The Place of Geobotany in Geology

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Abstract:
Geobotany is the study of plants as related to the geological substrate. In this article, the term geobotany is defined as it is understood and used among the geological fraternity. It is the visual survey and analysis of vegetation in order to discriminate geological differences in the subsurface. This chapter demonstrates the place of geobotany in geology by giving a reflective historical perspective on the use of plants in geology. Geobotany is significant in exploration of mineral resources and is of strategic importance in geologic mapping in vegetated terrain. For this purpose, the uses of plants in mineral exploration, and the entry levels at which plants are used to discriminate geological differences in the landscape are presented. These entry levels include the use of plants for general geological mapping (regional geobotany) purposes, and for specific identification of mineral deposits (indicator or target geobotany). How mineral uptake influences the spectral reflectance characteristics of plants (spectral geobotany) is presented in the last section of the chapter as a geobotanical technique that uses remote sensing technology. This historical review of the place of geobotany in geology, underscores the genesis and paradigmatic shift in research and development through which the discipline has evolved over time.

Keywords: Geobotany, element uptake, spectral reflectance, bioremediation, Kenya.

Introduction
'Rocks produce soils in which plants grow'.

Geobotany is the study of plants as related to the geological substrate. In this article, the term geobotany is defined as it is understood and used among the geological fraternity. It is the visual survey and analysis of vegetation in order to discriminate geological differences in the subsurface. This chapter demonstrates the place of geobotany in geology by giving a reflective historical perspective on the use of plants in geology. Geobotany is significant in exploration of mineral resources and is of strategic importance in geologic mapping in vegetated terrain. For this purpose, the uses of plants in mineral exploration, and the entry levels at which plants are used to discriminate geological differences in the landscape are presented. These entry levels include the use of plants for general geological mapping (regional geobotany) purposes, and for specific identification of mineral deposits (indicator or target geobotany). How mineral uptake influences the spectral reflectance characteristics of plants (spectral geobotany) is presented in the last section of the chapter as a geobotanical technique that uses remote sensing technology. This historical review of the place of geobotany in geology, underscores the genesis and paradigmatic shift in research and development through which the discipline has evolved over time.

Definition of Geobotany
Geobotany encompasses the linkage between geology and plants; and specifically how plants as an interphase are or can be used in geological studies, for example in mineral exploration, in biogeochemical studies, in medical geology and in remote sensing studies, to mention a few application areas.

In this chapter, geobotany is defined and used from a geological point of view; it is the science that deals with the visual survey of vegetation in order to identify geological differences in the landscape (Malyuga, 1964; Rainess and Canney, 1980). This visual survey often includes observations of physiological modifications in plants, such as dwarfism, morphological deformities, and chlorosis (Kovalevsky, 1987). These teratological (Raines and Canney, 1980) changes can occur in individual plants or whole plant communities. In this regard, geobotany is also concerned with the relationships between the form, composition and distribution of vegetation communities and their relationship to environmental factors, particularly in undisturbed terrain (Cole, 1984). Since vegetation type and characteristics can change with rock
type, vegetation has been used to derive geological information and to discriminate parent rock material. This is because vegetation reflects the interplay of many environmental factors including the geochemistry of the soil at the rooting depth, the type of soil, the aspect, and even variations of micro-relief. It is therefore useful for geological mapping and mineral exploration.

Geobotanical prospecting utilizes the principle of selective adaptation by plants to variations in geological conditions in the subsurface. This includes observations of the presence or absence of certain plant species or vegetation assemblages, observations of changes in abundance and vigor around a dispersion halo, and identification of conspicuous morphological modifications in individual plants or in a group of plants (Dorr et al., 1971). Thus, geobotany is based on the premise that plants, through their root systems, absorb geochemically available elements from the subsurface and thereby reflect the underlying geological conditions (Siegel, 1974).

It is important to realize that the term geobotany is frequently used to include biogeochemistry. While biogeochemistry is concerned with the detection of biogenic haloes of ore indicator elements in living organisms and their remains (Kovalevsky, 1987) using rapid and sensitive analytical instruments (Brooks, 1972), in practice it is difficult to treat geobotany and biogeochemistry as being mutually exclusive. This is because in virtually all geobotanical investigations it is common practice to sample and analyze the vegetal component for its constituent metallic elements when attempting to determine the "composition" of the subsurface geology. In other words, to ascertain that a plant is indeed a geobotanical indicator species, trace element analysis must be done in order to correlate the elemental concentration in the plant species with the substrate geochemistry. Consequently, this trend of thought has reached the point where most researchers consider and treat geobotanical and biogeochemical methods of prospecting as constituting a single discipline. This is appropriate since the absence or excess availability of a certain mineral element may result in the anomalous appearance and/or development of a plant, or even whole plant communities. Malyuga (1964) referred to the use of plants for mineral exploration as the biogeochemical or geobotanical method. The technique is used widely in the exploration for ore deposits, in the study of the character and depth of groundwater, and even in the determination of the presence of geological structures, which are often associated with ore deposits. In this chapter these terms are used interchangeably.

According to Raines and Canney (1980), the applications of geobotany can be summarized into three conceptual approaches. First, is the study of plant communities, including characteristic floras and specific indicator species; second, is the study of vegetation density, which includes extreme cases of complete absence or presence of vegetation; and third, is the study of plant morphology. Each approach involves investigations of the various ways in which individual plants or whole plant communities respond to mineral concentrations in the geochemical environment. It should be noted that the response can also affect plants in a non-visual fashion (i.e., in ways that are not detectable by the human eye), a realization that led to the development of remote sensing applications in geobotanical studies. It is noteworthy that the remote sensing concept was first envisaged by Socrates in c.400 BC, when he observed that "man must rise above the earth's surface, to the top of the atmosphere, in order to understand the environment in which he lives" (in Odhiambo, 1993).

When vegetation becomes stressed and develops a distinct spectral characteristic in the infrared part of the electromagnetic spectrum, identification of "spectral anomalies" at the red edge has enabled researchers to identify mineralized areas using remote sensing (Singhroy, 1989, and Odhiambo, 1993).

**Historical Development of Geobotany**

The use of plants in the search for subsurface mineral resources has been in practice since ancient times. In Rome, during the reign of Augustus Caesar (63 BC to 14 AD) the architect Vitruvius stated that water is to be sought in areas where certain trees are to be found growing naturally and not artificially planted (Agricola, 1556). Physiological effects of metal on vegetation were also observed by Agricola (1556), while Barba described the use of plants for mineral prospecting in Potosi, Bolivia in 1637 (Cannon, 1979). Other significant studies that formed the fundamental basis for geobotanical methods of mineral prospecting include the works of Lomonosov (1763) and Kapinsky (1941), both quoted in Malyuga (1964). In all these studies, emphasis was placed on observation of the depauperating effects of mineralization on whole plant communities. However, it was not until the early parts of the 19th Century that geobotanists propounded the notion of indicator species for specific mineral types. Today, more descriptive terms such as accumulators, specialists, or super tolerant plants are used more freely, caution being taken in declaring plants as indicators of specific mineral types (Cannon, 1979).

It is important to underscore what geobotany is understood to mean among geological fraternity. Questioning whether ecology, plant geography, and geobotany are three different sciences, or three different viewpoints of the same science and whether one is a part of the others, or if all three are synonymous, Rübel (1927) strived to correct the misunderstandings by non-ecologists, by discussing what ecology includes in the minds of ecologists, what plant geography means to plant geographers, and what geobotany comprehends. Rübel (1927) recognized geobotany as that part of botany which has to do with geo-, the earth, the action of all earthly factors, all changes of plants on the earth, and all distributional questions over the earth. Essentially what Rübel stated is that geobotany (plant ecology-plant geography) is the science of the relationship of plants to the environment, the earth. The article by Tadros (in Vegetatio, 1949) entitled, Geobotany in Egypt (A historical review) does not attempt to define the term, but proceeds to use it from a botanical perspective.

In the 3rd Edition of the Great Soviet Encyclopedia (1970-1979; in Free Dictionary, 2010) geobotany is referred to as phytogeography, a science concerned with the Earth’s vegetation as an aggregate of plant commu-
nities, or *phytocoenoses*. Essentially, these positions stem from the statement of the German naturalist A. Humboldt, which dates back to the beginning of the 19th Century, that vegetation is a unique element of nature. It should be pointed out that in these studies and academic discourses the use of plants from a geological perspective as originally envisaged by architect Vitruvius (*in Agricola, 1556*) is not addressed. The term geobotany cannot be stretched to include *palaeobotany*; a view proposed in the Great Soviet Encyclopaedia.

Recent geobotanical studies have been undertaken in several countries, especially in New Zealand and Australia (Brooks, 1972), in the Scandinavian countries (Rune, 1953; Talvite, 1979), USSR (Lomonosov, 1763; Kapinsky, 1941), Canada (Fortescue, 1980; Wagner, *et al.*, 1989; Singhroy, 1989), and in the USA (Siegel, 1974, 2013). In Africa, indicator ground-based geobotanical work has been done in Botswana and Namibia (Cole, 1980; 1984; Cole *et al.*, 1986), Zaire (Duvigneaud and Brenan, 1966), and in Zimbabwe (Wild, 1974; Brooks and Yang, 1984). In the East African region, similar studies have also been undertaken with respect to fluorite and chromite mineralization (Odhiambo, 1988; Odhiambo *et al.*, 1989) and in Burundi (Singhroy, pers. comm., 1990). Chromite indicator plants were identified in Zimbabwe by Wild (1974). These plants aided greatly in the exploration and delineation of chromite deposits in that region.

The levels at which plants are used to discriminate geological differences in the landscape include the use of plants for general geological mapping (regional geobotany) purposes, and for specific identification of mineral deposits (indicator or target geobotany). How mineral uptake influences the spectral reflectance characteristics of plants is an attribute of spectral geobotany. It should not be over emphasised that these entry levels are at the forefront of the developments in geobotanical applications. These entry levels are briefly discussed in the following sections.

**Regional Geobotany**

The term regional (or *background*) geobotany was introduced by Singhroy (1987) and adopted by Bruce and Hornsby (1987) in attempts to make the geobotanical concept more applicable in an exploration setting. It relies on the geobotanical concept at the community level, rather than at the species level. As a result, it does not require the use of special sensors onboard an aircraft and instead, satellite imagery can be used, thereby reducing exploration costs in terms of data acquisition and processing. The regional concept is based on the premise that the nature and distribution of plant communities occur as a result of environmental conditions and therefore variations in distribution from the established norm for an area may be indicative of anomalous changes in the geology. The model, therefore, requires an understanding of the general ecological conditions of an area in terms of the relationships between the bedrock units, the sacrificial materials (including soils, topography and plant communities) and the resulting spectral patterns observed on remotely sensed imagery.

Figure 1 show five hypothetical case studies by Fortescue (1980) designed to illustrate the complexity and the caution necessary when attempting to interpret the geology of an area using vegetation, particularly with the aid of remote sensing data with little or no ground truth and auxiliary data. It is evident from this figure that a given vegetation community can represent several geological conditions.

Thus, regional geobotanical remote sensing studies have been met with varying degrees of success. This is because the success of the technique depends to a large extent on plant response to the varied and complex environmental factors, from the species level to the community level. From the many case studies on regional geobotanical remote sensing research carried out in different parts of the world, some general trends that can be grouped into three main categories have been identified.

First is the use of vegetation for general geological mapping; this is based on the structural factors of vegetation response. Second are analyses of the spectral response characteristics of whole vegetation communities to excess availability (or absence) of certain mineral elements in the subsurface - which leads to spectral anomalies in the vegetation. Third are observations of the taxonomic factors of vegetation response to different geological conditions.

The application of remote sensing data and different image enhancement techniques has been used by several researchers in attempts to identify suitable enhancements for the digital data that best depict distinct lithological units.

In a study undertaken in the Spanish-Portuguese pyrite belt, Banninger (1985) made a comparison between Landsat MSS and TM data for geobotanical prospection. In a similar study, Aranoff *et al.* (1986) used an integra-
ted approach in which a deposit model, Landsat imagery, and sacrificial geochemistry were used to develop a procedure for locating tungsten mineralization associated with shallow buried intrusions. Although in these studies it was found that the mineralized sites with distinct geological units and mineralization could be delineated using satellite data, it should be noted that in the classifications used the pixels that were known to fall on mineralized areas were given distinct values during image classification in order to locate the known sites of the mineral deposits. All the data were represented in the form of co-registered images which constituted an image data base.

Cole et al. (1986) used imagery of differing spectral and spatial resolutions from Landsat MSS, Landsat TM, SPOT and airborne Daedalus II line scanner for studies of lithological units and the location of mineralized sites in Africa and in the United Kingdom. In this study, imagery was also used in monitoring the seasonal vegetation changes related to water stress in Botswana and the UK. It was found that the detection of mineral deposits on remotely sensed images depends on the identification of the geobotanical anomalies at the community level. In Botswana, it was found that large geobotanical anomalies that are confined to the ground layer can be identified on satellite-based remotely sensed images if the tree canopy is sufficiently open and if uptake of a toxic element by the trees causes contrasts in reflectance with that of the neighbouring vegetation. They also concluded that the size of a deposit is an important factor for detection mineral anomalies in these areas using remotely sensed data.

Bedell (1987) used edge-detection analysis of satellite imagery for detecting gold deposits in Tanzania. He found that remote sensing can assist the exploration geologist by differentiating structures both temporally and spatially when investigating the frequency and geometry of edges in plan view. He found that this is particularly important when use is made of different Gaussian filters and false colour composites of multitemporal data, as they provide suitable images for lineament interpretation. However, lithological units were not discriminated in the study.

Regional geobotanical techniques have also been used for traversing un-mapped geological terrain (Singhroy, 1989; Bruce and Hornsby 1987; Bruce, pers. comm., June, 1992) during helicopter surveys in Guyana.

In this regard, the advancements in geobotanical techniques using remote sensing data for geological applications lies in the identification of lithological units which have been correlated to distinct vegetation communities (Plate 1). Image classification can involve application of standard statistically based decision rules in order to identify the land cover types for pixels in the image. Unsupervised classification can be undertaken prior to the fieldwork with the objective being of identifying natural classes that can be recognised and described in the field. The result of the classification is presented in Plate 2. In this classification most of the unclassified pixels correspond to shadowed areas.

**Plate 1:** FCC Landsat TM showing the structural geomorphology and geobotanical units West Pokot, Kenya

**Plate 2:** Unsupervised classification Landsat TM in which natural vegetation classes (Geobotanical Units) are identified

**Indicator Geobotany**

Indicator geobotany recognizes the vegetation composition and/or communities that occur on mineralized areas as indications of associated mineral deposits. From a historical perspective, it is emphasised that indicator geobotany has evolved to include elemental analysis of the mineral composition in plants that are associated with specific mineral deposits. In this regard, vast literature exists with respect to indicator geobotany. Many works that have been published by the USSR (Russian) Academy of Sciences were extensively reviewed by Cannon (1960); Malyuga (1964); Chikishev (1965); Brooks (1983); Kovalevsky (1987); Cwick (1987); Odhiambo (1993).

The uptake of chromium and its influence on vegetation is used in this section to demonstrate the realm of indicator geobotany. Several researchers (Rune, 1953; Proctor and Woodell, 1971; Morton, 1992; Lamb, 1993) have noted that serpentine rocks have distinct vegetation communities. Indeed, the presence of unusually sparse flora over ultramafic rocks has led to many studies of the reasons for this apparent infertility. Dating back as far as the 16th Century (in 1583), Caesalpino (cited in Proctor and Woodell, 1971) described a plant restricted to the Upper Tiber Valley in Tuscany near Florence, Italy. Such vegetation is sometimes referred to as the serpentine barrens (Lamb, 1993). Serpentine soils
have been shown to have very toxic effects on vegetation (Malyuga, 1964; Lyon et al., 1968). The chromium content of non-serpentinic soils is in the order of 100µg/g (ppm), whereas in serpentinic soils, chromium values around 5000µg/g (0.5%) are common; however, the range varies from 1000 to 25,000µg/g, with the latter commonly found in heavily leached tropical serpentine soils (Jaffre, cited in Brooks, 1987). As a result, these soils develop distinct vegetation communities. For example, Mouat (1982) observed that the foothills of the Sierra Nevada are covered by an open Ceanothus chaparral with scattered digger pine (H. sabinianna), while surrounding metasediments and metavolcanics are covered by an oak woodland and grassland. Similarly Miekel (in Mouat, 1982) described serpentine and non-serpentine vegetation in the Appalachian Piedmont. Miekel noted that the serpentine is characterized by a stunted tree flora with an open canopy dominated by Virginia pine (Pinus virginiana), post oak (Quercus stellata), and black oak (Q. Marilandica). Non-serpentine flora on the other hand is dominated by a robust tree flora with a closed canopy often dominated by chestnut oak (Q. prinus L.) and white oak (Q. alba). Proctor and Woodell (1971) stated that the most conspicuous feature of the Lizard Peninsula in Cornwall is the restriction of Minuartia verna to serpentine soils.

In the serpentine endemic plants of the Great Dyke in Zimbabwe, Brooks and Yang (1984) reported a maximum chromium concentration of 77µg/g (ppm). Similarly, Jaffre et al. (1979) reported a mean of 45µg/g in 17 species (132 specimens) of Geissois from New Caledonia, where Lee et al. (1977) found less than 10µg/g chromium in plants growing in soils containing up to 1% (10,000µg/g) of this element. Wild (1974a) also recorded high concentration of chromium (2400µg/g) in dried and up to 48,000ppm in ashed leaves of Satureja abysinnica, a Zambian serpentine endem, Wild (1974) also found 30,000ppm in the leaves of Dicoma niccolifera, and up to 15,000ppm in the leaves of Pearsonsonia metallifera. Brooks (1987) believed that the very high concentration values of chromium in plant ash could be due to contamination by wind-blown dust from the Noro chrome mine, since other specimens of the same species from other parts of the Great Dyke gave a maximum value of only 2µg/g chromium in dried leaves (Brooks and Yang, 1984). It should be noted that the geochemical conditions (mainly pH and Eh values) may be completely different in the area where Wild's (1974) samples were collected, when compared with the sites where Brooks and Yang (1984) sampled. These environmental conditions are not stated in either study. How the samples were prepared (i.e., whether ashed, or just dried and then digested) is also not indicated.

Geobotanical results, presented by Odhiambo (1993) reveal a clear decrease in species diversity from non-mineralized Precambrian Basement gneisses to mineralized serpentine host rocks. Variation in species composition is exemplified by the characteristic Protea - Faurea - Maerua - Satureja vegetation community that occurs on the mineralized geobotanical unit, which can also be clearly identified on remotely sensed data. The species Protea kilimandischarica is a characteristic indicator of the area around the chromite mineralization. It is an evergreen and does not shed its leaves. Satureja abyssinica is closely associated with the chromite deposits in the area; its tiny purplish-pink flowers together with its sweet minty smell, makes it a conspicuous herbal species. The Acacia - Dodonea - Combretum - Ficus vegetation community surrounding the chromite mineralization is similar to that recorded by Brooks and Malaisse (1985) around the Great Dyke in Zimbabwe. They also noted this vegetation community as not being exclusive to the known chromium and nickeliferous soils.

Plate 3 shows a water lily which belongs to the plant family Nymphaeaceae, growing in the mine water in abandoned Pb-Zn mine water was found to contain concentration value of more than 10,000ppm lead (Odhiambo, 2014). Since water lily is an apparent accumulator of lead, it can be effectively used in bioremediation of the mine waters that have high lead concentrations. The analytical data obtained from the study justifies detoxification of the mine waters.

Plate 3: Water lily (family Nymphaeaceae) in Pb-Zn mine waters.

Spectral Geobotany

This section elucidates the historical advancement of the remote sensing concept that was first envisaged by Socrates in c.400 BC. Spectral geobotanical approach in geobotanical remote sensing has also been referred to as target geobotany (Singhroy, 1987). It crystallizes the relationships between spectral properties of plants and the geochemical stress phenomenon. There is a need therefore to establish an understanding that the geochemical condition of the substrate influences spectral reflectance properties of plants (Odhiambo, 1993).

Today, spectral geobotanical investigations are widely used in geobotany since leaves of healthy, actively growing plants produce broadly similar spectral reflectance curves (Horler et al., 1980; Goetz et al., 1983; Milton and Mouat, 1984; Singhroy, 1989). Spectroradiometers with narrow spectral band working in the vegetation reflectance edge (the near infrared portion, also called the red-edge) of the electromagnetic spectrum have been developed in order to measure and quantify the distinct spectral changes. The variations in
absorption and spectral reflectance characteristics of plants have been related to pigment content, cellular structure, and to the moisture content of leaves (Cwick, 1987). Odhiambo (1993; 2008) used the SE590 Spectroradiometer to analyse spectral reflectance characteristics (from 380nm to 1200nm) of vegetation in relation to mineral concentrations.

Hyperspectral (imaging spectroscopy) remote sensing is currently being investigated by researchers with regard to the detection and identification of minerals, terrestrial vegetation, and man-made materials. The concept of hyperspectral remote sensing began in the mid-80 and is currently being used widely by geologists for the mapping of minerals. In hyperspectral imaging, actual detection of materials is dependent on the spectral coverage, spectral resolution, signal-to-noise ratio of the spectrometer, on the abundance of the material and the strength of absorption features for that material in the wavelength region measured (Lee and Landgrebe, 1993).

The degree of association between chromite pathfinder elements and independent spectral parameters at the red edge of the electromagnetic spectrum raises the question as to whether or not a purely prospective (as opposed to a retrospective) approach to mineral exploration using geobotanical methods is feasible. The results presented by Odhiambo (1993) indicate that it is possible both at the general level of interpretation and at the species specific level. In either case, a positive correlation implies that as the concentration of an element increases in the sample, the value of the independent spectral parameter also increases. Conversely, a negative correlation implies a decrease in the value of the independent spectral parameter as the concentration of the element increases.

**General Methodology for Geobotanical Studies**

The historical aspects of the methodologies used in geobotanical studies for mineral exploration are not clearly elucidated in the literature surveyed. The methodology is to be found only in the contemporary studies summarized in this section.

In planning a geobotanical study, the sampling procedures adopted should take into account the potential differences in metal uptake by different plant species and plant parts. In addition, the stages of maturity and seasonal cycles should be considered, as recommended by Thornton (1986). This is of practical importance because in temperate countries the maximum "elemental peak" in plants is restricted to the first week of spring (Canney et al., 1979; Banninger, 1985). In these regions, this factor greatly limits the timing of fieldwork for geobotanical studies. The timing of the studies also has a bearing on the spectral discrimination of annual and perennial plants in both temperate and tropical climates. During the dry season in the tropics, annual plants are absent and spectral reflectance from perennial plants becomes more conspicuous on satellite images.

Normally, a brief reconnaissance survey where transects and sampling plots are established on the geobotanical units map should be undertaken in order to identify locations for collecting samples. Transects should be established in a direction perpendicular to the general strike of the lithological units. The data used in geobotanical sampling research should be collected during two field seasons that should be selected to coincide with the driest time (months) of the year when vegetation is most stressed, and mineral concentrations in the subsurface are at their highest (Cole, 1983; Lyon et al., 1982). In both cases the sampling period should take as short a time as possible in order to minimise climatic variations that might influence element uptake by plants. Sampling should be during the same time of day to avoid any diurnal climatic impacts on the vegetation.

Wet seasons should be avoided since leaching of elements from plant leaves may occur (Brooks, 1983), and concentrations in the subsurface may be diluted by the excess water available in the soil due to heavy rainfall. A second reason for the dry season being ideal for geobotanical studies is that the atmosphere is relatively cloud-free. As a result, conditions for collection of spectral data are ideal and cloud free satellite imagery is easily selectable (Odhiambo, 1993). Finally, fieldwork is not impeded by impassable roads, which can occur during wet seasons in most tropical environments.

**Geobotanical Samples**

Geobotanical samples should be separated (where applicable) into twigs and leaves; the reason being that the two plant parts (organs) are known to concentrate different amounts of trace elements. In addition, each sample should be split several times to provide replicates. This enables repeated determinations to test the repeatability of analytical results obtained. Standard plant material should be used (or prepared) with which to compare the results from the analyses.

Sample preparation in geobotanical trace element analysis is of utmost importance, since, for example, the ashing technique preconcentrates the elements in plant material. The concentration levels so obtained are usually much higher (sometimes by a factor of about 20 fold) than the values obtained for the same samples when the material has simply been dried and then digested (Odhiambo, 1993).

Several studies (Brooks et al., 1985; Odhiambo, 1988; and Odhiambo, 2015) have shown that strong correlations exist between soil and plant element concentrations. So, when preparing for fieldwork and data collection, one should endeavour to find out if any previous mineral evaluation studies around the study area had been done. If the results of such a mineral assessment program are available and the quality of the results are acceptable for the purposes of the research, then no additional geochemical analysis of the soils and rock samples is necessary. It is recommended that only a few soil samples may be collected from selected sample sites (from soil sampling pits) in order to determine the soil pH and Eh, soil organic matter content and soil texture, since these physicochemical factors control uptake mineral elements by plants.

Although Malyuga (1964) and Brooks (1972) have recommended that two or three of the more dominant plant species be sampled so that at least one of them is present at each sample point, experience using a pre-
selected sampling grid has shown (Malyuga, 1964; Kapinsky, 1941 cited in Brooks, 1972; Brooks, 1984; Cole, 1986; Kovalevsky, 1987; Odhiambo et al., 1989; Odhiambo and Howarth, 1993a) that geobotanical indicator plants are not necessarily the dominant species. Thus, all species should be sampled indiscriminately from each sample point, during the first field season. This biogeochemical approach to mineral prospecting using vegetation is based on the continuum concept (Elliot, 1983), where vegetation can be used as biogeochemical samples without the need for mapping vegetation units. Furthermore, with respect to elemental uptake by plants, it has been demonstrated (Kovalevsky, 1987) that some plants are more informative (non-barrier) while others are not (barrier type), as illustrated in Figure 2.

![Figure 2: Types of biogeochemical samples](image)

At every pre-selected sample point, plants should be sampled after a careful scrutiny of all the plants at that location in order to observe any visible signs of morphological anomalies. Each plant sample should consist of the apical leaves of the plant. In the case of tree species, leaves are collected from several locations (limbs or branches) around the canopy. These are then mixed to make one sample of approximately 10 to 15g in weight. This recommendation is based on the result of several studies which have shown that the elemental content of leaves can vary greatly from one side of a plant to another, depending on the location of the mineral deposit. There seems to be a longitudinal passage of inorganic material from the roots of one side of a plant to the limbs on the same side (Cannon, 1964; Singhroy, pers. comm., Feb., 1993).

During the second field season, geobotanical sampling and spectral measurements should be undertaken simultaneously. Plants found in proximity to a mineralized site during reconnaissance and are also in the non-mineralized sites should be sampled. In this case sampling can then be focused on the two or three dominant species (as recommended by Malyuga, 1964, and Brooks, 1972) that were found by analyses from first season data to respond well to the mineralization.

In the chromite mineralization studies undertaken in West Pokot District of Kenya, Odhiambo (1993) found that with the exception of manganese, the other minor elements that are associated with the chromite mineralization (the pathfinder elements, namely nickel, cobalt, and chromium) are non-essential plant micro-nutrients. These heavy trace elements are not known to be essential for normal development of vascular plants (Siegel, 1974; Raven et al., 1976 cited in Singhroy, 1989). The non-essentiality in plant nutrition is an important factor in geobotanical studies since it has also been shown that the uptake of essential elements (such as calcium, potassium, sodium, phosphorous, and sulphur) is controlled by plants (Kovalevsky, 1987). In trace element analysis this factor (non-essentiality) usually results in negative biogeochemical anomalies (Odhiambo, 1988). Availability of the trace elements to plants has been observed to result in physiological and/or morphological changes in plants due to their toxicity (Cannon, 1960; Malyuga, 1964; Brooks, 1972; Rose et al., 1979).

In plant samples, statistical analyses of the trace element concentrations show typical negative skewness which is characteristic of geochemical data (Siegel, 1974; Al Ajely, 1984). The data can therefore be subjected to standard statistical treatment, in order to establish whether or not the concentration values obtained are true geochemical anomalies within the geochemical environment. Using all the concentration values obtained for each element assayed in a study, statistical threshold levels are calculated to determine the mean element concentration, local background concentration value, and local threshold concentration value for all the elements. The local background value (LBV) is determined as the mean element concentration plus one standard deviation, while the local threshold value (LTV) is the mean concentration plus two standard deviations. Concentration values higher than the local threshold value are considered to be anomalous, as recommended originally by Marmo (1958), Sayala (1979), and Rose et al. (1979). Once these thresholds are ascertained, concentration plots can be constructed using the biogeochemical data (Odhiambo, 1993). Results from a study around the chromite deposits in Kenya showed that smoothing biogeochemical data rids it of some spurious concentration values. Further, known sites of chromite mineralization are clearly depicted and the serpentinite host rock is also clearly depicted by the chromium, nickel and manganese anomalies.

The synthesis of the element concentration plots performed by Odhiambo (1993) using the standard smoothing technique shows that, even though the technique rids the data of some spurious concentration values, it is still fairly accurate in locating the known sites of the chrome/nickel deposits, especially when results are compared to those obtained by the experimental plots.

It is concluded that concentrations of the chromite pathfinder elements in geobotanical samples causes measurable spectral shifts at the red spectral edge of associated vegetation. The spectral response of plants to element concentration is species specific since, a given plant species responds uniquely to mineralization when compared to another plant species. This observation concurs with observations made in the works of Masuo-
ka (1981), Labovitz et al., (1983) and Singhroy (1989). Secondly, the spectral response of plants is element specific. In this case, the effects of one element on the independent spectral parameters were observed to be unique from those of another element. The chromite mineralization shifts the red edge of the associated plants towards shorter wavelengths.

**Summary**

The importance of selecting pathfinder elements for analysis, together with the need to use high resolution spectroradiometers for analysis of the spectral reflectance characteristics of plants for mineral concentration in the subsurface has been underscored (Odhiambu, 2008). The chromite indicator species were identified on the basis of high accumulations of the pathfinder elements, coupled with their persistent occurrence in proximity to the chromite mineral deposits. Results from West Pokot District of Kenya case study demonstrate how chromite deposits can influence the associated vegetation.

The following conclusions are made from the study undertaken in West Pokot District of Kenya. First is the concern of lack of standard reference material in geobotanical studies. These are essential to ensure the quality of the biogeochemical data. The second conclusion concerns the use of remote sensing since mineralized geobotanical unit are unique with respect to their spectral reflectance characteristics. It is evident that the delineation of geobotanical units is of particular importance for geobotanical remote sensing studies.

The anomalous concentrations of chromium were found in *Satureja abyssinica*, *Leucas tomentosa*, and in *Protea kilimaniskarica*. In these plants, the amount of chromium does not exceed 500 ppm. These concentrations are much lower than the chromium concentration values obtained by Wild (1974) from the serpentine endemics around the Noro Chromite Mine area in Zimbabwe. However, they are similar to the values obtained by Brooks (1972; 1987) and Brooks and Yang (1984). Therefore, for purposes of prospective geobotanical mineral exploration, the need to identify non-barrier plants like *Protea kilimaniskarica* and *Satureja abyssinica* seems critical.

It is concluded that concentrations of the chromite pathfinder elements in geobotanical samples causes measurable spectral shifts at the red spectral edge of associated vegetation. The spectral response of plants to element concentration is species specific since, a given plant species responds uniquely to mineralization when compared to another plant species. This observation concurs with observations made in the works of Masuoka (1981), Labovitz et al., (1983) and Singhroy (1989). Secondly, the spectral response of plants is element specific. In this case, the effects of one element on the independent spectral parameters were observed to be unique from those of another element. The chromite mineralization shifts the red edge of the associated plants towards shorter wavelengths.

Following from the conclusions presented above, five recommendations made below arise mainly from the studies undertaken in Kenya and from observations made over the years in publications on geobotanical applications.

The first recommendation concerns the lack of standard reference material for use in geobotanical studies. There are two issues; first is the lack of any adequate reference standards. Secondly there are also no reference standard samples against which the spectra of different plants and their derived independent spectral reflectance parameters can be compared. The second issue necessitates the identification of an appropriate plant as a reference standard.

The second recommendation stems from the availability of chromium (and other elements) in the biogeochemical environment. It is evident that the chromite-tolerant plant species are associated with the mineralization. Therefore, the general lack of awareness among exploration geologists and environmentalists, as to the power of geobotanical research in mineral exploration, and the niche it occupies in environmental biogeochemistry and geoepidemiology raises the need to carry out further studies. The effectiveness of the technique in mineral exploration should be assessed, in exploration programs.

The third recommendation concerns measurement of pH and conductivity (Eh) conditions of associated soils. These conditions are not usually presented in the results of similar studies. They are essential in understanding geochemical availability of an element around a mineral deposit. These parameters should always be measured. Similarly, sample preparation technique used should always be clearly presented. This is because, for example, ashing of plant material preconcentrates the elements present in the sample as compared to plant material that is simply digested and then analysed. Such an approach would facilitate comparisons of the concentration ranges of chromium (or other elements of interest) in similar geobotanical studies from different regions.

Lastly, spectral geobotanical datasets are usually very large and should therefore be archived in a "central spectral data bank". This would facilitate quick referencing of the spectral reflectance parameters of plant samples from different geographical regions of the world.

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