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PROBLEMS AND PROSPECTS OF BOTANICAL METHODS OF MINERAL EXPLORATION WITH REFERENCE TO INDIA — AN APPRAISAL

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ABSTRACT

The present report attempts to evaluate the existing literature with regard to geobotanical and biogeochemical methods of investigation for mineral prospecting. The emphasis is laid on the validity of grouping of indicator plants into 'Universal' and 'Local' in the light of their limitations in application value. The report also stresses the essentiality of biosystematic studies prior to making any new reports from any mineralized areas. This suggestion is made taking in view the prevailing opinions on the evolution and adaptation of indicator plants. Moreover, few notable indicator species are now recognised as only ecotypes of the related species growing on unmineralised areas. A compilation of indicator plants is made and the scope of utilisation and profitable exploitation of these taxa is discussed. A few important aspects of biogeochemistry are also given which are necessary in systematic and effective orientation surveys. It was felt that instead of taking up this subject in the established line, the analysis of herbarium material, procured from different herbaria of the country would be of great use for a quick tracing and assessment of mineral rich areas in the country.

PLANTS AND MINERAL DEPOSITS

The scale of mineral exploration in the world is now of unprecedented proportions due to the increasing demands for the urgent needs of expanding industry. The exploration techniques have been revolutionized with the advances taken place both in geophysical and geochemical methods of prospecting. Recognition of ore deposits based on plant affinities to minerals or valuable rocks has been realised since 8th century in China when miners were guided by certain vegetation for the detection of specific ores (Cannon, 1960). Scandanavians were familiar with "Kis plants" which grow on copper ores. Zinc flora was known in Belgium and Rhine region. A systematic beginning on the subject with regard to geochemical affinity of plants was made at the end of 19th century.

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Attention was given on the relationships of plants to mineralized zones and this led to the development of botanical methods of prospecting for specific ores. Mineral prospecting through botanical methods has two complementary lines of study. Geobotanical studies involve identification of indicator plants, changing pattern in community structure, characteristic floras, morphological aberrations in vegetation etc. in response to substrate chemistry. While biogeochemical aspects of investigation concern with obtaining clues of mineral richness through chemical analysis. Even though the above botanical techniques were gainfully employed to identify different mineral resources elsewhere in the world, particularly in the erst-while USSR, the USA, Sweden, Finland, Australia and Central Africa, it has not attained any significant application in the Indian subcontinent for multiple reasons. A brief review of world literature with regard to above methods, their successful application and some limitations involved in the subject are essential to assess the importance of these methods particularly with reference to Indian situation. The following account discusses the use of indicator plants and biogeochemistry in the identification of mineral deposits.

UTILISATION OF PLANT INDICATORS

The foremost task of a geobotanical investigation is to identify indicator plant species in the target area. An indicator species may be defined as a plant species whose presence indicate a certain type of mineralization in the substrate. A survey of the literature with regard to indicator plants provide basically two main classes. The first group comprises the so called universal indicators which will not grow in nonmineralized substrates and can be used in any region of the world for their mineral specificity. Their presence indicates a high soil concentration of the element being sought. Thus, in one way universal indicators are endemic to specific mineralized areas (Ravikiran and Bedi, 1984). These plants do suffer from the disadvantage that they are usually rare and of limited distribution range. The second group—local indicators are those which are adapted to tolerating mineralized ground but which will grow elsewhere, provided that competition from other species is not great. Thus these plants are successful in combating stress conditions produced by high elemental concentration in the substrate simultaneously avoiding the competition from other species which cannot grow in these substrates. In essence, universal indicators have application value throughout the world while local indicators can be applied at local level. During the last 150 years, a number of indicator species have been recorded. A compiler of these indicators is confronted with the problem of what to include in the listing. As stated by Brooks (1972), it is very difficult to assess the credibility of reported claims which were based on slender evidence. In some cases, there was poor documentation and no confirmation of the report thereafter. However, there are numerous reviews with regard to plant indicators from various parts of the world and notable among them include that of Aery And Tiagi (1985), Brooks (1972, 1979), Cannon (1960, 1971), Dorn (1937) and Malyuga (1964).

1. *Limitations* :

Before getting into evaluation of these reports, if the definition of universal indicators is recalled, one would feel, how far a plant can be called endemic to mineralized zone. There are a good number of references which indicate plant species with distribution limited to specific mineralized areas eg.: *Silene cobalticola* Duvign. & Plancke, *Crotalaria cobalticola* Duvign. & Plancke and *Haumaniastrum robertii* (Robyns) Duvign. & Plancke, *Cynotis cupricola* and *Rendlia cupricola* Duvign. Brooks (1979) while discussing these indicators, expressed that the distribution of these so called universal indicators may be sometimes seen on barren areas. It is not justified saying a plant endemic to specific mineralization ignoring all other environmental factors for their influence on distribution of these plants. If this statement were true, the same plant species should occur wherever similar mineralization is taking place. This is not happening with many universal indicators. At best, universal indicators may be considered as endemic to that area where mineralization is one of the important parameters affecting its presence. Secondly, while grading a plant as universal indicator one should consider how far its distribution helped in identifying specific mineralized areas in different countries as universal indicators are supposedly have universal application value. One of the major disadvantages with universal indicators reported from various countries is their narrow distribution ranges. Plants reported as universal indicators by Duvigneaud (1958, 1959) and Duvigneaud and Smet (1963) were restricted to Zaire. Thus when the distribution is limited to narrow ranges, there is not much sense calling them universal indicators. It is also not appropriate to call an indicator 'Universal' for the mere reason of its unfailing absence in barren areas.

A Zambian flowering plant, *Becium homblei* of the Labiatae grows on soils rich in copper. This plant was later designated as universal indicator because of its limited distribution to mineralized areas and accumulation of copper internally. However, Reilly and Jane Stone (1971) suggested that an extrinsic factor namely bush fires, peculiar to the derived Savanna vegetation of South Central Africa was considered important for its continued survival in copper rich areas. They explain that prolonged protection of *B. homblei* from the external influence of fire would finally result in the complete disappearance of the plant as a result of uninterrupted accumulation of toxic concentrations of copper in leaves and stems. Thus the successful existence of *Becium homblei* is not only due to limited elemental tolerance but also owing to periodic bush fires during dry season which is specific to South Central Africa. A plant can not be graded as universal indicator when its distribution is particularly regulated by specific local ecological factor.

Many of the commercially important metals occur from different minerals and their combinations. For example, deposits of copper occur in a number of localities in Bihar, M.P., A.P., Karnataka, Rajasthan, U.P. and West Bengal and in certain parts of Sikkim. The important copper minerals include chalcopyrite, pyrrhotite and pentlandite which occur in different combinations along with different gangue minerals. Thus various mineral combinations of the same element with different gangue minerals have different effects and may not project same indicator plant, even in similar ecological zone. Thus universal indicators should be specified to specific mineral combinations and not to be reported as indicator for specific element as found in the literature.

Many of the universal indicators supposedely accumulate the specific element in high concentration as it is required by the plant for some specific physiological requirement. However, the availability of the said element depends on as many as twenty factors such as pH, drainage, the mobility of various ions, antagonistic effects of other elements etc. Thus if any of these factors is not favourable for the uptake of said element, there is little possibility for the said universal indicator to grow even though there is specific mineralization on similar ecological situation.

In recent years, botanists started observing the actual evolution of species and subspecies under stress conditions of metal toxicity and now there is growing understanding of metal tolerance mechanisms in various plants. The mechanisms of evolution of these species have been discussed in detail by Antonovics *et al.* (1971) and Reeves and Brooks (1983) along with the list of such metal tolerant plants. Stress regions are now considered potential sources for the evolution of new species. Many new species and varieties were reported from different mineral rich zones of the world. These were also simultaneously reported as universal indicators for different elements because of their total absence in barren areas (Table 1).

At this juncture, it is interesting to note the adaptability of *Asplenium adulterinum* and *A. serpentinum* on serpentine soils. These species developed over serpentine under the influence of magnesium. When these ferns were grown on soils which did not contain even traces of serpentinite, these species lost their characteristics and turned into common widely prevalent species of *Asplenium adiantum-nigrum* and *A. viride* respectively in the 6th generation (Nesvetailova, 1961). Thus the validity of new reports with regard to *A. adulterinum* and *A. serpentinum* is questionable.

In a similar way, the adaptability of *Viola calaminaria* to zinc bearing rocks is well known in W. Europe (Nesvetailova, 1961). This plant contains more than 13% zinc which comprises 1.5% on dry weight basis *i.e.* several times more than the average quantity of zinc bearing species which are related but growing on soils which do not contain any zinc in the substrate. Thus he feels that changes in the soil composition evidently produced the new species. He contends that *Viola calaminaria* must be an altered *Viola lutea* on zinc bearing soils. Popov (1949) named a whole series of endemic plants found near the Maguntan Volcano on Sakhalin. One of the endemic species found by him—*Artemisia limosa* was different from closely related *Artemisia borealis* in that it had two year development cycle and some minor morphological differences. Recent genetic studies of *Agrostis tenuis* have shown that this may be evolved within a few generations in species that can occur naturally on extreme habitats (Antonovics, 1960, Antonovics *et al.* 1971). This gradual evolution and adaptation of plants to mineralized areas into the so called new species is sometimes reversible, if they are brought back to normal soils. Thus the validity of new species reported from mineralized areas is to be carefully checked. This also explains the occurrence on extreme unmineralized sites of well known indicator species of mineralized bed rock in natural terrain. The well known copper indicator of Zambia, *Becium homblei* occur on granite soils (Horscroft, 1961 ; Howard Williams 1970) and *Polycarpaea spirostylis*, the copper indicator on laterite in Northern Territory, Australia (Cole *et al.* 1968). A totally different opinion of constitutional tolerance of some indicators to mineral toxicity was reported by Reeves and Baker (1984). The behaviour of *Thlaspi goesingense* towards metalliferous substrates is independent of the source of the seeds of this plant. Plants grown from seeds collected from both calcareous and serpentine populations showed more vigorous growth on unmineralized soils. Plants of both types, however, showed the ability to take up abnormal amounts of nickel, zinc, cobalt and manganese from various types of mineralized soils. The nickel and zinc accumulation parallels that already established for several other *Thlaspi* taxa which occur naturally in mineralized areas. If a seedling grown on serpentine soils is transplanted into a normal soils, the initial high nickel concentration of the whole plant steadily decreased. This is also primarily the result of dilution of the accumulated nickel by further growth of this plant. The similar metal tolerance and metal accumulation by plants of two different populations indicate that the plant metabolism incorporates an inbuilt metal tolerance mechanism. This may well take the form of the ability to synthesize a rather non-specific metal binding ligand. It is clear from the above studies that in *T goesingense,* evolutionary adaptation to mineralized soils does not appear to be prerequisite for successful colonisation. It appears from the foregoing account that plants which are potentially tolerant to excess of some element/elements can grow both on barren and mineralized soils. These are grouped as local indicators by various authors in the earlier literature. While plants which were evolved totally to different mineralized soils developed into new species/varieties (if the variations are irreversible)/ecotypes (if the variations are temporary) and limited their distribution to narrow ranges. These plants were grouped into universal indicators. Ravi Kiran and Bedi (1984) are of the opinion that universal indicators are more reliable indicators than local indicators. But in authors opinion, universal indicators with limited distribution, provide limited usefulness in the identification of new ore deposits. Nevertheless, they could be used with greater effect in specific biogeochemical province. On the other hand, local indicators, having potentiality to grow both on mineral rich and barren areas can be better used in the identification of new ore deposits. A greater uniformity was observed in the distribution of local indicators in different mine deposits of India. It could be stated that the presence of *Lindenbergia muraria* and *Justicia diffusa* at the Deri lead/zinc deposit (Rajasthan Mineral Development Corporation) of *Justicia* sp. at the Agnigundala lead/zinc deposits at A.P. (Venkatesh, 1964) of *Justicia diffusa* and *Lindenbergia muraria* on the Kumbharea Pb-Zn deposits and of *Justicia* sp. and *Lindenbergia* sp. at the Zawar zinc mineralized area (Aery, 1977) as an example of the uniformity of these plants in growing on the mineralized substrates and demonstrates their affinity with lead-zinc deposits. It is worthwhile now to take note of all the indicator plants whether universal or local, recorded so far from various countries and look for them/or their related species in different mineral rich areas. In the course of investigation, if an absolute metallophyte is identified, it could be used throughout that specific province with greater efficiency. Some of the local indicators will have greater possibility to occupy and delineate the ore deposits of the country. Our primary task with regard to geobotanical investigation is to identify these local indicators and map them with regard to their differences in frequency and abundance to delineate the new ore deposits. A list of indicator plants is compiled without grading them as universal or local (Table 1).

2. *Potential uses* :

Once having the knowledge of various indicator plants, if the distribution of these plants and possibly related species is mapped and superimposed with different mineral maps of India, there could possibly be some clues with regard to mineral indicators and also mineralized areas. This is one exercise which could be done without much difficulty as the distribution map of various possible indicators is drawn through herbarium and monograph studies. Secondly, the study of vegetation on mine pit areas would help us to know the type of vegetation that possibly grows on suspected mineral rich zones. Plant lists are to be prepared for different mine pit areas where commercial mining is on. These plants have potentiality to grow on similar ecological situation. As stated earlier, there are number of reviews on indicator plants and the length of this list varies in various reports. Tiagi and Aery (1985) listed about one hundred and sixty as indicator plants for twenty three elements. Brooks (1972) has listed seventy two plants as indicators of 16 elements out of which twenty two plants are graded as universal indicators. Brooks (1979) added six more to the earlier list (for nine elements) out of which thirty eight were grouped as universal indicators. Cannon (1960) has given a much shorter list of thirty two plants as indicators for twelve elements. From the above reviews, the following observations are noted :

- Majority of the plants (about 70 per cent) are the members of five families namely Cruciferae, Caryophyllaceae, Labiatae, Leguminosae and Chenopodiaceae.
- Many of the selenium and uranium indicators are represented by the genus *Astragalus* (20 species) and majority of them are graded as universal. However, none of them are recorded from India.
- Majority of the reported plants are indicators for copper (as many as fifty eight plants in the review of Tiagi and Aery, 1985) and represented mainly by Caryophyllaceae, Labiatae and Bryophytes.

— Boron indicators are represented by members of Chenopodiaceae or Plumbaginaceae. The plants reported for the indication of this element include *Kochia prostrata*, *Salicornia herbacea* and *Atriplex cana*, *Eurotia ceratoides*, *Salsola nitraria*, *Anabasis salsa* and *Limonium fruticosum*. Excluding the last mentioned species, the remaining are halophytes indicating a type of soil in which boron is found along with other salts.

— Members of Ranunculaceae and Violaceae were reported to show affinity to nickel mineralization. Two genera namely *Pulsatilla* and *Hybanthus* represent these indicators.

— All known indicators of cobalt are restricted to the copper belt of Southern Zaire and Northern Zambia. The reported indicators of cobalt include *Crassula alba*, *Crotalaria cobalticola*, *Haumaniastrum robertii* and *Silene cobalticola*. All species of *Nyssa* are able to accumulate cobalt to a significant degree but its role as indicator to cobalt mineralization is still not confirmed (Brooks, 1979).

— As many as eighteen plants were reported as indicators of zinc. Nine of them belong to Caryophyllaceae or Cruciferae. Some of these claims are doubtful in view of the fact that frequent association of zinc with copper and lead in sulfide deposits. However, the members namely *Viola calaminaria* and *Thlaspi calaminare* and *Minuartia verna* are not only indicators but accumulators of zinc. *Lindenbergia muraria*, *Impatiens balsamina*, *Justicia diffusa* and *Waltheria indica* are four species reported to occupy successfully on zinc mineralized areas in India.

In the compilation of the list of indicator plants, some of the authors have listed purely plant species that are used basing on geobotanical studies. While others compounded this list with plant species which were used as indicators basing on their elemental composition of ash. However, Cannon (1960) separately listed the plant species used in biogeochemical investigations from Australia, Canada, Cuba, Finland, Germany, Greece, Japan, Nigeria, Norway, Sweden, USA and erst-while USSR. Very elaborate listing is noted in the compilation of Tiagi and Aery (1985). In his list of indicator plants, *Lycopodium* spp. and *Symplocos* spp. were graded as universal indicators for aluminium. It is incorrect to state any plant or plants as universal indicators without mention of specific names. Plant like *Bulbostylis barbata* which was reported as universal indicator for copper by Brooks (1979) grows in fact in many barren areas in India. In a similar way, many reputed universal indicators for copper such as *Gypsophila patrini*, *Haumaniastrum robertii* were reported to find in barren areas. Prior to reporting of any plant as universal indicators, authors should be sure of a species absence in barren areas to avoid confusion, as mere mapping of any universal indicator should delineate ore bodies of specific element (as per the definition). In fact, this Malyuga's (1964) much used classification of indicators into universal and local is to be replaced by much detailed groupings done by Duvigneaud and Denaeyer-de-Smet (1963) who have provided many more terms to classify each plant growing in mineral belts more correctly and precisely. However, such a grouping demands more detailed documentation of each species reported with regard to its distribution which is lacking in many earlier references. The foregoing account speaks of the importance of indicator plants in mineral exploration. It also tells us the fact, the possibility and potentiality of all indicator plants for guiding specific mineralized areas whether they are universal or local as grading in the literature is more subjective. Cognisance of such plant species will help a Geobotanist to identify and concentrate on the distribution and abundance of such plant groupings which have known sensitivity/tolerance/ adaptation to mineralized areas.

BIOGEOCHEMICAL METHODS

Biogeochemical methods of prospecting depend on the chemical analysis of elements in the vegetation. The basis of this method is that an element in the soil or bed rock will be accumulated in a direct proportion by the plant and consequently anomalous amounts in the vegetation are taken as reflection of anomaly in the substrate. Plant chemical analysis was first used in the years 1938-1940 in prospecting for tungsten and tin in Corn Wall (Cannon, 1960), for nickel in Finland (Rankama, 1940). Later on, investigations based on plant chemical analysis were carried out in the erst-while USSR, (Malyuga 1947 and 1958a and b and Tkalich 1938, 1952), the United States (Anderson and Kurtz 1955; Cannon, 1955; Harbaugh 1950; Warren *et al.* 1951 and Worthington 1955), Japan (Murakami *et al.* 1958); Canada (Warren *et al.* 1949; Warren and Delavault 1950, 1950a and b, White 1950), Australia (Debnam, 1955) and Norway (Vogt, 1939, Vogt and Bergh, 1947, Vogt and Braadlie, 1942). Cannon (1960) has summarised the investigations carried out till 1960 enlisting the important species that were used in the delineation of mineral rich areas. Following the pioneering work of Tkalich (1938, 1952), the erst-while USSR remained a main center of biogeochemical prospecting work in the world. Much of the Russian work was carried out by Malyuga and his co-workers at the Vernadsky Institute, Moscow. (Malyuga 1947, 1950, 1954, 1958a, b, 1959, 1960, Malyuga *et al.* 1959, 1960, Malyuga and Makarova, 1955). In the United States too, plant chemical methods were extensively used for the exploration of uranium (Cannon, 1957, 1960a, 1964). Following the compilation of the list of plants used in biogeochemical investigation by Cannon (1960), Brooks (1972) summarised all the available data on the application of geobotany and biogeochemistry to various elements from different countries. The successful application of biogeochemical methods of prospecting involves knowledge of many disciplines including botany, chemistry, ecology, geology, plant chemistry, soil science and statistics. A brief account of terminology involved in the subject is essential before its review.

1. *Essential and nonessential elements* : The reproducible uptake of soil elements by plants of the same species under same conditions is an essential prerequisite for successful biogeochemical prospecting. Elements which are required in the healthy growth of plants are termed essential elements. By late 19th century, it has been established that carbon, hydrogen, oxygen, nitrogen, phosphorus, sulphur, potassium, calcium, magnesium and iron were universally essential for plant growth. Later, another six elements, boron, chlorine, copper, manganese, molybdenum and zinc were recognised to be necessary in small quantities. Indicative of the extremely small concentration of these elements required in nutrition, (in most cases not less than 1 mg l^{-1}) they are termed minor or micro elements.

2. *The distribution of the minor elements in soil* : Distribution of minor elements is a function not only of soil type but also of particle size and depth within the profile. The nature of the parent material determines the abundance of various elements in the profile as a whole but the mobility of the constituents, together with other factors such as the climate determine their distribution within the soil profile.

3. *Ion absorption* : There are three ways whereby ions are absorbed by plants. Two of these pathways involve uptake through the root system. While the third, foliar absorption, involves absorption through aerial parts of the plant (Brooks,

1972). Uptake through the root system is carried out either by diffusion mechanism or by cation exchange which results in the production of CO_2. Most plants are selective in the mineral absorption and the ability of a plant species to restrict uptake of a toxic element is known as exclusion mechanism. Plants which operate a total exclusion mechanism are useless for biogeochemical prospecting. But those that have partial exclusion mechanism or none at all often quite suitable for this purpose. In total contrast to above situation, there are some plants which do preferential enrichment of certain element known as the Goldschmidt enrichment principle (Goldschmidt, 1937). Brooks (1972) has provided concentrations of a number of elements in plants and soils. The ratio of these two quantities is a measure of the biogenic characteristics of each element. To say that an element is biogenic implies either that it has a physiological role in the species concerned or else that it was concentrated in such a high degree whether it has role or not. Elements which are accumulated without requirement are known as ballast elements (Frey-Wyssling, 1935). Elements with an enrichment coefficient of 0.10 or greater are biogenic and that those with coefficient less than 0.01 are non biogenic. Between these two groups lies a third group with intermediate properties. An evaluation of the enrichment coefficient of various plants given some indication of the likely behaviour of the species when growing over mineralized ground and indeed data are already available for normal background levels of various elements in vegetation, particularly in North America (Cannon, 1960; Warren, 1962). It is not always an advantage if a species exhibits high enrichment coefficient, as this only increases the background levels in plants and may render an anomaly more difficult to detect. Porportional uptake (with respect to substrate) and 'reproducibility' are two essential prerequisites for any plant to be an ideal species in the biogeochemical prospecting for minerals.

4. *Pathfinder elements* : The concept of pathfinder is well established in mineral exploration basing on plant chemical analysis. Pathfinders are generally associated elements of the mineral of sought after element and the concentration of these elements in plant ash provide a better reflection of the richness of the specific mineral than the sought after element itself. Warren and Delavault (1959) have described several successful uses of pathfinders. Warren *et al.* (1952b) have investigated the use of iron and manganese in vegetation as indicators for other elements. Tkalich (1953) has used iron for the same purpose. Talipov *et al.* (1968) have explored the possibility of using arsenic in vegetation as a pathfinder for gold and obtained positive results. Aery and Tiagy (1985) have reported chromium as pathfinder element in the search of Pb-Zn deposits of Rajastan. The pathfinding elements vary in different situations and they are to be identified during the orientation survey. Such data are usually obtained from the statistical analysis of inter-elemental relationships of vegetation with that of soil.

5. *Factors affecting elemental accumulation by plants* : Successful biogeochemical prospecting depends on the accumulation of element concerned in a reproducible manner and that the degree of accumulation should be in direct proportion to the concentration of the element in the soil. A plant which observes above principles in total is rarely found. However, there could be plants which observe these principles to a great extent. Selection of the ideal species is done based on a preliminary orientation survey. This survey also takes into account the influencing factors of mineral uptake. So far, twenty variables were described as controlling factors in the mineral uptake of vegetation. Nevertheless, all these factors never operate

simultaneously in a given area. And moreover, the influence of some of these factors may be minimum while of others is considerable. Brooks (1972) has discussed in detail some of these factors. Notable factors include (1) Type of plant sampled, (2) Type of plant organs sampled, (3) Age of the plant, (4) Drainage, (5) Photosynthesis, (6) Availability and antagonistic effects of elements and (7) the pH of the soil.

The factors of significant importance in mineral uptake are usually identified in the orientation survey. Some remedial measures to overcome these limitations were suggested by Brooks (1972). Thus selection of plant/organ to be sampled/age of the species is made basing on good correlations obtained between the elemental concentration in the soil and that of plant ash. If the pH of the soil is not favourable, use of elemental ratios of pairs of elements of similar availability are taken into consideration. Poorly drained soils are avoided to mitigate the effect of drainage. Antagonistic effects are overcome through the use of elemental ratios.

6. *Background data for biogeochemical prospecting*: Elemental concentrations in different plants growing on nonmineralized areas is essential in biogeochemical prospecting of minerals. These concentrations are termed background levels. These values are useful in comparison of data obtained from mineral rich areas with that of background levels. Most of the existing knowledge of background data is derived from North America (Warren, 1962) followed by the erst-while USSR. In India there is very little work done in this direction.

7. *Orientation Survey*: Here survey would be conducted in a known mineralized area and a thorough analysis of plants with respect to mineralization is carried out to identify species of importance in the guiding of mineralized areas in a given biogeochemical province. Through this survey, some data base is obtained with regard to plants which are metal tolerant and metal accumulating. Ideal species are also identified which can be relayed on for biogeochemical prospecting. While selecting the site for such an orientation survey, the following points are to be taken care of Brooks, 1972 :

— The area should contain an anomaly/anomalies.

— Concentrations of elements in anomalies of the test area should ideally approximate those of the area which is to be surveyed later.

— The selected site should be climatically, ecologically, geologically and geomorphologically representative of the target area which is to be surveyed ultimately.

— The selected site should be least interfered by any biotic factors before and there should be no introduced species in the area.

Correlation coefficients (CV) are to be estimated between the elements of various plant species with the corresponding values in the soil or bed rock. This function varies in value between +1 and −1. Plants having exclusion mechanism for specific element or plants having preferential enrichment of specific element can be eliminated through this function. And also it helps in the identification of best species to be selected for later exploration surveys. A second step of great importance is the determination of specific organ of a plant species which reflect the soil anomaly ideally where CV would be closer to +1. A third step is the determination of what concentration of an element in plant ash should be taken as representing an anomaly in the soil or rock beneath. And the most important of all the reproducibility of an element accumulation in a plant is provided by calculation of the coefficient of variation for the element content of different specimens of same species selected from an area which has a uniform content of that element. Antagonistic elements are to be brought out by calculating 'r' values between the contents of different pairs of elements in the plants. If a plant is showing good correlation between different elements in the plant ash and a sought after element in the soil, then it is to be identified as pathfinder element.

8. *Analysis of herbarium specimens* : The analysis of herbarium specimens have revolutionised the method of biogeochemical prospecting. Analysis of herbarium specimens is a simple rapid and inexpensive method of assessing the potential areas of mineralization in any country. Chenery (1948) carried out an analysis for aluminium in over 4000 herbarium specimens. Persson (1956) analysed the soil attached to herbarium specimens of copper mosses to detect cupriferous localities in Sweden. Cole (1971) identified cuprophytes over a copper deposit in Southern Africa and checked herbarium material. Goodman and Roberts (1971) analysed bryophytes from herbaria to monitor atmospheric pollution. Brooks *et al.* (1977) have analysed nearly 2000 herbarium specimens of 232 species of genera *Homalium* and *Hybanthus* in order to identify plant accumulators of nickel which were indicative of nickeliferous rocks. The analysis resulted in the identification of many nickel accumulators. For this work, Brooks and his group approached more than fifty herbaria for small samples of leaf material. Six herbaria in India supplied the material and they include Blatter Herbarium, St. Xaviers' College; Central National Herbarium, Howrah; Central Circle, BSI, Allahabad; Eastern Circle, BSI, Shillong and Southern Circle, BSI, Coimbatore. However, none of these materials showed any significant accumulation of nickel. At this juncture, it is worth noting of new points. The literature on biogeochemistry lists a good number of plants being used in the identification of ore rich areas. The method of herbarium analysis may be gainfully employed in India with little difficulty as there are good number of herbaria located in different parts of the country with rich collections of local floras. Even the procedure for herbarium specimen analysis is quite simple. Dried leaf samples with an average weight of 0.03 mg are placed in 5 cm^3 borosilicate test tubes and ignited at 500°C in a muffle furnace. The ash in each tube is then dissolved in 2 M hydrochloric acid or nitric acid. The solutions are analysed for different elements by atomic absorption spectrophotometry. All concentration data can be expressed on a dry weight basis. This task can be easily taken up by Botanical Survey as its divisions like Central National Herbarium and various regional circles could supply a good number of suspected plant accumulators collected from various parts of the country for a quick scanning for the metal contents and thereby identifying the metal rich localities of the country.

Table 1 : List of Plant Indicators for various elements

Plant name/Element	Family	Country	Reference
Aluminium			
Ilex aquifolium Linn.	Aquifoliaceae	Italy	Hutchinson (1943)
Boron			
Eurotia ceratoides C. A. Mey	Chenopodiaceae	USSR	Buyalov and Shuyryayeva (1961)
Salsola nitraria Pall.	-do-	-do-	-do-
Kochia prostrata Schrad.	-do-	-do-	-do-
Salicornia herbacea L.	-do-	-do-	-do-
Atriplex cana C. A. Mey	-do-	-do-	-do-
Anabasis salsa (C.A.M.) Benth.	-do-	-do-	-do-
Limonium suffruticosum Ktze.	Plumbaginaceae	-do-	-do-

Table 1 : *Contd.*

Plant name/Element	Family	Country	Reference
Crassula alba Forsk..	Crassulaceae	Zaire	Brooks *et al.* (1977)
Crotalaria cobalticola Duvign. & Plancke	Leguminosae	Katanga	Duvigneaud (1959)
Haumaniastrum robertii (Robyns) Duvign. & Plancke	Labiatae	Zaire	Brooks (1977)
Silene cobalticola Duvign. & Plancke	Caryophyllaceae	Katanga	Duvigneaud (1958)
Copper			
Aeolanthus biformifolius De. Wild.	Labiatae	Zaire	Malaisse *et al.* (1978)
Acalypha dikuluwensis Duvign. & J. Dewit.	Euphorbiaceae	Zaire	Duvigneaud and Denaeyer-de-Smet (1963)
Acrocephalus simplex	Labiatae	Katanga	Duvigneaud (1958)
A. robertii	-do-	-do-	-do-
Anisopappus hoffmanianus	Compositae	Zaire	Duvigneaud and Denaeyer-de-Smet (1963)
Armeria maritima Willd.	Plumbaginaceae	Wales	Henwood (1857), Ernst (1969)
Ascolepsis metallorum Duvign. & G. Leonard	Cyperaceae	Zaire	Duvigneaud and Denaeyer-de-Smet (1963)
Becium homblei de Wild	Labiatae	-do-	Howard-Williams (1970)
B. peschianum Duvign & Plancke	-do-	-do-	Duvigneaud and Denaeyer-de-Smet (1963)
Bulbostylis barbata Kunth	Cyperaceae	Australia	Nicolls *et al.* (1965)
B. burchelli	-do-	-do-	Cole (1971)
Commelina zigzig Duvign. & J. Dewit	Commelinaceae	Zaire	Duvigneaud and Denaeyer-de-Smet (1963)
Crotalaria cobalticola Duvign. & Plancke	Leguminosae	-do-	Duvigneaud (1959)
C. francoisiana Duvign. & Timperm.	-do-	-do-	Duvigneaud and Denaeyer-de-Smet (1963)
Cyanotis cupricola	Commelinaceae	-do-	-do-
Ecbolium lugardae N.E.Br.	Acanthaceae	S. W. Africa	Cole (1971)
Elsholtzia haichowensis	Labiatae	China	Se Sjue-Tszin and Siui Ban-Lian (1953)
Eschscholzia mexicana Greene	Papaveraceae	USA	Chaffee and Gale (1976), Lovering *et al.* (1950)
Gladiolus actinomorphanthus Duvign. & van Bockstal	Iridaceae	Zaire	Duvigneaud and Denaeyer-de-Smet (1963)
G. duvigneaudii van Bockstal	-do-	-do-	-do-
G. klattianus S. Sp. *angustifolius*	-do-	-do-	-do-
G. peschianus Duvign. & van Bockstal	-do-	-do-	-do-
G. tscombeanus S. Sp. *parviflorus* Duvign. van Bockstal	-do-	-do-	-do-
Gutenbergia cuprophila Duvign.	Compositae	-do-	-do-
Gypsophila patrini Ser.	Caryophyllaceae	USSR	Nesvetailova (1961)
Haumaniastrum katangense (S. Moore) Duvign. & Plancke	Labiatae	Zaire	Duvigneaud and Denaeyer-de-Smet (1963)
H. robertii (Robyns) Duvign. & Plancke	-do-	-do-	-do-
Helichrysum leptolepis DC.	Compositae	S. W. Africa	Cole (1971)
Impatiens balsamina Linn.	Balsaminaceae	India	Aery (1977)
Lindernia damblonii Duvign.	Scrophulariaceae	Zaire	Duvigneaud and Denaeyer-de-Smet (1963)
L. perennis Duvign.	-do-	-do-	-do-
Lychnis alpina Linn.	Caryophyllaceae	Fennoscandia	Brooks *et al.* (1979a, b)

Table 1 : Contd.

Plant name/Element	Family	Country	Reference
Pandiaka metallorum	Amaranthaceae	Zaire	Duvigneaud and Denaeyer-de-Smet (1963)
Polycarpaea corymbosa Lamk.	Caryophyllaceae	India	Venkatesh (1964, 1966)
P. spirostylis F. Muell.	-do-	Australia	Brooks Radferd (1978)
Rendlia cupricola Duvign.	Gramineae	Zaire	Duvigneaud and Denaeyer-de-Smet (1963)
Sopubia metallorum Duvign.	Scrophulariaceae	-do-	-do-
S. neptunii Duvign. & van Bockstal	-do-	-do-	-do-
Sporobolus stelliger Duvign. & Kiwak.	Gramineae	-do-	-do-
S. deschampsioides Duvign.	-do-	-do-	-do-
Vernonia cinerea Less.	Compositae	India	Venkatesh (1964, 1966)
V. ledocteana	-do-	Zaire	Duvigneaud and Denaeyer-de-Smet (1963)
Iron			
Acacia patens F. Muell.	Leguminosae	Australia	Cole (1965)
Burtonia polyzyga Benth.	-do-	-do-	-do-
Calythrix longiflora F. Muell.	Myrtaceae	-do-	-do-
Chenopodium rhadinostachyum F. Muell.	Chenopodiaceae	-do-	-do-
Eriachne dominii R. Br.	Gramineae	-do-	-do-
Goodenia scaevolina F. Muell.	Goodeniaceae	-do-	-do-
Manganese			
Crotalaria florida var. *congolensis*	Leguminosae	Zaire	Duvigneaud (1958)
Maytenus bureauvianus	Celastraceae	New Caledonia	Jaffre (1977)
Mechonia grandiflora	Amaranthaceae	Katanga	Duvigneaud (1958)
Polygala baumii	Polygalaceae	-do-	-do-
Nickel			
Hybanthus austrocaledonicus	Violaceae	New Caledonia	Brooks *et al.* (1974)
H. floribundus (Lindl.) F. Muell.	-do-	Australia	Severne and Brooks (1972), Cole (1973)
Pulsatilla patens Mill.	Ranunculaceae	USSR	Strozheva (1954)
Selenium and Uranium			
Astragalus beathi C. L. Porter	Leguminosae	USA	Trelease and Beath (1949)
A. bisulcatus A. Gray	-do-	-do-	-do-
A. crotalariae A. Gray	-do-	-do-	-do-
A. diholcos (Rybd). Tidestrom	-do-	-do-	-do-
A. eastwoodae Jones	-do-	-do-	-do-
A. ellisiae (Rydb) C. L. Porter	-do-	-do-	-do-
A. grayii Parry Wats.	-do-	-do-	-do-
A. moencoppensis Jones	-do-	-do-	-do-
A. oocalysis Jones	-do-	-do-	-do-
A. osterhauti Jones	-do-	-do-	-do-
A. pectinatus Boiss.	-do-	-do-	-do-
A. racemosus Pursh	-do-	-do-	-do-
A. tranus Jones	-do-	-do-	-do-
A. albulus Woot & Staud.	-do-	New Mexico	Cannon (1957)
A. argillosus Mandenova	-do-	USA	-do-
A. confertiflorus A. Gray	-do-	-do-	-do-
A. pattersonii A. Gray	-do-	-do-	-do-
A. thomsonae S. Wats.	-do-	-do-	-do-
Aster venustus Jones	Compositae	-do-	-do-

Table 1 : *Contd.*

Plant name/Element	Family	Country	Reference
Zinc			
Armeria halleri Wallr.	Plumbaginaceae	Pyrenees	Palou *et al.* (1965)
Hutchinsia alpine	Cruciferae	-do-	-do-
Minuartia verna	Caryophyllaceae	W. Europe	Ernst (1968)
Thlaspi calaminare Leg et Curt	Violaceae	-do-	-do-
Viola calaminaria (Lindl.) F. Muell.	Caryophyllaceae	-do-	-do-
Silene cucubalus Wibel.	Caryophyllaceae	USSR	Vinogradov (1935)
Stellaria verna	-do-	-do-	-do-
Thlaspi alpestre Linn.	Cruciferae	Brazil	-do-
T. arvense Linn.	-do-	-do-	-do-
Impatiens balsamina L.	Balsaminaceae	India	Tiagi and Aery (1981)
Waltheria indica Linn.	Sterculiaceae	-do-	Gandhi and Narayana (1975)
Lindenbergia muraria	Scrophulariaceae	-do-	Aery (1977)
Justicia diffusa Willd.	Acanthaceae	-do-	-do-

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