DETECTION OF NICKELIFEROUS ROCKS BY ANALYSIS OF HERBARIUM SPECIMENS OF INDICATOR PLANTS

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(Received June 24, 1976; revised version accepted October 18, 1976)

ABSTRACT


Nearly 2000 herbarium specimens and 232 species of the genera Homalium and Hybanthus were analysed for nickel in order to identify plant accumulators of nickel which were indicative of nickeliferous (usually ultrabasic) rocks. The specimens were originally collected from all parts of the tropical and warm-temperate World between latitudes 40°N and 40°S. They represented a sampling density of about 1 specimen per 2000 km². The survey resulted in the re-identification of all previously known hyperaccumulators (>1000 μg/g on dry-weight basis) of nickel (five species) and in the discovery of five additional species (all from New Caledonia) from these two genera.

Fourteen previously unknown strong accumulators (100-1000 μg/g) of nickel were also discovered, most of which were growing over ultrabasic rocks.

From the collection localities of the accumulators, it was possible to pinpoint many of the World’s major ultrabasic areas in warm temperate and tropical regions. The principle of the method should be applicable to other genera and other elements.

INTRODUCTION

Because the elemental content of most plants reflects to some extent the nature of the substrate on which they are growing, inorganic analysis of plant material is of importance to geologists, biogeochemists and exploration geochemists. Such analyses have been used to locate mineral deposits and to identify areas potentially favourable for the discovery of certain types of mineralization (Brooks, 1972; Malyuga, 1964). Ultrabasic rocks, which are characteristically high in nickel, are of considerable importance because they are often hosts for economic deposits of nickel, chromium, platinum and other metals.

Relatively few plants are able to accumulate concentrations of nickel
exceeding 15 μg/g on a dry weight basis, unless they are growing over ultra-basic rocks, in which case nickel concentrations of 25–50 μg/g may be found (Lyon et al., 1970). Values above 100 μg/g are uncommon, even for an ultra-basic environment, and values exceeding 1000 μg/g are restricted to a small group of highly unusual plants which may be termed hyperaccumulators.

The term hyperaccumulator is used in this report to refer to the concentration in the plant, irrespective of the concentration in the substrate.

The already published list of hyperaccumulators of nickel now including eleven species: *Alyssum bertolonii* (Minguzzi and Vergnano, 1948); *Dicoma macrocephala* (Wild, 1970); *Dicoma niccolifera* (Wild, 1971); *Geissois pruinosa* and *Homalium guillainii* (Jaffré and Schmid, 1974); *Homalium kanaliense*, *Hybanthus austrocaledonicus* and *Hybanthus caledonicus* (Brooks et al., 1974); *Hybanthus floribundus* (Severne and Brooks, 1972; Cole, 1973); *Psychotria douarrei* (Jaffré and Schmid, 1974); *Sebertia acuminata* (Jaffré et al., 1976).

Except for the two *Dicoma* species (Rhodesia), *H. floribundus* (Australia) and *A. bertolonii* (Italy), all these hyperaccumulators are from New Caledonia.

The interest in nickel hyperaccumulators has arisen partly because of their possible significance in mineral exploration and partly because of the interesting problems in plant chemistry and physiology presented by high accumulations of an element which is normally toxic to vegetation at such concentrations.

The presence of several species of the genera *Homalium* and *Hybanthus* in the list of hyperaccumulators, raises the question as to whether this nickel-accumulating ability is a world-wide characteristic of these genera, or whether it is confined to New Caledonian and Australian species. The World's herbaria contain well over 200 million plant specimens which have been collected over the past 150 years, and which to date have seldom been used for other than taxonomic purposes.

Analysis of herbarium specimens would be a simple, rapid and inexpensive method of carrying out such a world-wide survey but very little work of this nature seems to have been done in the past. Some years ago, 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 sheets for collection localities of other specimens of these species without actually analysing herbarium material. It appears that the only record of the analysis of phanerogams from herbaria is the work of Chenery (1948) who carried out an analysis for aluminium in over 4000 herbarium specimens. His method was, however, semi-quantitative and required a leaf sample of over 6 cm² in area. More recently, Goodman and Roberts (1971) analysed bryophytes from herbaria to monitor atmospheric pollution. The paucity of work involving analysis of herbarium material probably reflects the fact that it is only in recent years that instrumentation has progressed far enough to allow for the...

* Probably identical with *A. murale* (Malyuga, 1964).
analysis of samples sufficiently small to satisfy the requirements of herbarium curators.

For the work reported in this paper, more than fifty herbaria throughout the World were approached for small samples of leaf material from their collections of Homalium and Hybanthus. Thirty-five of these institutions (Table I) supplied material.

These samples were analysed for the nickel content in an attempt to find additional nickel accumulators and nickeliferous rocks. Although the nature of the substrate is often unknown for herbarium specimens, studies on known nickel accumulators (Severne and Brooks, 1972; Brooks et al., 1974; Jaffré and Schmid, 1974) have shown that nickel values over 1000 µg/g (dry weight) are only associated with plants growing over ultrabasic rocks. These and other studies showed that values from 100 to 1000 µg/g were invariably associated with ultrabasic areas, except occasionally for plants growing over laterites not overlying ultrabasic rocks, where values of up to 200 µg/g were found. Analysis of a sufficient number of each species of these plants should enable a distinction to be made between nickel levels characteristic of ultrabasic environments and those typical of more acidic substrates.

ANALYTICAL PROCEDURES

Dried leaf samples with an average weight of about 0.03 g, (about 1 cm²) were placed in 5-cm³ borosilicate test-tubes and ignited at 500°C in a muffle furnace. The ash in each tube was then dissolved in 1 cm³ of 2M hydrochloric acid. The solutions were analysed for nickel by atomic absorption spectrophotometry. Corrections for non-atomic absorption were made by using a hydrogen continuum lamp. All concentration data were expressed on a dry-weight basis. To convert to an ash weight basis all values should be multiplied by 15.

RESULTS AND DISCUSSION

General

The genera Homalium (Flacourtiaeceae) and Hybanthus (Violaceae) comprise approximately 240 and 150 species respectively. The co-operating herbaria provided 1926 specimens for analysis, including 128 Homalium and 104 Hybanthus species. Because of space limitations, precise collection localities are not given but can be furnished by the authors on request.

Fig. 1 shows those species of which at least one specimen had an anomalously high nickel level (>15 µg/g dry weight). The figure shows the number of specimens analysed and the range of nickel values found. Any extremely high value differing by more than a factor of two from the remainder of the range is specially indicated by broken lines. Occasionally there are low va-
<table>
<thead>
<tr>
<th>Country</th>
<th>Institution</th>
<th>Address</th>
</tr>
</thead>
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<tr>
<td>Argentina</td>
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<td>San Miguel de Tucuman</td>
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<td>Argentina</td>
<td>Museo de Ciencias Naturales</td>
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<td>Herbarium Australiense, C.S.I.R.O.</td>
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<td>O.R.S.T.O.M.</td>
<td>Nouléa</td>
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<td>Manila</td>
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<td>Portugal</td>
<td>Centro Botanico</td>
<td>Lisbon 3</td>
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<td>Bolus Herbarium, Univ. of Cape Town</td>
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<td>Botanical Res. Inst., D.S.I.R.</td>
<td>Durban</td>
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<td>National Herbarium</td>
<td>Pretoria</td>
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<td>Sweden</td>
<td>Inst. Systematic Bot., Univ. of Uppsala</td>
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<td>United States</td>
<td>Academy of Natural Sciences</td>
<td>Philadelphia, Pa.</td>
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<td>United States</td>
<td>New York Botanic Garden.</td>
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</tr>
<tr>
<td>United States</td>
<td>Univ. of Missouri Herbarium</td>
<td>Columbia, Mo.</td>
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Fig. 1 Range of nickel concentrations (μg/g dry weight) in Homalium and Hybanthus species containing at least one value higher than 15 μg/g. Extreme values differing by more than a factor of two from others are shown by broken lines. For each species, the country or countries of origin of specimens with anomalous values are indicated by the following code: AN = Australia (Northern Territory), AQ = Australia (Queensland), AS = Australia (South Australia), AW = Australia (Western Australia), B = Borneo, BR = Brazil, C = Cameroons, CH = China (Hainan), CO = Colombia, CU = Cuba, F = Fiji, G = Guatemala, GU = Guyana, H = Honduras, I = India, M = Malaya, MX = Mexico, NC = New Caledonia, NG = New Guinea, P = Paraguay, PA = Panama, PH = Philippines, PR = Puerto Rico, R = Rhodesia, RU = Ruanda Urundi, SL = Sierre Leone, SU = Sudan, US = United States, V = Venezuela, Z = Zaïre.
values which are anomalous and these are also shown by broken lines. The figure clearly illustrates the predominance of New Caledonia as a source of hyperaccumulators (> 1000 μg/g) and strong accumulators (100–1000 μg/g) of nickel.

**Identification of nickeliferous (ultrabasic) substrates**

Tables II and III give additional data for hyperaccumulators and strong accumulators of nickel. All specimens were taken from different sites and where possible, the nature of the substrate was determined from a knowledge of the sample locality.

Although this herbarium survey was carried out at a very low sampling density over a large part of the Earth between the equator and the 40° latitudes, it delineated many of the World’s major ultrabasic areas (i.e. Cuba, Puerto Rico, the Philippines, Western Australia and New Caledonia). In the hypothetical case that none of these areas had been known before the survey, it is clear that a number of important finds would have been made. It is therefore not unreasonable to expect that surveys of this nature could be used to delineate previously unknown ultrabasic areas in geologically poorly mapped areas elsewhere.

**The discovery of additional nickel-accumulating plants**

This work has resulted in the discovery of five new hyperaccumulators (Table II) and fourteen strong accumulators (Table III) of nickel. The effectiveness of the herbarium survey is further shown by the fact that all previously known hyperaccumulators of nickel were “rediscovered” without the necessity of field work.

Perhaps the discovery of these new nickel-accumulating plants will stimulate fresh research into the ecology and plant chemistry of these species with particular reference to their significance in mineral exploration.

**The regional distribution of nickel-accumulating plants**

Tables II and III show the peculiarly regional distribution of nickel accumulators. All the hyperaccumulators of the genus *Homalium* are confined to New Caledonia. Sleumer (1974) has recognized sixteen species of *Homalium* in New Caledonia. Of these, seven were hyperaccumulators and four were strong accumulators. New Caledonia also has two hyperaccumulators of the genus *Hybanthus*.

Outside of New Caledonia, only one other hyperaccumulator (from these genera) is known (*H. floribundus* from Western Australia).
### TABLE II

Hyperaccumulators (>1000 µg/g dry weight) of nickel

<table>
<thead>
<tr>
<th>Species</th>
<th>Total No.</th>
<th>No. above 1000 µg/g</th>
<th>Locality</th>
<th>Highest Ni conc. (µg/g dry weight)</th>
<th>Nature of substrate</th>
</tr>
</thead>
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<tr>
<td><em>Homalium</em></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td><em>austrocaledonicum</em> Sleum.</td>
<td>6</td>
<td>4</td>
<td>New Caledonia</td>
<td>1805</td>
<td>ultrabasic</td>
</tr>
<tr>
<td><em>deplanehei</em> Warb.</td>
<td>10</td>
<td>2</td>
<td>New Caledonia</td>
<td>1850</td>
<td>ultrabasic</td>
</tr>
<tr>
<td><em>francis</em> Guillaumin Briq.</td>
<td>7</td>
<td>7</td>
<td>New Caledonia</td>
<td>14500</td>
<td>ultrabasic</td>
</tr>
<tr>
<td><em>guillainii</em> Briq.</td>
<td>2</td>
<td>2</td>
<td>New Caledonia</td>
<td>6926</td>
<td>ultrabasic</td>
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<tr>
<td><em>kanalense</em> Briq.</td>
<td>6</td>
<td>5</td>
<td>New Caledonia</td>
<td>9420</td>
<td>ultrabasic</td>
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<tr>
<td><em>mathieuanum</em> Briq.</td>
<td>3</td>
<td>1</td>
<td>New Caledonia</td>
<td>1694</td>
<td>ultrabasic</td>
</tr>
<tr>
<td><em>rubrocostatum</em> Sleum.</td>
<td>2</td>
<td>1</td>
<td>New Caledonia</td>
<td>1157</td>
<td>ultrabasic</td>
</tr>
<tr>
<td><em>Hybanthus</em></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>austrocaledonicus</em> Schinz et Guillaumin</td>
<td>4</td>
<td>4</td>
<td>New Caledonia</td>
<td>13760</td>
<td>ultrabasic</td>
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<tr>
<td><em>coledonicus</em> (Turcz.) Cretz.</td>
<td>11</td>
<td>2</td>
<td>New Caledonia</td>
<td>5917</td>
<td>ultrabasic for values &gt;1000 µg/g</td>
</tr>
<tr>
<td><em>floribundus</em> F. Muell.</td>
<td>13</td>
<td>2</td>
<td>W. Australia</td>
<td>6660</td>
<td>ultrabasic for values &gt;1000 µg/g</td>
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</table>

### TABLE III

Strong accumulators (100–1000 µg/g dry weight) of nickel

<table>
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<tr>
<th>Species</th>
<th>Total No.</th>
<th>No. above 100 µg/g</th>
<th>Locality</th>
<th>Highest Ni conc. (µg/g dry weight)</th>
<th>Nature of substrate</th>
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</thead>
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<tr>
<td><em>Homalium</em></td>
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<td></td>
<td></td>
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<td><em>angustifolium</em> Keay</td>
<td>5</td>
<td>1</td>
<td>Sierra Leone</td>
<td>155</td>
<td>unknown</td>
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<td><em>decurrens</em> Briq.</td>
<td>5</td>
<td>1</td>
<td>New Caledonia</td>
<td>176</td>
<td>various incl. ultrabasic</td>
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<tr>
<td><em>gitingense</em> Elmer</td>
<td>2</td>
<td>2</td>
<td>Philippines</td>
<td>144</td>
<td>unknown</td>
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<tr>
<td><em>le-ratorum</em> Guillaumin</td>
<td>7</td>
<td>4</td>
<td>New Caledonia</td>
<td>643</td>
<td>various incl. ultrabasic</td>
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<td><em>panayum</em> F. Villar</td>
<td>11</td>
<td>1</td>
<td>Philippines</td>
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<td>ultrabasic</td>
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<tr>
<td><em>pleandrum</em> Blake</td>
<td>3</td>
<td>2</td>
<td>Puerto Rico</td>
<td>343</td>
<td>ultrabasic</td>
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<td><em>rubginosum</em> Warb.</td>
<td>1</td>
<td>1</td>
<td>New Caledonia</td>
<td>397</td>
<td>ultrabasic</td>
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<tr>
<td><em>serratum</em> Guillaumin</td>
<td>6</td>
<td>1</td>
<td>New Caledonia</td>
<td>116</td>
<td>ultrabasic</td>
</tr>
<tr>
<td><em>Hybanthus</em></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>brevifolius</em> Dominc.</td>
<td>4</td>
<td>1</td>
<td>W. Australia</td>
<td>229</td>
<td>ultrabasic</td>
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<tr>
<td><em>linearifolius</em> Urb.</td>
<td>11</td>
<td>1</td>
<td>Cuba</td>
<td>107</td>
<td>ultrabasic</td>
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<tr>
<td><em>malpighifolius</em> Standley</td>
<td>1</td>
<td>1</td>
<td>Mexico</td>
<td>638</td>
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<td><em>setigerus</em> Ball.</td>
<td>3</td>
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<td>Brazil</td>
<td>130</td>
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<td><em>wrightii</em> Urb.</td>
<td>2</td>
<td>1</td>
<td>Cuba</td>
<td>350</td>
<td>ultrabasic</td>
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<tr>
<td><em>yuatanensis</em> Millsp.</td>
<td>12</td>
<td>1</td>
<td>Mexico</td>
<td>134</td>
<td>unknown</td>
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</table>
CONCLUSIONS

The survey has been successful in showing that herbarium specimens may be used to discover new accumulator plants, and to indicate areas of specific geology.

There is no reason why the same principles should not be applied to other genera for other elements. In the present survey, the nickel content of vegetation was used to delineate geology. Nickel itself was not the specific target. Mineral deposits of many elements would be too localised for herbarium surveys to be of use. This is not, however, true of some porphyry copper deposits where mineralization can extend over a large area and could possibly be determined by a herbarium survey.

To date, herbaria have been most co-operative in furnishing small samples for this work, but this attitude may well change if inordinately heavy demands are made upon their services. Curators of herbaria have to maintain a fine balance between providing material for research and preserving irreplaceable specimens; this requirement is likely to prove the most serious limiting factor for future surveys of this nature.

ACKNOWLEDGEMENTS

The authors would like to express their deep appreciation to the 35 herbaria (Table I) who so generously contributed material for this survey.

REFERENCES


