEG and represents a long and productive partnership between the JGE's publisher, Elsevier, and ourselves stretching back more than twenty five years.

During that time an impressive body of knowledge on exploration geochemistry has been documented under the watchful eye of the JGE's Editor-in-Chief, Eion Cameron. Such a relationship is not broken lightly, but recent actions by Elsevier have called into question the desirability of renewing our contract with them. Problems have ranged from petty to serious, with more than a touch of farce at times, but their cumulative effect has been to project a strange image of an organization which has somehow managed to become both increasingly amateurish and arrogant at the same time.

The single most important factor which has soured our relationship has been the arbitrary and massive increase in the institutional rates charged for the JGE by Elsevier (see Eion Cameron's editorial on this in Explore No 94, p5). Institutional rates are the rates charged to libraries and other large organizations and they have been increased by 52% in US dollar terms between 1995 and 1997, to stand at their present level of $US 1139.00. Compare this with the institutional rate of $US 1295.00 for another Elsevier earth science journal, *Geochimica et Cosmochimica Acta*, which has over six times the number of pages per annum.

Compare it also with other high quality journals which are not published by Elsevier. For example, The *Canadian Mineralogist* has an annual institutional rate of $US 310.00 while *Economic Geology* costs all of $US 138.00, and this despite the fact that both publish approximately fifty per cent more pages than the JGE. Clearly it is possible to publish a journal at institutional rates which are significantly lower than those charged currently for the JGE. To be fair to Elsevier they have agreed that the increase in the JGE price was exorbitant and they will be making some small reductions in the institutional rate over the next two years, but is this too little, too late? While journal prices have been increasing well ahead of the rate of inflation, libraries' budgets have not. They have therefore had to reduce the range of journals which they can offer to their readers, and once a journal is dropped it is unlikely that it will be reinstated. Now that it has exceeded the psychological barrier of $US 1000.00 the JGE has become particularly vulnerable to elimination by librarians, desperate to stretch their funds as far as possible. So what do we do?

Our current five year contract continues until the end of December 1999. We are obliged to commence negotiations with Elsevier over the terms of a new agreement by mid 1998, with a final decision being made by the end of that year. We shall proceed with this in good faith but it would be remiss of us if we were to pin all our hopes on a satisfactory outcome to these negotiations. Elsevier exists to make a profit for its shareholders; the AEG exists to promote the science of exploration geochemistry. Those aims may have become irreconcilable. Consequently we feel that it is important to investigate alternative publishers, and we shall be doing this in parallel with our discussions with Elsevier during the course of 1998. Elsevier publishes some 1200 journals, including 21 in the earth sciences.

Having recently announced their merger with Wolters Kluwer — a rival publisher — they will become still larger with sales of $US 8 billion, making them the world's largest publisher in the scientific and professional fields. Is big beautiful? Not necessarily, but Elsevier can claim with justification that they do offer some very real benefits to authors. Their bi-monthly newspaper is distributed free of charge to thousands of research scientists active in the field of geochemistry and geophysics. This includes abstracts and contents of recent or forthcoming issues from the JGE, thus ensuring worldwide exposure for authors. In addition the journal is distributed and marketed internationally, and is

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**Scope** This Newsletter endeavors to become a forum for recent advances in exploration geochemistry and a key informational source. In addition to contributions on exploration geochemistry, we encourage material on multidisciplinary applications, environmental geochemistry, and analytical technology. Of par-ticular interest are extended abstracts on new concepts for guides to ore, model improvements, exploration tools, unconventional case histories, and descriptions of recently discovered or developed deposits.
**Format** Manuscripts should be double-spaced and include camera-ready illustrations where possible. Meeting reports may have photographs, for example. Text is preferred on paper and 5- or 3-inch IBM-compatible computer diskettes with ASCII (DOS) format that can go directly to typesetting. Please use the metric system in technical material.
**Length** Extended abstracts may be up to approximately 1000 words or two newsletter pages including figures and tables.
**Quality** Submittals are copy-edited as necessary without re-examination by authors, who are asked to assure smooth writing style and accuracy of statement by thorough peer review. Contributions may be edited for clarity or space.
All contributions should be submitted to:
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**EXPLORE** is the most widely read newsletter in the world pertaining to exploration geochemistry. Geochemical laboratories, drilling, survey and sample collection, specialty geochemical services, consultants, environmental, field supply, and computer and geoscience data services are just a few of the areas available for advertisers. International as well as North American vendors will find markets through **EXPLORE**.
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## NOTES FROM THE EDITORS

*Sherman Marsh and Tom Nash*

Two recent symposia, the 18th IGES in Jerusalem, and the 4th ISEG in Vail, have brought AEG members together to share science and deepen friendships. The spirit and dimensions of the meetings is described well in the note by David Garnett. We also are committed to formal and informal publication of our science and professional views. The formal publication, *Journal of Geochemical Exploration* (JGE), has encountered difficulties under the current publisher. The AEG Council has discussed with concern the reduced number of manuscripts submitted to JGE, and the loss of institutional subscribers. President Garnett reviews this situation and calls for your input to the publication process and possible courses of action in the next year or two.

**EXPLORE** exists to facilitate informal communication of technical and professional information, and once again we solicit your input. Looking back a few years, it becomes obvious that only a small number of our members make the effort to communicate. Don't be bashful! We'll gladly work with you on almost anything that might be of interest to our readers. One area that is ripe for coverage is personal experiences, anecdotes, or histories—share these with newcomers before they are lost. Case histories, failed or successful, on methods, environments, and deposit types, are worth sharing and placing into the written record.

## President's Message

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covered by a range of indexing and abstracting services. Discounts of 30% are available on all books published by the Elsevier Science Group of companies. Finally, they are investing heavily in electronic publishing and can be expected to offer some increasingly sophisticated options in this field in the next few years.

Why, then, should we consider breaking with Elsevier? Many of the day-to-day problems could be eliminated with tighter management control and increased professionalism, but while they remain these problems continue as a constant source of irritation, particularly to Eion Cameron and Betty Arseneault, our Business Manager. However, there are two main issues which are more fundamental and potentially more intractable: who owns the science that is published in a journal and how much should we expect our fellow scientists to pay to learn what we have published? Is it not absurd that the scientists who carry out the research and write the papers should hand over copyright of these papers to Elsevier?

Is it not equally absurd that Elsevier should then be allowed to hold these papers hostage until such time as libraries pay a large ransom for release of this science to fellow scientists? This may sound melodramatic, but is it so far from the truth? We need to disseminate knowledge of exploration geochemistry as widely as possible and if Elsevier is not prepared to play their part in this then we have no choice but to look elsewhere.

Termination of our links with Elsevier would result in some profound changes and would create some very real challenges. Elsevier owns the copyright to the JGE name and can be expected to attempt to continue to publish the journal under that name. We would need to start a new journal, with a new title and would need to persuade libraries that it was of sufficient stature to be worth carrying. Our aim would be to retain ownership of the title of the new journal and to hold the copyright of papers published in it. This is a daunting proposition, and is a decision which we would not take lightly. It is also a decision which we would not want to take alone.

This is one of the most important issues that has faced the AEG in recent times and I ask for comment from as many of you as possible. When we make the final decision it is absolutely essential that we have the support of the great majority of members, and the more input we have from you the more chance we have of making the best choice. In order to bring the issue into focus, let me conclude with a series of questions: Do you agree that the present institutional price for the JGE is too high? Do you agree that we are justified in exploring the possibilities of breaking with Elsevier, in favour of an alternative publisher. If we did break with Elsevier, do you have any suggestions for the title of the new journal?

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TECHNICAL NOTE

# Scale effects in geochemical haloes of hydrothermal mineral deposits.

*Sergey A.Sandomirsky and Mir D. Karger*

Anisotropy, zoning, and periodicity are critical components for understanding the relations of geochemical haloes of hydrothermal mineral deposits. These features create opportunities for solving many problems in applied geochemistry (such as, evaluation of truncation levels of orebodies, and correlation of ore intervals in mines and drill holes). The common situation, however, is that some geochemical regularities established in one cross-section of a mineral deposit may be inapplicable in adjacent cross-sections. We believe, nonetheless, that the principle reason of such variability of geochemical haloes, as well as ore grade distribution, is quite simple. The fact is that the pattern of exploration drill sites or sampling sites does not match the variation in the geochemical haloes. The precision and robustness of solutions of exploration tasks could be enhanced significantly if network geometry could be adapted to the patterns of geochemical haloes.

To investigate the relationships between parameters of both networks and spatial variations of geochemical observations and of geochemical haloes, two mineral deposits were selected: the Pereval'noye tin deposit (Komsomol'sk region, Russia) and the Novokonstantinovskoye uranium deposit (Ukraine).

The variation of geochemical haloes in a given direction is conveniently measured by the function , called "semivariogram" (Matheron, 1963) — we shall refer to it below simply as a variogram —, or by the autocorrelation function $R$ (). These functions are connected by the simple expression:

$$= R(0) - R().$$

The empirical value of is equal to half the mean-squared difference between concentrations or functions of the concentrations in samples spaced a distance apart. Averaging is performed over all pairs of such samples in the given sampling interval (Matheron, 1963). A variogram is convenient for two reasons. First, it can be used to analyze the correlation patterns of the geochemical haloes in terms of variances that are familiar to geologists. Second, variogram interpretation techniques take into account its "geometric base", that is shapes and orientations of the samples used in description of a geochemical halo.

### Scale effects in a tin deposit

The Pereval'noye deposit is confined to Jurassic and Cretaceous volcanic, volcanosedimentary and clastic rocks (Sandomirsky and Karger, 1988; Barsukov and others, 1976; Bakulin, 1970). Tin ores consist of quartz-cassiterite veins, containing substantial amount of sulfide minerals — arsenopyrite, galena, and chalcopyrite. They formed at tempera-

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tures of 200 - 300 °C. The morphology of the orebodies is rather simple and has been investigated fairly thoroughly. They are mainly steeply dipping vein-like bodies emplaced in fractures and fragmentation zones and, less commonly, metasomatic bodies in propylites and tourmalinites, also of vein-like shapes. The geochemical haloes of such deposits

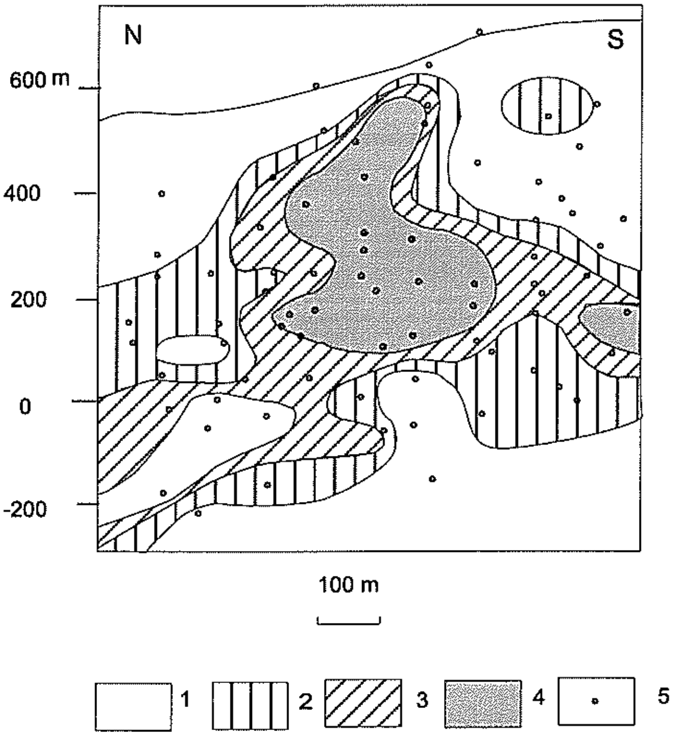


*Figure 1. Distribution of (A) weighted average tin concentration in the vertical longitudinal projection of the North zone of Pereval'noye tin deposit. (1) less than X - 0.5s (where X is the average concentration and s is the standard deviation); (2) from X - 0.5s to X; (3) from X to X + 0.5s; (4) more than X + 0.5s; (5) drill hole.*

are strongly anisotropic. They are much more variable over a given distance in the transverse direction (that is, across the strike) than in the longitudinal direction (along the strike and dip) (Fig. 1). The results of D.C. arc emission spectrometric analysis of continuous core and trench-type samples were used as input data. We will show the influence of the sampling network on the pattern of anisotropy.

The anisotropy of the geochemical haloes was analyzed by comparing the variograms for tin and lead in the transverse and longitudinal directions of the ore zone. The transverse variograms were computed from logarithms of concentrations of these elements, obtained by continuous core and trench samples. The longitudinal variograms were calculated from logarithms of the weighted-average concentrations in cross sections bounded by minimum anomalous concentrations (5% significance level of background distribution). Henceforth, for simplicity, we shall denote the variograms and their parameters across strike, along dip, and along strike by subscripts t, d and s, respectively.

All variograms have similar configurations (Figs. 2, 3): as increases in the interval from 0 to $a$, increases, reaching some threshold value $C$ at » $a$. The parameter $a$ — the radius

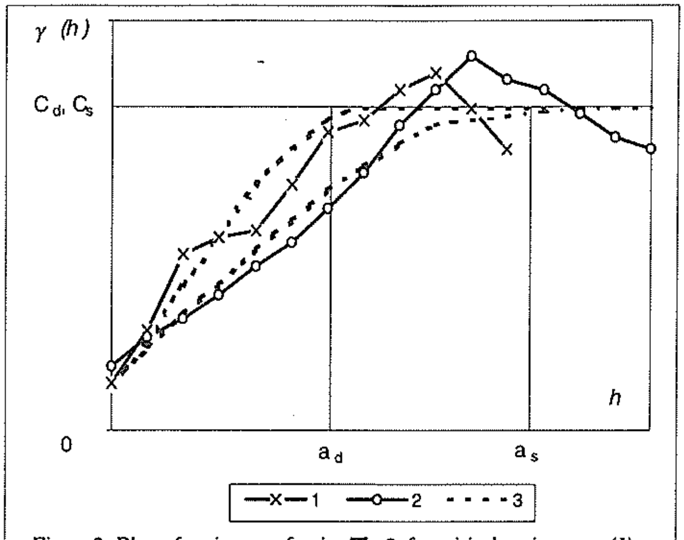


*Figure 2. Plots of variograms for tin. Plots of empirical variograms: (1), (2); (3) plots of corresponding theoretical variograms. C ,a - threshold and radius of influence for variogram along dip of orebody; C, a - threshold and radius of influence for variogram along strike of orebody.*

of influence of the sample — defines the minimum distance at which the samples may be assumed to be uncorrelated, and the parameter $C$, the threshold, is equal to the total variance over the entire sampling interval. In transverse variograms and > $a$, fluctuates around this threshold. The fluctuations are commonly quasiperiodic, which is interpreted typically as an expression of the periodicity of a geochemical halo (Matheron, 1963). Given this and physical meaning of the parameters $a$ and $C$, we conclude that the geochemical haloes exhibit a multilevel quasiperiodic hierarchical structure in three-dimensional space. If this is so, then the values of at significant minima of repre
sent the dimensions of the elements or components of which the geochemical halo is made up. At any corresponding hierarchical level, these elements may be assumed to be

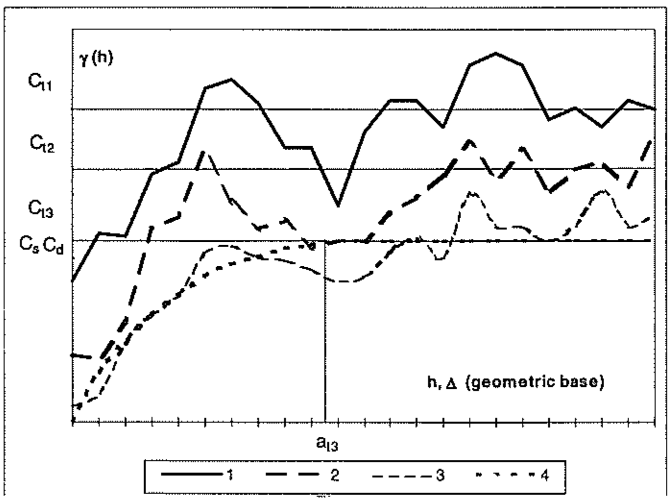


*Figure 3. Scaling procedure for matching between transverse () and longitudinal (,) variograms for tin. (1) Initial variogram for tin calculated on geometrical base D (C > C , C ); (2) Variogram calculated on geometrical base 2D (C > C , C ); (3) Variogram calculated on geometrical base 4D, satisfying condition C » C , C ; 4D is the geometrical base to be sought, a is the radius of influence to be sought. The geometric base scale is 1 meter.*

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quasihomogeneous. Note also that the dimensions of neighboring elements identified in the variograms differ by a factor of about 2.

Analysis of the geologic environment of our ore zone indicates that this configuration of the geochemical halo results from a more or less regular repetition of mineralized structures of various order (fine ore stringers are grouped into distinct, separate sequences of stringers, which, in turn, are grouped into vein-like zones, which are also grouped *en echelon*, and so on). A multilevel hierarchic structure of ore haloes, in particular of hydrothermal geochemical haloes, has also been noted in various other deposits (David, 1977; Kantsel' and Chervonenkis, 1983; Myagkov, 1984).

The variograms plotted in different directions differ in their radii of influence, which fits the anisotropy hypothesis, but do not differ in the values of the thresholds — the relationship C » C < C commonly holds for different parts of our zone. This relationship means that the variograms and, derived on identical geometric bases, express a longitudinal variability of the same scale. But in the transverse variability, expressed by the variograms , high-order variation of the geochemical halo that was not smoothed by the trench-sampling technique makes a large contribution to the overall variation. A comparison of the longitudinal and transverse variability is meaningful only after the scale of the latter is reduced to the "base scale" of

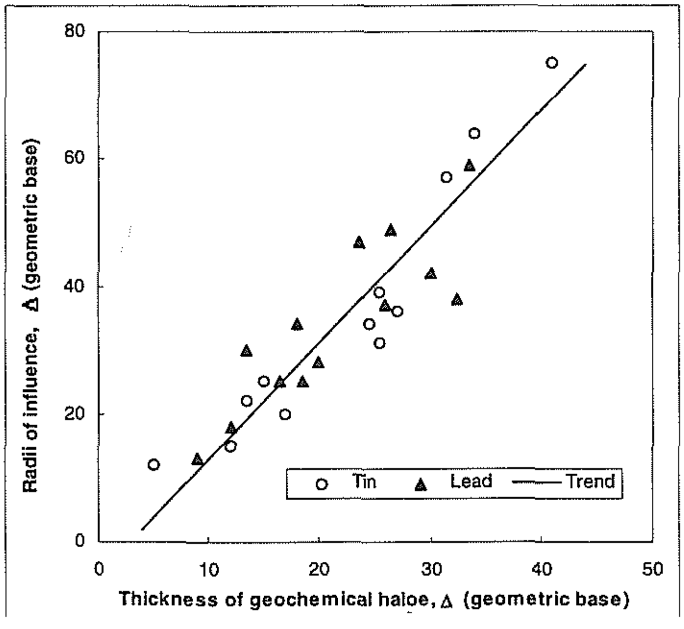


*Figure 4. Direct proportional relationship between radii of influence and thickness of the geochemical halo of tin (1) and lead (2). Radii and thicknesses are measured in units of initial geometric base D (equal to 1 meter).*

the longitudinal variability. To make this conversion it is best to use less detailed concentration profiles in the transverse sections, derived by grouping of samples into aggregates. One needs not increase the size of the grouping window, with a concurrent decrease in C (Fig. 3), beyond the point at which the condition C » C , C is satisfied. The size of the grouping window thus ascertained is equal to a geometric base of unknown transverse variability of the geochemical halo.

This matching of scales makes the corresponding radii of influence of all three measurements comparable over the full width of the ore zone. The most noteworthy feature is the direct proportionality between the radius of influence and the width or lateral scales of the geochemical halo bounded by the minimum anomalous concentrations in both the transverse and longitudinal directions (Fig. 4). Corresponding investigations for higher-order scales of variability produced similar results.

The results suggest the hypothesis that the variability of the geochemical halo at a given hierarchical level in our ore zone exhibits geometrical anisotropy, with a constant ratio between radii of influence in three mutually perpendicular directions (for our zone a : a : a » 1 : 28 : 45). The value of the radius of influence in a given direction at a given point is governed by the size of the geochemical halo in this direction. We name this manifestation as "morphological" anisotropy. These results also confirm our view of this deposit and its geochemical haloes as being made up of a set of quasihomogeneous veins or lenses of similar shape in an *en echelon* arrangement on each scale of variability. This representation enables us to construct a simple model of the hydrothermal deposit in which both correlation and variance pattern of the geochemical halo are defined by the morphology of the orebodies. This model can be used to forecast the longitudinal and transversal variability of geochemical and geometric characteristics of an ore zone on the basis of

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several isolated cross-sections.

We can assume that a similar model also describes

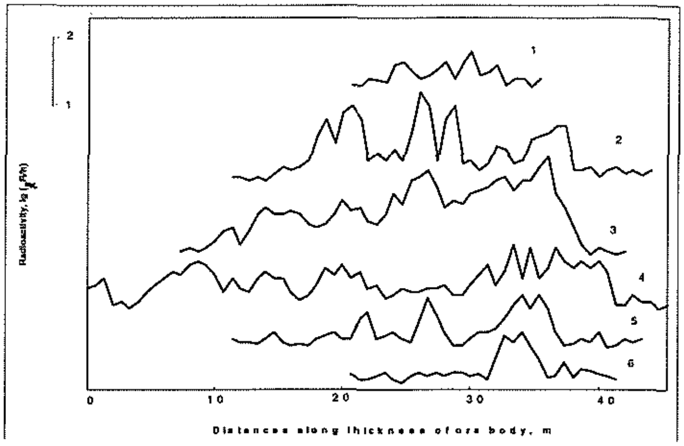


*Figure 5. Concentration profiles (logarithms of mR/h) through the orebody transverse to gamma-log section 1 (1-6 - ordinal numbers of sections downward along the dip of orebody). Vertical scale ruler refers to the concentration profile in cross-section 1. The other profiles are plotted on the same logarithmic scale.*

relations between thickness of orebodies and the correlation pattern of a geochemical halo in isolated cross-sections. But it is hard to prove this model on the basis of common core and trench-type samples in the case of small thicknesses of orebodies when thickness is comparable with the sizes of the

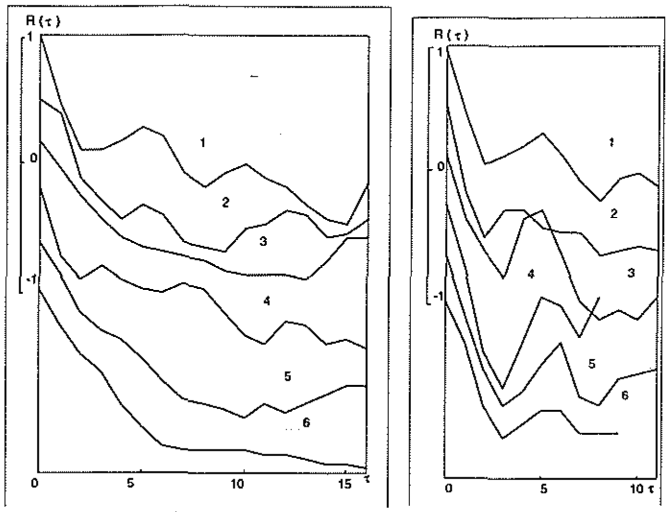


*Figure 6. Autocorrelation functions R(t) for ore intervals on sections 1-6 transverse to the gamma-log section 1: a) based on logarithms of values in original samples, b) based on logarithms of values in enlarged samples. The quantity t measured in units of length of the original (a) and the enlarged (b) samples. Vertical scale ruler refers to the autocorrelation function of cross-section 1. The other functions are plotted on the same scale, the first point at each plot has autocorrelation value equal 1.*

applicable sample. In this situation, it is impossible to estimate scale parameters of geochemical halo variability. To overcome this obstacle, well-logging data can be helpful. Using well-logging data, we can simulate any desired sample length, thus providing a representative number of samples for any ore cross-section.

### Scale effects in a metasomatic uranium deposit

The Novokonstantinovskoye uranium deposit, mentioned above, was selected for analysis of the local pattern of its geochemical haloes. In this deposit, gamma-ray well logging data are equivalent to geochemical sampling.

The deposit is situated in the footwall of a major fault in a deep-seated tectonic part of a Precambrian shield. The deposit is confined to an elongate gneissic block, which has undergone transverse flexure both in plan and in section and is hosted by sodic rocks metasomatized at moderate temperatures of 350-450 °C (Karger and Gurevich, 1990; Omel'yanenko, 1984).The orebodies that make up the deposit are located in albitite associated with numerous steeply dipping faults. At their deepest levels, the orebodies are large and lenticular, but up-dip they become flattened veins and seams.

Analysis of the local geochemical halo variability was performed on the basis of data from gamma-ray well logging along two vertical sections across the deposit. These data were then averaged so as to obtain a set of observations equivalent to continuous sampling of the core by samples of constant length. Therefore, for simplicity, we shall hereafter

* Intra-ore distance means the relative distance, measured with respect to the size of either the orebody or some element of its internal pattern. It could be the length or the thickness of an orebody. Using intra-ore distances it is convenient to compare identical parts of orebodies of different size. For example, if we use orebody length as a unit, and put the origin of coordinates in the center of orebody, then for any orebody, the intra-ore distance of its upper edge will equal to 0.5, independent of its absolute length.

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use the terms "samples" and "sampling".

The concentration profiles plotted (Fig. 5) and the autocorrelation functions calculated for them (Fig. 6 a) are typical for such data (David, 1977; Karger and Gurevich, 1990). They reflect the anisotropy of the transverse variability of the halo and its quasi-periodic nature. The curves in figure 4, while they differ in their fine details, are more similar with respect to most noticeable features —distances between points confining principal maxima or minima, for instance. As can be seen, the sizes of these features are consistent with the visible thickness of the orebody in the corresponding section (transverse sections are taken down-the-dip of the body). This example, as well as relationships established in the tin deposit, lead us to conclude that the sizes of similar-scale elements of inhomogeneity of the halo in any given transverse or longitude section are directly proportional to visible thickness or elongation of the orebody in that section. In other words, we deal here with morphological anisotropy, e.g., a tight relationship between the morphology of the orebodies and the measure of intra-ore distances* (Karger and Sandomirsky, 1986). This manifestation, however, usually cannot be observed in pure form. The reason for this is that investigation of geological objects — orebodies, particularly — by means of a network of discrete observations involves a censoring, namely selection of objects on the basis of their sizes (Karger and Sandomirsky, 1982). In this case, the censoring factor is the ratio of the parameters of observation network (sample size, sampling interval) and the size of the elements of inhomogeneity of the geochemical halo of a given scale, which varies from section to section.

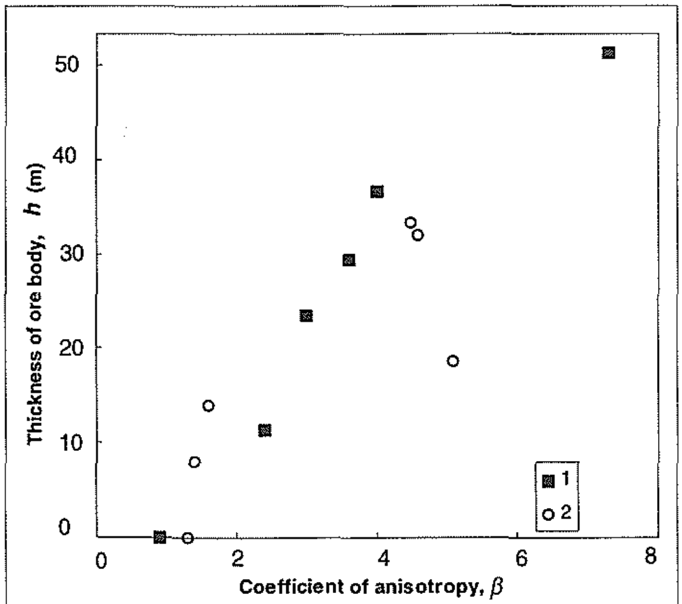


*Figure 7. Relationship between thickness of orebody h and coefficient of anisotropy b along sections of orebody transverse to gamma-log sections 1 and 2.*

Accordingly, the sensitivity of the sampling network also varies whenever the network is not tied to morphology of the orebody thus, we have the effect of non-uniform censoring of the geochemical halo, the net result of which is that observations in different sections may prove to have different orders of accuracy.

If this is so, and if we want to make assessments of orebody parameters with predictable error, we need to transform the raw observations or sampling sites to the same scale of geochemical variability of the halo or, in other words, we need to impart the same scale to all the observations in the set. For this purpose we have developed a scaling procedure.

In each profile we combine samples of original length $l$ into samples of length $L = lb, b\ ^3\ 1$, consequently making the concentration profile less detailed. We choose the value of $b$ so, to obtain maximum correlation of the resulting, less-detailed concentration profile with other new less-detailed concentration profiles.

The new concentration profiles obtained by this scaling proved to be very similar in different sections. Even more similar are plots of autocorrelation functions, calculated for these new profiles and depicted on Figure 6 b. What also happened was that approximately equal numbers of enlarged samples now filled all sections comprised within the visible

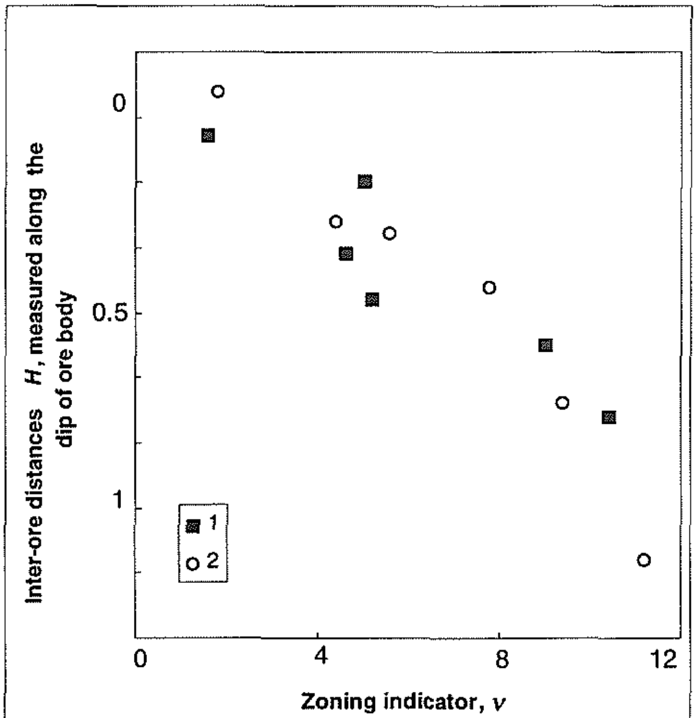


*Figure 8. Zoning indicators n versus intra-ore distances H to supraore sections, measured on gamma-log sections 1 and 2 along the uranium orebody.*

thickness $h$ of orebody — that is., the thickness outlined by the cut off grade. The values of $b$, which vary from 7.0 to 1.0, correlated closely with the thickness (Fig. 7). A value of $b$, equal 1.0 corresponds to the profile situated in the supraore (area above orebody, possibly in outcrop) sub-background halo. As the scaling was independent of , these results seem to confirm the hypothesis of morphologic anisotropy of the geochemical halo ($b$ is the coefficient of anisotropy) and the censoring scheme of its sampling. Consequently, we actually have obtained an equal-scale set of observations distinguished by the fact that each profile through the ore interval contains a constant number of enlarged samples; that is, each ore interval has constant "effective" thickness.

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### Scale effects in the vertical dimension

Let us now deal with the problem of vertical variability of the geochemical halo. The interesting results would be expected from its analysis in frequency domain. The matter of fact is that scaling procedures, we applied to derive the equal-scale representation of the geochemical halo, caused the most substantial correction just in the frequency pattern of the geochemical halo. Let us consider the behavior through the profile of the quantity

$$n = S_1(t)/S_2(t),$$

where $S_1(t)$ and $S_2(t)$ are average values of the spectrum $S(t)$ of orebody's thickness in the frequency ranges $t$ [2, $/aL$) and [$/aL$, $/bL$], with ($a > b > 1$). The $S(t)$ spectrum is calculated from the residuals of the logarithms of the raw unscaled values, taken within the boundaries of the ore interval, and remaining after subtraction of the trend. The trend was calculated on the basis of the coefficient $b$ and represents the average for the samples occurring in a window with width of $mL$, $m > 2$, centered on a given sample. Figure 8 gives the values of $n$ calculated for $m = 4$, $a = 6$, and $b = 2$. As can be seen, $n$ increases monotonously with depth. Similar results are also obtained with different values of $a$ and $b$ and with moderate variation of the assumed boundaries of the ore interval. Therefore, down the dip of the orebody, a monotonous redistribution of the variance of the geochemical halo occurs from high frequencies to the low ones.

In Figure 8, the intra-ore distances, mentioned above, are assumed as a measure of depth. If we use common vertical depth instead, then the uniform relationship of Figure 8 breaks down into separate relationships corresponding to individual cross-sections. Their angular coefficients are related positively to the vertical spread of mineralization over the corresponding section. Consequently, here we again run into morphological anisotropy, which can be eliminated by transforming common vertical depths into intra-ore distances.

Strange as it may seem, acquired results resemble the variability of sedimentary cross-sections without loss of intervals, for which advanced methods of cross-section correlation and matching are well developed. If this is really so, then the principles of algorithm of drill hole section's correlation are clear: they have to be the same as principles of correlation of sedimentary formations, as developed by Show (1964).

Thus, an important attribute of the geochemical haloes of a hydrothermal deposit is their morphological anisotropy, which occurs because of the tight relationship between the morphology of the orebody and the measure of intra-ore distances. In practice, this relationship usually is obscured by the effect of non-uniform censoring in sampling the halo, caused by the fact that deposits are sampled without taking into account the variability of the local pattern of the halo. But this effect can be eliminated by transforming the raw sample set into a set of observations on the same scale, matching to the scale of geochemical halo variability. Analysis of a geochemical halo, represented in equal-scale of its variability, reveals a monotonous variability of the frequency characteristics of concentration profiles in transverse sections of the halo down and up the dip of the orebodies. This fact can be used for quantitative prediction of the level of erosional or underground truncation of the orebodies, on the basis of some idealized reconstruction of the geochemistry of the identical orebody.

### Conclusions

The main result of our investigation is that using a model of morphological anisotropy of a geochemical halo, as well as ore-grade distribution, we can describe their spatial variability by a single structural function (variogram or autocorrelation function), depending on a parameter related to the scale effects of variation of a geochemical halo. A specific feature of this description is its equal accuracy over the entire volume of a geochemical halo. The scaling parameter can be easily derived from a relatively few cross-sections, sampled in detail.

We believe this approach to be more effective in comparison with common geostatistical procedures, requiring subdivision of ore-bearing space into uniform parts and using combined variogram models to achieve results of equal accuracy. We also recognize that the model of morphological anisotropy with scale effects better fits hydrothermal ore deposits formed by infiltration processes. Ore deposits of different genesis — contact metamorphic, for instance — could be described by a more complicated model.

The authors would like to acknowledge the advice and tremendous work performed by Ted Theodore, U S Geological Survey, converting our Russian English into something more close to American English, that we hope helps to make our ideas more understandable to American geologists. The authors sincerely thank Boris Kotlyar for helpful recommendations and encouragement.

*Continued on Page 22*

# PRE-CONFERENCE EXCURSION: THE COASTAL PLAIN & NORTHERN ISRAEL

*by Richard Mazzuchelli*

The Northern Israel Excursion was a fascinating mix of geology, geochemistry, archaeology, history, and scenery, laced with cultural and culinary insights and generally good times for the small band of participants. The major geological-geographical features of central and northern Israel: the Judean Mountains, the Judean Foothills or Shefela, the Coastal Plain, Mount Carmel, the Galilee, the northern sector of the Dead Sea Rift and the Golan Heights were amply demonstrated by our affable

*Dubi expounding at the Bet Hakerem valley*

geological guide, Dove "Dubi" Levitte of the Geological Survey of Israel, with other local guides. The geology of the Judean Mountains and Mt. Carmel is dominated by Cretaceous to Tertiary limestones, which have been quarried from antiquity for

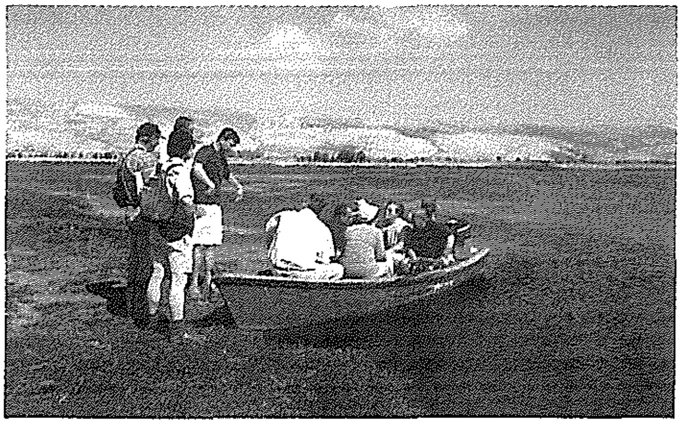
*Ancient quarry at Bet Oren*

building materials, olive presses, and other uses.

We gained a good appreciation for the importance of Israel's most crucial resources of water and agricultural land and the balance between the two, no better exemplified than by the Hula Valley Project. This part of the Jordan River Valley had been drained and the rich peaty soils cultivated during the 1950's, but this caused problems, such as the spontaneous combustion of peat and nutrient leakage into Lake Kinneret (Sea of Galilee),

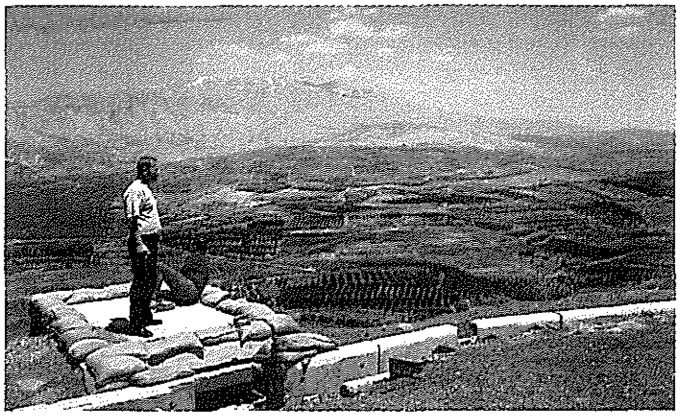
*Continued on Page 10*

## Pre-Conference *Continued from Page 9*



*Inspecting Lake Hula Project at close quarters*

Israel's main source of fresh water. The area has been re-flooded to form a recreational lake and wetland area, with careful monitoring of hydrogeochemistry. A combined hydrogeochemical-historical-hedonistic investigation was conducted by Hamat Gader, within a kilometer of the Jordanian border, where most participants on the trip tested the healing powers of the sulfurous hot springs, once one of the largest thermal bath complexes in the Roman world. The Pleistocene volcanoes and cinder cones, which mark the Golan Heights, were of interest, not only geologically, but as the strategic line of fortifications between Syria and Israel.



*Didier Stroz (reclining) and bus driver look towards Mt. Herman from Golan Heights*

Our archaeological guide, Didier Strozz, brought to life the 150,000 years or so of fascinating human history, which started in the Carmel Caves in the Palaeolithic Era, traced through Biblical events such as the demonstration of the Lord's supremacy over the false prophets by the prophet Elijah on Mt. Mukhraka, the birth of Christianity in Nazareth, Capernaum and Tiberius, to the Roman city of Caesaria, the Crusader era in the city of Acre and the Nimrod Fortress, the Muslim period started by Saladin's victory over the Crusaders, right up to climactic recent events such as the Yom Kippur war in 1973.

Adding to the memorable four days were luncheon stops at the Druze folk-art centre at Dalyat el Carmel, the Jewish city of mystics and art centre at Zafat and a Kibbutz near Nazareth, which conducts pig-farming on raised platforms (so the despised animals do not set foot on Israeli soil), providing pork as a speciality at the attached tourist restaurant.

Everything and anything is possible in today's Israel. Congratulations and thanks to the organisers and guides for a wonderful experience.

**Dr. Richard H. Mazzucchelli**
*President*
*Searchtech Pty Ltd.*
*Kalamunda, WA*
*Australia*

## 18th INTERNATIONAL GEOCHEMICAL EXPLORATION SYMPOSIUM (IGES)

Jerusalem, May 25 - 30, 1997
*by David Garnett*

We have the ancient Greeks to thank for symposia, both the concept and the word. In their infinite wisdom they defined a symposium as 'a drinking party; a convivial meeting for drinking, conversation and philosophical discussion etc' (Shorter Oxford English Dictionary). It's not entirely clear what activities are covered by the 'etc', but what is clear is that a scientific symposium is expected to be far more than a mere meeting at which scientists sit politely in serried ranks in a darkened room listening to other scientists describing their recent discoveries. Of course this is important, but I'm pleased to report that the 18th IGES in Jerusalem fully maintained that Mediterranean tradition of a true symposium. My last President's message (**Explore 96**) gave an overview of our activities, so let me indulge myself at a more personal level with this account. Since the above definition of a symposium lists three main features it is sensible to address each of these in turn.

1. *Drinking (and eating)* We all know that geochemists are eminently responsible, sensible people. Consequently it will come as no surprise that I can claim with confidence that there was absolutely no raucous behaviour or other unseemly activity during the entire course of the symposium. It was probably no more than a coincidence that the Prime Minister of Israel appeared to delay his arrival at our hotel until we had all departed for the Israel Museum — for a very fine reception. There is good evidence that participants in symposia are like armies — they march on their stomachs. Conference organisers take note: get the food and drink right and the rest is easy. The 18th IGES Organising Committee, lead by their capable Co-Chairmen Ron Bogoch and Moshe Shirav, certainly got it right in Israel. Those of you who start the day with little more than a cup of coffee may have difficulty understanding this, but I am still trying to get back to normal after my week of breakfasts at the Renaissance Hotel. We had such a choice - fish, fresh fruit and dried fruit, cereals and many other creations that were far too tempting to resist. I had great difficulty knowing where to start.....or stop. In a land of milk and honey it was entirely appropriate that the highlight of this cornucopia of culinary delights was a bowl of fresh honey, still in the comb. The wide variety of restaurants gave us the opportunity to learn more about the local cuisine, influenced as it is by a variety of cultures, while some of us also took the chance to expand our knowledge of the wines of the region.

2. *Conversation.* Symposia are for meeting people, not just for listening to them, so the informal contacts are at least as important as the formal structured talks. In an international

*Continued on Page 11*

## 18th IGES ... *Continued from Page 10*


*Some Symposium participants*

organisation like the AEG the IGES series offers a rare opportunity for Councillors to discuss issues round a table, rather than listening to each others voices emerging from the ether during our normal conference calls. Equally there is the chance to talk to other AEG members, and to others who are not yet members. In Jerusalem it also gave us the opportunity to make contact with Elsevier's representative, Charles Pallandt, to discuss the future of the Journal of Geochemical Exploration. Tours of the Old City, the Israel Museum, the outdoor AEG dinner at the Ticho House and the very generous hospitality of the organising committee at their own homes all gave us a chance to learn more about our host nation, and perhaps even to stop talking about geochemistry for a minute or two. I even had a very pleasant ten minute conversation with a lady from Israeli security immediately preceding my departure from Tel Aviv airport at the end of the symposium.

3. *Philosophical Discussion.* In the formal sessions one of the most stimulating features of the 18th IGES was the enthusiasm with which the audience was prepared to participate in discussion. Debate even became quite heated at times - a major achievement in the normally staid world of science. We avoided parallel sessions, another major achievement, and managed to integrate the poster sessions with the rest of the meeting. It is often claimed that it is harder to prepare a good poster than it is to prepare an oral presentation, so it was particularly pleasing to see so many outstanding poster presentations. The range of topics covered was greater than most, if not all, previous symposia. While the majority of papers focussed on some aspect of exploration geochemistry, we also had sessions on environmental geochemistry and - most unusual of all - a final topic on Archaeology and Geochemistry. Now we know where Cleopatra did, or did not, get her eye make-up.

A review of the abstracts volume shows that there is no shortage of variety in our approaches to exploration geochemistry. In terms of sample types, old stalwarts such as soils and stream sediments are now joined by soil gases, ground and river waters, and even snow — but does nobody collect fresh rock any more? There were remarkably few papers based on lithogeochemistry. Geomicrobiology, biogeochemistry, organometallics and humic substances all received attention as we become increasingly aware that organic processes can be important factors affecting element mobility. Analytical techniques continue to advance on a broad front and already offer many exciting solutions to problems if we can only ask the right questions. We still have a long way to go with speciation studies (why does As V revert to As III in distilled deionised water at room temperature?) but at least we are going in the right direction. In addition we are feeling our way towards a better understanding of dispersion processes through considerable thicknesses of overburden, using a variety of techniques. Which technique is best and how deep can we go? Regional surveys may not be so glamorous but they do provide essential baseline information and it was good to see that time, effort and resources continue to be devoted to them. It would be pointless to attempt to summarise all the papers but, to chose one theme, the following are a selection of the more intriguing findings on gold geochemistry:

- Unground light mineral fractions of soils from a variety of gold deposits in Canada and the USA yield good recoveries of gold by cyanidation even though the gold is encapsulated rather than being present as free gold.
- Organically-bound gold constitutes more than 85% of the total gold in the dispersion halo in the humic layer of tropical rainforest soils, and is up to 30% richer than the primary mineralization.
- Transported overburden need not represent a 'no-go' area for exploration geochemists, particularly if it has been there for a long time. Indeed, dispersion patterns in the transported materials may be of larger dimensions than in the basement below. It is even possible to accumulate ore-grade levels of metal within transported overburden.
- Gold concentrations in sewage sludge can be sufficiently high to make them economically attractive, but what is the source of the gold and why does it correlate so well with chromium?
- Further evidence continues to accumulate for movement of gold in gaseous or water-soluble forms.

It is always good to have something to look forward to and I hope that I may yet get to hear the paper on biogeophysical investigations (i.e. dowsing) in Russia. Different forms of dowsing are described in the abstract (simple and resonance with metallic frames, pendulums and needles), and although the abstract was included in the 18th IGES program the author was forced to withdraw at the last minute. Perhaps we will hear more at the 19th IGES in Vancouver in 1999. I hope so. Our thanks, once again, to Ron Bogoch, Moshe Shirav and the rest of their team for making the 18th IGES such a success on both scientific and social levels. The ancient Greeks would have been proud of you.

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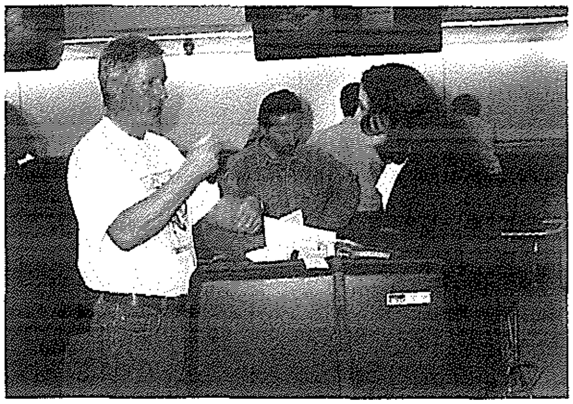

*Dave Garnett at Customs: this is NOT part of the Greek definition of symposium.*

## IGES - SOUTHERN ISRAEL FIELD TRIP

### DEAD SEA, NEGEV, ARAVA VALLEY, ELAT
*by Naomi Porat and Ian Robertson*

Seventeen participants from 10 countries joined us on June 1st for a four day post-conference excursion to southern Israel. The trip was led by Dr Naomi Porat (Geological Survey of Israel), with other leaders joining us for different parts of the route. The weather (38°C) was unusually mild for the Negev desert and, of course, completely dry. We left the Mediterranean climate of the Mountains of Judea (Upper Cretaceous chalk and chert) and, within 25 km, had reached the lowest point on land (410 m below sea level), the Dead Sea Rift Valley. This is set in the arid landscape of the Judean Desert and floored by Pleistocene to Recent marls and conglomerates of Lake Lisan, the much larger precursor to

*Guides Naomi Porat and Moshe Shirav explain the geology of the Arava Valley.*

the Dead Sea. Near the marginal rift fault we visited mottled sanidinite facies rocks at Nebi Musa, metamorphosed by combustion of bituminous materials.

A visit to the ruins and caves of Qumran, where the Dead Sea Scrolls were discovered, provided a cultural and scenic stop and then past the historic hilltop fortress of Masada. Hot, saline, sulphur springs, aragonite and black mud were some of the features shown us by Yosi Yehieli on the shores of the Dead Sea. A short swim in its saline waters, so dense than one floats high in the water, provided a pleasant break during the lunch stop.

We then proceeded to visit most of the industrial mineral sites in southern Israel. At the Dead Sea Works, the group was shown the pond evaporative processes used to exploit minerals from the saline (>300g/l tds) Dead Sea to produce salts of K, Br, Mg and, of course, table salt. Near vertical beds of coarsely crystalline halite, exposed by quarrying, were inspected at the Mt Sedom Diapir. This has a caprock of insoluble material. In the dry bed of Nahal Heimar, natural asphalt had oozed into and cemented coarse sediments and was probably derived from crude oil or from deeply buried oil shales. We then travelled east towards Dimona and south to Mizpe Ramon. The day closed with a magnificent sunset view of the cirque at Makhtesh Ramon. Here, Jurassic and Triassic limestones, sandstones, shales and alkaline magmatic rocks have been exposed beneath early Cretaceous sediments by erosion of a massive, faulted, anticlinal structure, some 40 km long.

The next day provided further synoptic and detailed views of the Makhtesh. Progressive backwards movement of the near-vertical scarp (300-400 m high) had left behind old, truncated debris fans. Gypsum and a flint clay quarries were visited within the Makhtesh. Gypsum reserves are estimated at 10 Mt. The flint clay excavations had exposed a magnificent mottled zone at the unconformity between Jurassic and Triassic sediments, complete with pisolitic structures with boehmite and diaspore, indicating a period of intense lateritic weathering in these times (contrasting with the present arid climate). The flint clay has an alumina content of 35-55% $Al_2O_3$.

Our route took us through some stunning Negev scenery, back towards the rift-bounded Arava valley and south to the ancient copper mining area of Timna. This provided an

*Ancient (8-10th century) ore processing at Millstone Wadi in the Precambrian basement.*

*Continued on Page 13*

## Southern Israel Field Trip *Continued from Page 12*

*Examining the copper oxide minerals in sandstone, Timna area.*

opportunity to visit the shafts, galleries and smelting sites of oxide-copper mines dating back 6000-3400 y, excavated with stone and bronze tools in Lower Cretaceous sandstones. Small ruins of Egyptian temples of the Pharaonic period had been dedicated to Hathor, the goddess of, among other things, mining. A brief visit to the modern oxide copper mine at Timna rounded off the day. Here, dolomites, sandstones and shales of the Lower Cambrian, which had undergone carbonate dissolution and collapse in the early Cretaceous, has produced a resource of 1-2% Cu, recently mined by open cut and underground operations. The drive to Elat provided a chance to admire the mountains of the Precambrian massif in Jordan, complete with vast alluvial fans developed along the eastern margin of the rift valley.

The next day concentrated on the quite small, but intensely faulted, Precambrian basement of Israel of *metavolcanics, metasediments and granitoid gneisses.* A magnificent view of intensely faulted country from the Mt Yoash lookout set the scene, showing four countries (Israel, Egypt, Saudi Arabia and Jordan). A vast erosion surface has truncated the Precambrian rocks and has been tilted southeast towards the Gulf of Elat.

Ancient exploitation and modern exploration sites in this terrain were shown us by Moshe Shirav and Ron Bogoch. At Millstone Wadi, Au had been extracted during the early Islamic period (8-10th century) by milling quartz-rich material. The exact source of the ore has not been precisely determined, despite intensive stream sediment geochemistry. Nearby, in the Har Roded gneiss, *in situ* Au-As anomalies have been found by recent wadi sampling. Conichalcite (Cu-Ca arsenate), Fe oxides, chrysocolla and submicroscopic Au occur near the surface and have been investigated by drilling.

The resort town of Elat provided memorable non-

*Continued on Page 14*

## Southern Israel Field Trip *Continued from Page 13*

geological activities. Colourful fish and their coral world were seen by all participants at the Underwater Observatory, a tower-like structure anchored to the coral reef in about 8 m of water. The more curious went snorkelling in the Coral Nature Reserve and the most adventurous went for a deeper scuba dive in the nearby university experimental grounds. The contrast between the prolific marine life of the Red Sea and the surrounding desert was startling.

The last day, we visited a phosphate operation 30 km east of the ancient city of Avdat, in the wilderness of Tzin. Four phos-phate layers (20-28% $P_2O_5$), in marls, chalks and cherts of the Upper Cretaceous, are being exploited by Rotem-Amfert. They are 1-5 m thick and consist of francolite (an apatite variety) and calcite. East of Dimona, a pilot power plant, with an oil shale feedstock, managed by PAMA, has reserves of 2500 Mt at a 12% organic content. Geologists from both companies generously hosted the group and showed us around their properties.

This field trip passed mainly through hyper-arid regions, from the northern Negev, west of the Dead Sea, through the dissected central Negev mountains to the rift-bounded southern Arava valley and Elat. It provided a valuable introduction to desert landscapes and the exploration problems they present and was spiced with sites of economic, cultural and historic interest.

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### Deadlines for the Next Four Issues of EXPLORE

Contributors's deadlines for the next four issues of **EXPLORE** are as follows:

| Issue | Publication date | Contributor's Deadline |
|---|---|---|
| 98 | January 1998 | November 30, 1997 |
| 99 | April 1998 | February 28, 1998 |
| 100 | July 1998 | May 31, 1998 |
| 101 | October 1998 | August 31, 1998 |

## IGES WEST AFRICA FIELD TRIP

*by Ian Robertson and Paul Taufen*

### INTRODUCTION

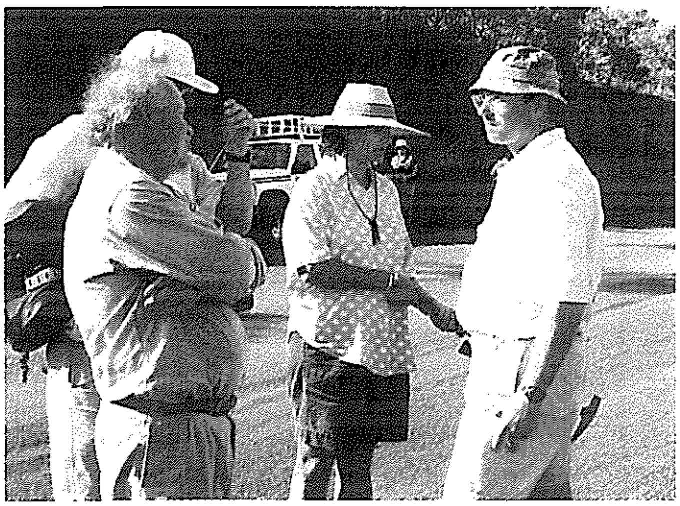
This was a nine-day field trip to Birimian-hosted Au deposits in Mali and the Ivory Coast and was organised by the AEG as part of the 18th IGES. It included visits to three active mines and a number of advanced Au prospects. The trip focused on primary ore deposit geology, on landscape evolution in the area and its influence on the nature of the lateritic regolith and on strategies for geochemical Au exploration. West Africa has had a very long history of Au production, to before the 6th century.

The excursion was attended by a cosmopolitan group of 12 geologists normally based in the USA, Canada, South Africa, Australia, Belgium, Mali and Burkina Faso and was ably lead by Eric Hanssen (Iamgold) and Philippe Freyssinet (BRGM). Linguistically, there were two groups, French and English speaking, many managing both languages; consequently there was much light-hearted banter.

The field trip presentations covered geological, geophysical and remote sensing experience over the exploration leases. The field trip guide contained detailed deposit and prospect descriptions, with colour maps, and described the West African regolith and landscape from the West Mali savanna to the tropical rainforests of the southern Ivory Coast.

**The regolith landscape in Mali and Ivory Coast.** The regolith changes from ferruginous duricrust terrain to ferruginous latosols on moving from the dry savanna of Mali to the wet tropical forest of southern Ivory Coast. Between these is a transitional zone of preserved duricrust in latosol.

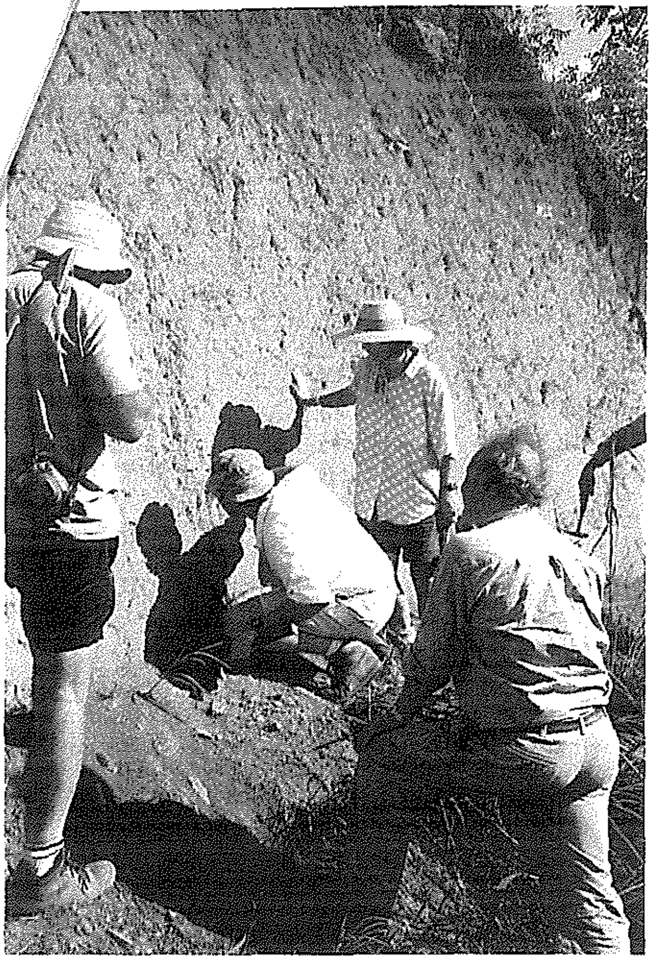
In the Malian savanna climate, which has a seasonal annual rainfall between 900 and 1500 mm, the common in-situ regolith profile is from top to bottom:



*Discussion of latosols by M. Mercier, S. Prud'homme, and P. Freyssinet.*

*Continued on Page 15*

## Africa Field Trip *Continued from Page 19*



*Guide Freyssinet and friends: this could be laterite.*

Light grey silty soil
Pisolitic gravel
Duricrust
Mottled Zone
Saprolite
Parent Rock

Other types of more complex profiles are not unusual, particularly where previous duricrusts have been dismantled and their debris (transported short or even long distances) now overlies saprolite.

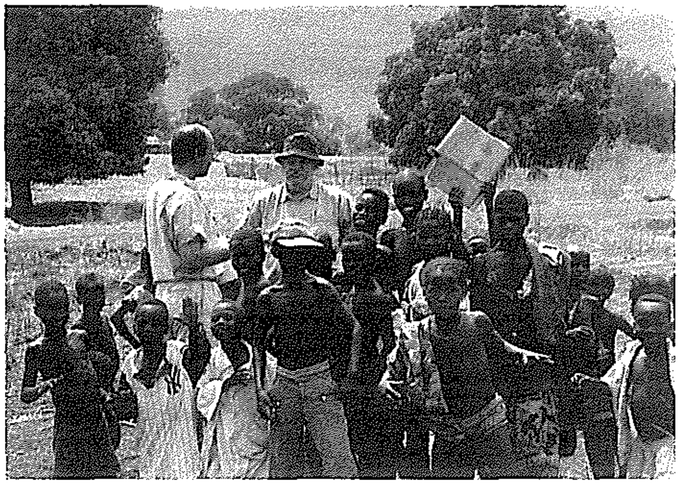
Philippe Freyssinet described a simple model relating rainfall, hydration state of iron oxides, and cementation/duricrust formation in the regolith. Cementation and the formation of ferruginous duricrust is due to hematite precipitation. With greater rainfall, as one moves from savanna to rainforest, hematite becomes unstable in favour of goethite, a much weaker cement, and soil profiles change accordingly. With increased annual rainfall above 1500 mm, ferruginous duricrusts become degraded and mechanically eroded from above, and transformed into nodules with goethitic matrices due to encroachment of higher water-tables from below.

There are commonly two ferruginous duricrust laterite surfaces in the Malian savanna, an older, higher-elevation surface, and a younger, lower-elevation surface. The hiatus between the two is attributed to a dry, erosional episode. Ferruginous duricrust and derived gravels form a minor ore type in Mali, and have provided an easily-mined Au resource at the Sadiola and Syama deposits.

The Sadiola, Segala, Loulo, and Yalea deposits and resources of the Malian savanna are characterised by ferruginous duricrust landforms. Ity, Lafigue, and Angovia occur in tropical rainforests with ferruginous latosol environments. The Syama deposit occurs in a transitional regolith setting with slightly degraded duricrusts.

**Gold dispersion mechanisms in the regolith.** Based on observations and discussions of Au anomalies with geologists at each visited site, there are a number of mechanisms whereby Au can be dispersed in the regolith to provide the large surface anomalies commonly observed.

Gold in fresh rock and saprolite is dispersed within the duricrust; mechanical breakdown and transport of Au-anomalous duricrust can further enlarge Au anomalies. Old artisanal workings, generally shown by hummocky ground, have enlarged original anomaly patterns considerably (e.g., pristine Au anomaly at Syama Extension of 160 ppb; ancient waste dumps of about 1000 ppb Au) and this reworked material has been further dispersed by colluvial and alluvial action. In some instances, ore has been carried from ancient workings to crushing and panning sites, causing additional false anomalies. In depositional environments, alluvial Au occurrences can be close enough to the surface to provide anomalies in surface soil surveys.



*P. Freyssinet and M. Mercier with local fans at site of artisanal gold workings.*

### THE FIELD TRIP

On flying into Mali, the visibility progressively decreased. Even at 3000 m the ground was scarcely visible due to a pale yellow haze of fine suspended dust brought southwest from the Sahara by the Harmattan winds.

**Kenieba inlier - Sahel environment.** The participants gathered at the picturesque Mande Hotel on the banks of the Niger in Bamako and, at dawn the next day, flew in two Cessna 420Cs to the Sadiola Mine in western Mali, near the

*Continued on Page 16*

## West Africa Field Trip *Continued from Page 15*

*Discussion at a "breakaway" near Loulo.*

Senegalese border. Here, Lower Proterozoic Birimian greenschists have been exposed by erosion within the roughly triangular Kenieba window, an inlier of about 26 000 km$^2$, and is surrounded by unconformable, mainly flat-lying Upper Proterozoic sandstones; the window is rimmed with a marked scarp. Although there is very little Upper Proterozoic weathering on this unconformity, the rocks of the Kenieba Inlier have been deeply weathered since the Mesozoic and have well-developed duricrusts.

Ancient workings at *Sadiola* penetrated the duricrust and extensively excavated the top of the mottled zone, where Au has concentrated. Large blocks of duricrust hangingwall have collapsed subsequently. It was re-discovered in 1987-1989 by a large-scale regional geochemical survey covering 6400 km$^2$. At Sadiola, Au is accompanied by As, Sb, Cu, Mo, W, Sn, B and F. This deposit contains reserves of approximately 4.5 million ounces. It occurs in the Kofi carbonate-siltstone formation and was emplaced in shears during the waning stages of metamorphism. Gold (fineness 850-970) is generally fine-grained, although it coarsens near the base of the duricrust and occurs with quartz, micas, smectite and kaolinite. Weathering reaches 30-40 m around the pit and 200 m in the mineralised zone. The planned pit is 2000 x 700 x 200 m.

On the way to Segala, driving through picturesque thatched Malian villages with painted walls and quaint granaries, there was an opportunity to inspect the intense activity of some locals who had sunk numerous small (600 mm dia) shafts that penetrate 7-8 m of sand to excavate and pan a thin layer of alluvial gravel beneath for coarse Au.

Old Au workings at *Segala*, 25 km north of Kenieba, also were rediscovered by soil geochemistry. Mineralisation at Segala is characterised by quartz-carbonate-sericite alteration in carbonated metasediments with disseminated arsenopyrite. Soil geochemistry shows clear anomalies in Au, As and

*Continued on Page 17*

## West Africa Field Trip *Continued from Page 16*

W. Two zones of elevated Au have been identified to date. Worthwhile Au soil anomalies, distinct from known artisanal workings have been identified. Some very active native workings were visited which not only excavated the base of the duricrust but also followed small ore shoots into the saprolite.

The *Loulo* deposit is located about 40 km northwest of Kenieba, is hosted in tourmaline sandstones and contains an estimated Au resource of 1 million oz. The nearby Yalea calc-silicate skarn system is an additional 1.8 million oz resource. It was discovered in 1981 by a regional soil (paramagnetic fraction) and stream geochemical survey using pisolitic gravels. Loulo 0 occurs on a topographic high due to erosion resistance of massive tourmalinite rocks which contain the mineralisation. Adjacent is an albitised pink sandstone forming part of the resource. Arsenic, W and B are associated with Au. Later soil geochemistry revealed major geochemical anomalies along the parallel, weakly mineralised, subcropping Loulo 1, Loulo 2 and Loulo 3 trend. There were plenty of arguments over the origin of the tourmaline and the timing of its emplacement and opportunities to inspect some of the regoliths and landforms left by erosion of at least two levels of duricrust, to enjoy exploration camp hospitality and haute cuisine.

Waiting at Loulo airstrip in 40°C and 80% humidity was not for those unused to Africa. It was necessary to juggle loads between the aircraft to get airborne and dodge thunderheads on track for Syama, 430 km away in southern Mali. Who had all those rocks in his rucksack? Who embarked and nearly tilted the plane on its tail? Who said 'The walls of this plane seem awfully thin'?

**Transition from Sahel to rainforest environment.** The *Syama* mine is located in the Boundiali greenstone belt of southern Mali, about 75 km north of the Ivory Coast border. It is hosted in chlorite and epidote altered tholeiitic basalts with carbonaceous shears. Drilling to 1990 defined a Au resource of about 4.3 million oz but this may be open at depth. Exploration history at Syama is similar to deposits in the Kenieba inlier; the deposit occurs under old workings and was rediscovered by regional geochemistry which located a 20 km long Au anomaly at 10 ppb. There is also a radiometric K anomaly which seems to have been enlarged by old mining activity. Not all geochemical Au anomalies are related to underlying mineralisation in the basement; placer Au occurrences and old Au processing sites were also identified by soil geochemistry.

There was an opportunity to examine and photograph regolith sections. These showed the transition from the duricrust-dominated profiles of the Sahel to the latosol-dominated profiles of the rainforest environment, in an

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## West Africa Field Trip *Continued from Page 17*

annual rainfall regime of 1100 mm here. Also, there were numerous umbrella-shaped termite mounds as evidence for active bioturbation.

**Rainforest environment.** Driving south from Syama, through the Ivory Coast border at Pogo, to Korhogo and beyond, the country changed rapidly, becoming greener and the trees taller (wooded, savanna landscape).

The *Lafigue* prospect is located in central Ivory Coast and was found in 1994 by a regional stream sediment and mapping survey. The $<125\ \mu m$ fraction was analysed for Au and the $<63\ \mu m$ fraction was analysed for trace elements.

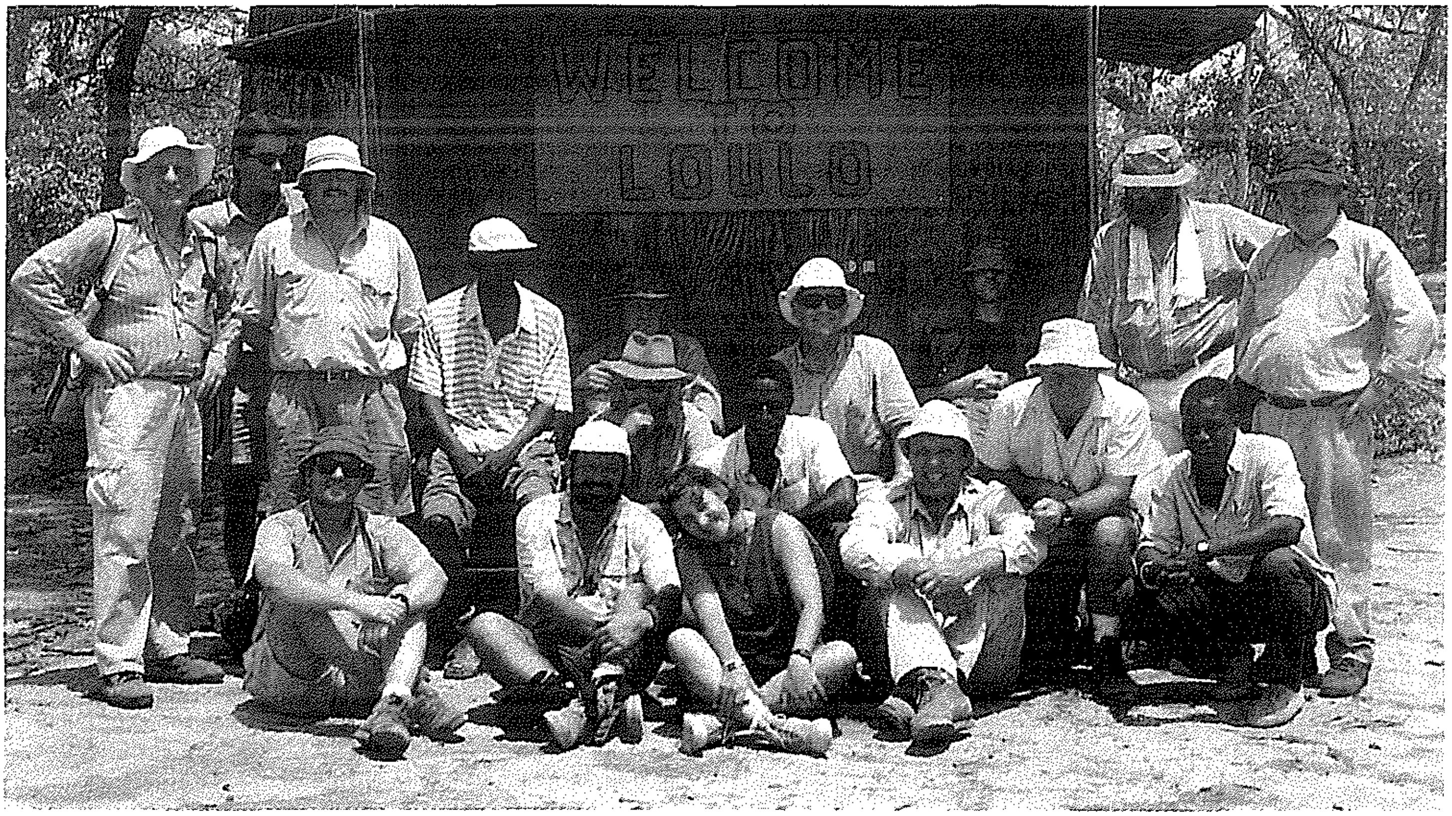
The Lafigue drainage anomaly covered 25 $km^2$. This was investigated by soil sampling which led to identification of auriferous quartz-carbonate-tourmaline veins and carbonate-quartz-pyrite-sericite-albite altered wallrocks along thrust contacts between mafic volcanics and meta-norites. Trenching tends to overvalue the Au content, due to supergene enrichment in the upper two metres. The trenches revealed colluvial dispersion of quartz-tourmaline in a surface soil horizon and evidence of a layer in the colluvium of transported saprolite, a product of previous mining activity, and the development of a red clay latosol matrix. Gold in this environment is not all metallic; some is organically bound so the $<180\ \mu m$ fraction is preferred.

*Discussion of laterite at Saiola by Tahon, Freyssinet, Robertson, Prud'homme, and Mercier.*

En route to Yamoussoukro, there were opportunities to examine regolith profiles over granites with mottled saprolites. Duricrust had become unstable and was in the process of transformation to latosols of kaolinite, goethite and quartz. Stone lines had developed. Between Yamoussoukro (legislative Capital of Ivory Coast) and Angovia, the landscape showed 'half orange' morphology; dominated by chemical rather than erosive degradation, with preserved duricrust on some hill tops and soil creep in the latosols on the slopes with development of stone lines.

The *Angovia* deposit, where mining is to commence at the end of 1997, is located in central Ivory Coast, 50 km west of Yamoussoukro. It comprises a resource of approximately 900,000 oz Au in a fault zone within mafic and felsic volcanic host rocks and some schists. Nearby basalts were dated at 2.1-2.05 billion years. It occurs in a transitional landscape of sub-bauxitic lateritic surfaces with steep, colluvium-covered slopes of ferruginous latosols. The ore zone occurs in hydrothermally altered sheeted dykes. Associated elements are Cu, Sb, Mo, B and W. There are some regional As anomalies but Angovia is not associated with these. The deposit was located by a regional stream sediment program followed by soil sampling to define a soil Au anomaly 1.8 km long and 300 m wide.

The *Ity* mine (discovered in 1957) is located in the western Ivory Coast (annual rainfall 2000 mm), near the border with Liberia in mainly regrown rainforest terrain (previously cleared or partly cleared for cultivation) and there are no unaltered duricrusts. It occurs in three bodies of




*The West African Field Trip group at the Golden Wing Lounge, Loulo.*

garnetite skarn on the tops of adjacent hills. It was indicated by stream sediment sampling and soil geochemistry but artisanal workings made it difficult to pinpoint the source of the Au anomalies which are associated with felsic-mafic rock contacts. The Au reserves are 205 thousand oz and geochemical pathfinders to the skarn mineralisation are Cu, Mo, W, Bi, Ag and, to a lesser extent, As. There has been considerable loss of carbonate by weathering with resultant collapse and enhancement of Au grades. Both the red clay matrix of the latosol and ferruginous granules are Au bearing. There is mineralised gravelly lateritic material above these deposits, with Au enrichment of 140%, particularly at Ity, and the size of the target has been enhanced relative to the saprolite.

All that remained was to return via the striking and bizarre Notre Dame de la Paix Basilica at Yamoussoukro to Abidjan. This completed the geological-geochemical traverse from savanna duricrust terrain through to rainforest latosol terrain. The large distances travelled on bumpy roads, the heat and humidity were factors to be stoically tolerated but the opportunity to see these very significant new mines, at a particularly interesting stage of development, to contrast the regolith environments and the exploration difficulties and opportunities they presented far outweighed any discomfort. It was a truly unique opportunity for those that participated.

## ACKNOWLEDGEMENTS

Eric Hanssen provided excellent organisation in a difficult environment and Philippe Freyssinet provided lucid discussions of regolith geology. Contributors to the substantial field guide were Andre Tahon, Philippe Freyssinet, Jon Hill, Eric Hanssen, Germain Crestin, Mamadou Diallo, Kassoum Diakite, Matt Mullins, Peter Pelly, Robert Thivierge, Laura Duffett, Rupert Allan and Jean Kaisin. Hosting companies were Anglo American, Gencor, Iamgold, La Source Compagnie Miniere, Oliver Gold and Randgold.

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## RECENT PAPERS

This list comprises titles that have appeared in major publications since the compilation in **EXPLORE** Number 96. Journals routinely covered and abbreviations used are as follows: Economic Geology (EG); Geochimica et Cosmochimica Acta (GCA); the USGS Circular (USGS Cir); and Open File Report USGS OFR); Geological Survey of Canada Papers (GSC Paper) and Open File Report (GSC OFR);Bulletin of the Canadian Institute of Mining and Metallurgy (CIM Bull.): Transactions of Institute of Mining and Metallurgy, Section B: Applied Earth Sciences (Trans IMM). Publications less frequently cited are identified in full. Compiled by **L. Graham Closs**, Department of Geology and Geological Engineering, Colorado School of Mines, Colden, CO 80401-1887, Chairman AEG Bibliography Committee. Please send new references to Dr. Closs, not to **EXPLORE.**

Arnason, J.G., Bird, D.K., Bernstein, S., and Keleman, P.B., 1997. Gold and platinum-group element mineralization in the Kruuse Fjord Gabbro Complex, East Greenland. EG 92: 490-501.

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## Technical Note

*Continued from Page 8*

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# CALENDAR OF EVENTS

International, national, and regional meetings of interest to colleagues working in exploration, environmental, and other areas of applied geochemistry.

■December 8-11, 1997, **Fall American Geophysical Union meeting,** San Francisco, Calif. INFORMATION: AGU meetings department, 2000 Florida Ave. NW, Washington D.C. 20009. TEL. 202-462-6900, 1-800-966-2481, FAX. 202-328-0566, e-mail: meetinginfo@kosmos.agu.com.

■January 27-30, 1998, **Exploration methods '98-Pathways to Discovery,** Vancouver, B.C., Canada by Society of Economic Geologists and British Columbia and Yukon Chamber of Mines. INFORMATION: Jack Patterson, British Columbia and Yukon Chamber of Mines, 840 W. Hastings St., Vancouver, B.C. V6C 1C8, Canada. TEL. 1-604-681-5328, FAX 1-604-681-2363.

■March 30-April 3, 1998, **9th International Symposium on Water/Rock Interactions,** Taupo, New Zealand. INFORMATION: B.W. Robinson, Wairakei Research Centre, Institute of Geological and Nuclear Sciences, Private Bag 2000, Taupo, New Zealand, TEL 64-7-374-8211, FAX 64-7-374-8199.

■April 13-17, 1998, **The Seventh International Kimberlite Conference,** Cape Town, South Africa. INFORMATION: Department of Geological Sciences, University of Cape Town, Private Bag, Rondebosch, 7700, South Africa, 7IKC@GEOLOGY.UCT.AC.ZA, FAX: +27 21 650 3783, TEL: +27 21 650 2931. Secretary/Treasurer: James Gurney +27 21 531 03162 FAX: +27 21 531 9887.

■May 18-20, 1998, **Geological Association Canada/Mineralogical Association Canada,** Quebec, Canada. INFORMATION: A Morin, Dept. Geologie et de genie geololoque, Universite Laval, Pavillon Adrein-Pouliot Sanite-Fay, Quebec, G1K 7P4 Canada. TEL. 418-656-2193. FAX 418-565-7339; includes a 2.5 day pre-meeting MAC short course entitled **Mineralized Porphyry-Skarn Systems,** INFORMATION (for the short course only) Dave Lentz, TEL: (506) 547-2070; FAX:(506) 547-7694.

■June 1-4, 1998, **Pan American Current Research on Fluid Inclusions (PACROFI) VII,** Las Vegas, Nevada. INFORMATION: Jean Cline, Dept. of Geosciences, University of Nevada, Las Vegas, Nevada 89154-4010, FAX: 702-895-4064, email: jcline@nevada.edu.

■August 10-14, 1998, **General meeting of the International Mineralogical Association,** Toronto, Canada, INFROMATION: E. Schandl, Dept. of Geology, University of Toronto, Toronto, Canada M5S 3B1. TEL 416-978-7084, FAX 416-978-3938.

■October 26-29, 1998, **Annual Meeting of the Geological Society of America,** Toronto, Ontario, Canada. INFORMATION: Pierre Robin, Dept. of Geology, 22 Russell St., Toronto, ON M5S 3B1, Canada, TEL 416-978-3022, FAX 416-978-3938.

■April 11-16, 1999, **19th International Geochemical Exploration Symposium,** Vancouver, Canada. INFORMATION: Venue West Conference Services Ltd., #645-375 Water Street, Vancouver, BC, Canada V6B5C6, TEL. 604-681-5226, FAX 604-681-2503, email: congress@venuewest.com.

■October, 25-28, 1999, **Annual Meeting of the Geological Society of America,** Denver, Colo. INFORMATION: TEL 1-800-472-1988, meetings@geosociety.org.

■April 24-28, 2000, **5th International Symposium on Environmental Geochemistry,** Cape Town, South Africa. INFFORMATION: 5ISEG, Department of Geological Sciences, University of Cape Town, Private Bag, Rondebosch, 7701, South Africa, FAX 27-21-650-3783. Email: 5iseg@geoglogy.uct.ac.za.

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Editors note: Council has decided that all new applicants will receive the journal and newsletter upon application for membership. The process of application to the Nepean office, recommendation by the Admissions Committee, review by the Council, and publication of applicant's names in the newsletter remains unchanged.

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