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Review of the use of regional geochemical maps for identifying areas where mineral deficiencies or excesses may affect cattle productivity in tropical countries.

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## CONTENTS

### SUMMARY

1. Introduction

2. Economic implications of mineral deficiencies in grazing livestock

3. Incidence of mineral deficiencies and toxicities in tropical regions

4. Characteristics of mineral deficiencies and toxicities in tropical regions
   - 4.1 Cobalt
   - 4.2 Copper and molybdenum
   - 4.3 Fluorine
   - 4.4 Iodine
   - 4.5 Iron and manganese
   - 4.6 Magnesium
   - 4.7 Phosphorus
   - 4.8 Potassium
   - 4.9 Selenium
   - 4.10 Sodium and chloride
   - 4.11 Sulphur
   - 4.12 Zinc

5. Factors influencing mineral requirements

6. Sources of minerals for grazing livestock

7. Factors affecting the mineral content of soils and plants

8. Diagnosis and mapping of mineral deficiency and toxicity in grazing livestock
   - 8.1 Sampling media
     - 8.1.1 Animal tissue and fluids
     - 8.1.2 Forage
     - 8.1.3 Soils
     - 8.1.4 Drainage sediments
   - 8.2 Discussion
   - 8.3 Conclusions

Page

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Introduction</td>
</tr>
<tr>
<td>2</td>
<td>Economic implications of mineral deficiencies in grazing livestock</td>
</tr>
<tr>
<td>3</td>
<td>Incidence of mineral deficiencies and toxicities in tropical regions</td>
</tr>
<tr>
<td>4</td>
<td>Characteristics of mineral deficiencies and toxicities in tropical regions</td>
</tr>
<tr>
<td>5</td>
<td>Factors influencing mineral requirements</td>
</tr>
<tr>
<td>6</td>
<td>Sources of minerals for grazing livestock</td>
</tr>
<tr>
<td>7</td>
<td>Factors affecting the mineral content of soils and plants</td>
</tr>
<tr>
<td>8</td>
<td>Diagnosis and mapping of mineral deficiency and toxicity in grazing livestock</td>
</tr>
<tr>
<td>8.1</td>
<td>Sampling media</td>
</tr>
<tr>
<td>8.1.1</td>
<td>Animal tissue and fluids</td>
</tr>
<tr>
<td>8.1.2</td>
<td>Forage</td>
</tr>
<tr>
<td>8.1.3</td>
<td>Soils</td>
</tr>
<tr>
<td>8.1.4</td>
<td>Drainage sediments</td>
</tr>
<tr>
<td>8.2</td>
<td>Discussion</td>
</tr>
<tr>
<td>8.3</td>
<td>Conclusions</td>
</tr>
</tbody>
</table>
Application of drainage sediment geochemical maps for animal mineral (trace element) status investigations in tropical countries

9.1 Samburu-Marsabit region, Kenya
9.2 Swaziland
9.3 Northern Sumatra
9.4 Northeast Zimbabwe
9.5 Harare region, Zimbabwe
9.6 Eastern Bolivia
9.7 Sierra Leone
9.8 Uganda and Solomon Islands

10 Conclusions
11 Further investigations
12 Acknowledgements
13 References
SUMMARY

Although undernutrition is accepted as the most limiting factor to grazing livestock production in tropical areas, mineral (trace element) deficiencies or imbalances in soils and forages have long been known to be responsible for low production and reproduction problems among grazing livestock in many developing countries. It is, therefore, important to identify those areas where mineral (trace element) deficiencies or toxicities are negatively affecting cattle productivity. For grazing livestock, deficiencies of Co, Cu, I, Fe, Mn, Se and Zn together with excesses of Cu, F, Mn and Mo have been recognised. In addition, As, Pb, Cd, Hg and Al are toxic to animals.

As farming systems in developing countries progress and farmers are encouraged to seek higher levels of productivity from forage fed livestock, the deficiencies or imbalances of minerals in their forage will become more important and more necessary to correct even if they do not present obvious clinical symptoms. Apart from some notable exceptions such as the goitres of iodine deficiency and dental mottling and skeletal deformities associated with excess fluoride, few deficiency or toxicity syndromes induced by anomalous intakes of trace elements are distinguished by diagnostically specific clinical symptoms. Screening large numbers of animals for evidence of mineral deficiency without first recognising which areas to target, would be an expensive and laborious process and would probably be subject to variations due to season, climate and physiological status at the time of sampling. The diagnosis and mapping of areas with trace element deficiency or toxicity problems in grazing livestock has generally been executed by mapping forage, animal tissue or fluid compositions. Unfortunately this is not only an expensive procedure, but it may be unsuitable for mapping large areas.

The term mineral is usually used by veterinary scientists and in animal husbandry to describe major (e.g. Ca, Cl, P, K, Na, Mg and S) and trace (Cu, Co, Fe, I, Mn, Mo, Se, Zn etc.) elements although in many publications trace element is used as an alternative to mineral. The terms macrominerals and microminerals are also used instead of major and trace elements. As most geochemical surveys are concerned with trace elements (e.g. Cu, Co, Mo, Zn), the term trace element is used in this report instead of microminerals. The term mineral is used where major or both major and trace elements are being described.
Regional geochemical mapping is a relatively rapid, cost-effective and reliable method of providing a data base on the levels of trace elements in the environment. In this report the relevance of regional drainage geochemistry for mapping areas which may have animal trace element deficiency and toxicity problems is investigated by comparing the results of local soil-plant-animal studies with regional and national drainage sediment geochemical maps. Regional drainage sediment geochemical mapping surveys designed to identify mineral deposits have been carried out in many developing countries including Bolivia, Kenya, Sierra Leone, Solomon Islands, Sumatra, Swaziland, Uganda and Zimbabwe. This report examines the potential for the application of this existing mineral exploration regional geochemical data for animal health studies.

Although geochemical maps often indicate areas where deficiencies in cattle might occur, the maps should not be considered to provide a definitive indication of areas with potential deficiency problems. The report is intended to increase awareness of the potential for inter-disciplinary studies in this field and also to demonstrate to veterinary scientists that the prudent use of regional geochemical data can be of value in predicting the risks of trace element deficiencies and/or toxicities in grazing livestock.

In view of the importance of demand-led research and of socio-economic/cultural factors in affecting successful uptake, it is suggested that further studies should be concentrated in areas where:-(a) productivity is generally low, without a specific cause such as lack of fodder, having been identified, and (b) there is a good possibility that farmers wish to increase productivity and would be prepared to pay for additional inputs. Controlled trials, demanding a considerable amount of time and resources, would be required to prove the economic viability of mineral supplementation. However, in cases where there is a reasonable indication of which microminerals are limiting, it may be justifiable to include them with macromineral supplements (P, Na, Cl) as a type of insurance, until analysis and production data verify that a particular micromineral is required.

If follow-up veterinary studies recommended in this report verify that drainage geochemical maps correlate well with dietary mineral deficiencies confirmed by mineral supplementation trials for productive livestock, then this should confirm the value of geochemical mapping as a cost effective method of identifying areas and elements where
deficiency or toxicity might occur. The maps could, therefore, be used to indicate the need for further specific veterinary investigations and correction (through supplementation) in the interests of achieving higher levels of animal productivity. Finally, it is important to remember that in many developing countries, energy, protein or P deficiencies may mask trace element deficiencies and the effects of these will not appear until the more limiting deficiencies have been rectified.

The Centre for Tropical Veterinary Medicine (CTVM), Edinburgh University was commissioned to carry out a one month literature search and study of the mineral status of livestock and pastures in the tropical countries covered by the current report. The objective of the review was to investigate the potential for correlating existing documented reports of mineral status in these countries with the geochemical distributions given in the current report. The CTVM review (BGS Technical Report WC/92/60) should be read in conjunction with the current report.

The study was carried out under Project 91/16 Environmental Geochemistry as part of the ODA/BGS R&D Programme in Developing Countries, forming part of the British Government aid programme. The project seeks to (1) investigate the feasibility of using regional geochemical data, including that from ODA sponsored mineral exploration surveys, for environmental studies in developing countries, (2) compare drainage sediment and soil as sampling media for environmental geochemical surveys and (3) initiate multidisciplinary studies of the significance of natural and anthropogenic trace element deficiencies and excesses in determining the causes of animal and human nutritional diseases. The Overseas Development Administration also partly funded the geochemical surveys in Bolivia, Kenya, Sierra Leone, Solomon Islands, Sumatra, and Zimbabwe through various technical cooperation projects. Permission to use regional geochemical data sets was granted by the Directors of the Geological Survey of Zimbabwe and the Directorate of Mineral Resources (Indonesia). Tacit approval to use regional geochemical data for Bolivia, Kenya, Sierra Leone, Solomon Islands, and Swaziland is assumed in the absence of any response from the Directors/Chief Geologists of the respective Geological Surveys.
1 INTRODUCTION

Although undernutrition is accepted as the most limiting factor to grazing livestock production in tropical areas, trace element deficiencies or imbalances in soils and forages have long been thought to be responsible for low production and reproduction problems among grazing livestock in many developing countries (McDowell et al., 1983). For grazing livestock, deficiencies of Co, Cu, I, Fe, Mn, Se and Zn together with excesses of Cu, F, Mn and Mo have been recognised. As, Pb, Cd, Hg and Al are toxic to animals. Deficiency problems are less common in non-ruminants as they tend to receive a greater variety of feeds produced from a larger area. Their trace element diet is therefore more varied, and usually less deficient or extreme.

In most developing countries there are no comprehensive data on the background levels of trace elements in the environment. Without these data, veterinary scientists, planners and other government authorities cannot identify chemical factors that may have animal health implications. The diagnosis and mapping of areas with deficiency or toxicity problems in grazing livestock has generally been executed by mapping forage, animal tissue or fluid compositions. Unfortunately this is not only an expensive procedure, but it may also be unsuitable for mapping of large areas due to localised variations in soil chemistry which will be reflected in forage composition variations. Significant variations between forage plant species and with forage maturity further complicate forage composition mapping.

It has been recognised for many years that there is a close relationship between trace element concentrations in rocks, the drainage sediments and soils derived from them, and trace element deficiency problems in cattle (Webb and Atkinson, 1965; Thornton, 1983; Aggett et al., 1988). Regional geochemical mapping is generally accepted as being a cost-effective method of establishing the levels of trace elements in the surface environment. The major geochemical factors controlling baseline levels of elements in drainage sediments include catchment lithology, chemical mobility, climate, topography, dispersion and dilution of metals during transport (Plant and Raiswell, 1983). Geochemical mapping was originally designed to aid the detection of potentially economic concentrations of metalliferous minerals but there is now an increasing trend toward using geochemical mapping techniques for environmental studies (Aggett et al., 1988; British Geological Survey, 1990, 1991; Plant and Moore, 1979; Plant, 1983; Plant and Stevenson, 1985; Thornton, 1983; Webb and Atkinson.)
1965). Regional geochemical maps indicate the levels of chemical elements in the environment and provide information on their distribution and dispersion. They can be used to delineate areas with natural and anthropogenic trace element deficiencies or excesses that could prejudice animal health.

Regional drainage sediment geochemical mapping surveys designed to identify mineral deposits have been carried out in many developing countries including Bolivia, Kenya, Sierra Leone, Solomon Islands, Sumatra, Swaziland, Uganda and Zimbabwe (Plant et al., 1988). In order to provide essential background information, this report includes a review of (1) the economic importance of trace element imbalances in grazing livestock and the extensive distribution of trace element deficiencies and toxicities in tropical regions, (2) deficiency and toxic characteristics of 15 elements, (3) factors influencing animal mineral requirements, (4) sources of minerals (5) factors affecting mineral content of plants, (6) methods used for the diagnosis of mineral imbalances, and (7) procedures for mapping areas which may be subject to mineral imbalances. Following the background review, regional geochemical maps for Cu, Co, Mn, Mo and Zn are evaluated in order to see if existing mineral exploration regional geochemical data can be used to identify areas where trace element deficiencies or excesses may affect cattle productivity. Unfortunately, no data are available for F and Se. The correlation between low concentrations of Cu, Co, and Zn in drainage sediment geochemical samples and known trace element deficiencies in grazing livestock and wildlife is demonstrated in Swaziland and Kenya. Animal health implications of geochemical maps for Northeast Zimbabwe, the Harare region of Zimbabwe, eastern Bolivia, northern Sumatra and northern Sierra Leone, which show extensive areas of low trace element concentrations, are also discussed.

Finally, the report outlines additional multi-disciplinary studies required to demonstrate the relationship between stream sediment, soil, forage and animal tissue/fluid chemistry thereby permitting an in-depth assessment of the relevance of regional stream sediment geochemical mapping for identifying areas that may be subject to Cu, Co, Mn, Zn, Se and I deficiencies or toxicities in animals. In addition proposals are made to develop a cost-effective strategy for low density sampling of high order drainage channels with catchment areas of 100 to 400 km².
The term mineral is usually used by veterinary scientists and in animal husbandry to describe major (eg. Ca, Cl, P, K, Na, Mg and S) and trace (Cu, Co, Fe, I, Mn, Mo, Se, Zn etc.) elements although in many publications trace element is used as an alternative to mineral. The terms macrominerals and microminerals are also used instead of major and trace elements. As most geochemical surveys are concerned with trace elements (eg. Cu, Co, Mo Zn), the term trace element is used in this report instead of microminerals. The term mineral is used where major or both major and trace elements are being described.

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2 ECONOMIC IMPLICATIONS OF MINERAL DEFICIENCIES IN GRAZING LIVESTOCK.

Mineral deficiencies or imbalances in forages are partly responsible for low production and reproduction problems among grazing livestock in developing countries (McDowell et al., 1983). Following reports from South Africa in the 1920’s that P supplementation produced improved overall performance with weight gains of 20-30%, there have been numerous studies of increased productive performance related to mineral supplementation.
Table 1: Latin American, African and Asian studies on effects of mineral supplementation on calving percentages (from McDowell et al., 1984)

<table>
<thead>
<tr>
<th>Country</th>
<th>Control</th>
<th>Supplement</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bolivia</td>
<td>67.5</td>
<td>80.8</td>
<td>55°</td>
</tr>
<tr>
<td>Bolivia</td>
<td>73.8</td>
<td>86.4</td>
<td>7°</td>
</tr>
<tr>
<td>Brazil</td>
<td>55.0</td>
<td>77.0</td>
<td>55°</td>
</tr>
<tr>
<td>Brazil</td>
<td>49.0</td>
<td>72.0</td>
<td>55°</td>
</tr>
<tr>
<td>Brazil</td>
<td>25.6</td>
<td>47.3</td>
<td>55°</td>
</tr>
<tr>
<td>Colombia</td>
<td>50.0</td>
<td>84.0</td>
<td>55°</td>
</tr>
<tr>
<td>Panama</td>
<td>62.2</td>
<td>68.8</td>
<td>55°</td>
</tr>
<tr>
<td>Panama</td>
<td>42.0</td>
<td>80.0</td>
<td>55°</td>
</tr>
<tr>
<td>Peru</td>
<td>25.0</td>
<td>75.0</td>
<td>55°</td>
</tr>
<tr>
<td>Philippines</td>
<td>57.0</td>
<td>79.0</td>
<td>10</td>
</tr>
<tr>
<td>Philippines</td>
<td>76.0</td>
<td>80-82</td>
<td>55°</td>
</tr>
<tr>
<td>South Africa</td>
<td>51.0</td>
<td>80.0</td>
<td>86.8°</td>
</tr>
<tr>
<td>Thailand</td>
<td>49.0</td>
<td>67.0</td>
<td>93</td>
</tr>
<tr>
<td>Uruguay</td>
<td>48.0</td>
<td>64.0</td>
<td>55°</td>
</tr>
<tr>
<td>Uruguay</td>
<td>86.9</td>
<td>96.4</td>
<td>55°</td>
</tr>
<tr>
<td>Uruguay</td>
<td>27.0</td>
<td>70.0</td>
<td>6</td>
</tr>
</tbody>
</table>

*aControl animals received only common salt (NaCl).  
bBone meal.  
cBone phosphate.  
dComplete mineral mixture.  
eDicalcium phosphate + triple superphosphate.  
fDicalcium phosphate + copper sulphate.  
gComplete reference to the source of these values is cited by McDowell & Conrad (55).

For the 16 trials given in Table 1, the mean calving percentage was 76% for animals receiving additional mineral supplementation compared with only 53% for animals receiving only salt. Reports of improved weight gains through supplementation are summarised in Conrad and McDowell (1978). An investigation in Colombia (CIAT, 1977) evaluated in Miles and McDowell (1983) demonstrated that mineral supplementation significantly increased all cattle production parameters (Table 5 in McDowell et al; 1984). Assuming that the costs of mineral (trace element) supplements are proportionally small compared with production gains, the economic benefits of supplementation to national economies should be significantly high. It is, therefore, critically important to identify those areas where mineral deficiencies or toxicities are negatively affecting cattle productivity.
3. INCIDENCE OF MINERAL DEFICIENCIES AND TOXICITIES IN TROPICAL REGIONS

Mineral deficiencies and excesses have been reported from most regions of the world, but the problem appears to be particularly severe in developing countries in the tropics (Table 2 and Figs 1-3; mineral deficiencies or toxicities are confirmed or highly suspected (McDowell et al. (1984)). In addition to the countries indicated in Table 2 and Figs 1-3, Cu deficiency has been reported in the Gulf Emirates, Japan, Tasmania and New South Wales; Co deficiency in Australia; and Se deficiency in Libya, Israel, Egypt, the Gulf States and Zimbabwe (C.F. Mills and J. Ridgway, pers. comm.) In developing countries especially, grazing livestock depend on local forage for their mineral requirements. McDowell (1976) and McDowell et al. (1984) showed that within the tropical regions of Africa, Latin America and Asia, I deficiency has been reported in most countries, Co, Cu, Se and Zn deficiency in 20-34 countries and Fe and Mn deficiency in 4-7 countries. The mineral most likely to be deficient is P followed by Co and Cu although Na and I deficiencies are also very widespread. Co and Cu are more likely to be detrimental to animal health than Na or I (McDowell, 1976). Se, Mo and F toxicity is widespread throughout the tropics. This is a provisional list and will be extended as further research is carried out but it does give an indication of the magnitude of the problem.

A survey of Latin American forages (McDowell et al., 1977) showed marginal or deficient trace element levels in many areas. Deficient levels were recorded for Co in 43% of forage samples, Cu in 47%, Fe in 24%, Mn in 21% and Zn in 75% thus confirming that Zn, Cu and Co are likely to be the most common trace element deficiencies in tropical areas.

Trace element deficiencies may be confounding factors in cattle diseases caused primarily by other factors. In the Eastern Plains of Colombia, where a wasting disease (secadera) is caused by acute thiamine deficiency complicated by Zn, Cu and less frequently Co and Se deficiency, McDowell et al. (1985a) showed that 80-100% of soils and 70-100% of forage samples were deficient in Cu, Zn and to a lesser extent also in Co and Se. Excess Mo, with 26-72% above the critical level, may be complicating the secadera problem because it can produce a secondary Cu deficiency.
Table 2. Geographical locations of mineral deficiencies or toxicities for ruminants in the tropical countries of Latin America, Africa and Asia (27, 52, 56, 64)

<table>
<thead>
<tr>
<th>Deficient Elements</th>
<th>Calcium</th>
<th>Magnesium</th>
<th>Phosphorus</th>
<th>Potassium</th>
<th>Sodium</th>
<th>Sulphur</th>
<th>Cobalt</th>
<th>Copper (or molybdenum toxicity)</th>
<th>Iodine</th>
<th>Manganese</th>
<th>Selenium</th>
<th>Zinc</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Argentina, Bolivia, Brazil, Colombia, Costa Rica, El Salvador, Guatemala, Guyana, India, Malawi, Mexico, Panama, Peru, Philippines, Senegal, Surinam, Uganda, Venezuela, Zaire.</td>
<td>Argentina, Brazil, Chile, Colombia, Costa Rica, Guatemala, Guyana, Haiti, Honduras, Jamaica, Kenya, Malawi, Peru, Surinam, Trinidad, Uganda, South Africa, Uruguay, Venezuela.</td>
<td>Antigua, Argentina, Bolivia, Botswana, Brazil, Ceylon, Chile, Colombia, Costa Rica, Cuba, Dominican Republic, Ecuador, El Salvador, Egypt, Ghana, Guatemala, Guyana, Haiti, Honduras, India, Indonesia, Jamaica, Kenya, Malagasy Republic, Malawi, Malaysia, Mexico, Nicaragua, Nigeria, Panama, Paraguay, Peru, Philippines, Puerto Rico, Senegal, Somalia, South Africa, Surinam, Swaziland, Tanzania, Trinidad, Ugan da, Uruguay, Venezuela, Zaire, Zimbabwe.</td>
<td>Brazil, Haiti, Panama, Swaziland, Uganda, Venezuela.</td>
<td>Bolivia, Brazil, Chad, Colombia, Dominican Republic, Guatemala, Kenya, Malawi, New Guinea, Nigeria, Panama, Philippines, Senegal, Somalia, South Africa, Surinam, Swaziland, Thailand, Uganda, Uruguay, Venezuela.</td>
<td>Brazil, Colombia, Ecuador, Uganda.</td>
<td>Argentina, Brazil, Colombia, Costa Rica, Cuba, Egypt, El Salvador, Guyana, Haiti, India, Indonesia, Katanga, Kenya, Malaysia, Mexico, Nicaragua, North Africa, Peru, Philippines, South Africa, Surinam, Uganda, Uruguay, Zaire.</td>
<td>Argentina, Bolivia, Brazil, Colombia, Costa Rica, Cuba, Dominican Republic, Ecuador, El Salvador, Ethiopia, Guatemala, Guyana, Haiti, Honduras, India, Indonesia, Kenya, Malaysia, Malawi, Mexico, Panama, Peru, Philippines, Senegal, South Africa, Sudan, Surinam, Swaziland, Tanzania, Trinidad, Uruguay, Venezuela, Zaire, Zimbabwe.</td>
<td>Worldwide.</td>
<td>Argentina, Brazil, Burma, Costa Rica, Panama, South Africa, Uganda.</td>
<td>Bahamas, Bolivia, Brazil, Colombia, Costa Rica, Dominican Republic, Ecuador, Guyana, Honduras, Indonesia, Malawi, Mexico, Paraguay, Peru, South Africa, Swaziland, Thailand, Uganda, Uruguay, Venezuela.</td>
<td>Argentina, Bolivia, Brazil, Colombia, Costa Rica, Dominican Republic, Ecuador, El Salvador, Guatemala, Guyana, India, Indonesia, Kenya, Malawi, Mexico, Panama, Peru, Philippines, Puerto Rico, South Africa, Swaziland, Uganda, Uruguay, Venezuela.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Toxic Elements</th>
<th>Fluorine</th>
<th>Manganese</th>
<th>Selenium</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Algeria, Argentina, Ecuador, Guyana, India, Mexico, Morocco, Saudi Arabia, South Africa, Tanzania, Tunisia.</td>
<td>Brazil, Costa Rica, Indonesia, Peru, Surinam.</td>
<td>Argentina, Brazil, Central African Republic, Chad, Chile, Colombia, Ecuador, Honduras, India, Iran, Kenya, Madagascar, Mexico, Nigeria, North Africa, Peru, Puerto Rico, South Africa, Sudan, Upper Volta, Venezuela.</td>
</tr>
</tbody>
</table>
Fig 1. Tropical countries in which copper (Cu) deficiency or molybdenum (Mo) toxicity in grazing cattle have been reported (after McDowell et al., 1983)
Fig 2. Tropical countries in which cobalt (Co) deficiency in grazing cattle has been reported (after McDowell et al., 1983)
Fig 3. Tropical countries in which selenium (Se) deficiency and toxicity in grazing cattle have been reported (after McDowell et al., 1983)
4 CHARACTERISTICS OF MINERAL DEFICIENCIES AND TOXICITIES IN TROPICAL REGIONS

The most important characteristics of a range of macro- and micromineral deficiencies and toxicities are outlined below. Reference should be made to McDowell et al. (1984) and Mertz (1986, 1987) for further details and bibliographic reference sources.

4.1 Cobalt

Cobalt deficiency is largely restricted to grazing ruminants that have little or no access to mineral (trace element) concentrates. The clinical signs of Co deficiency, including poor appetite, lack of vigour, muscle wasting and low body weight are often difficult to distinguish from those of malnutrition related to a low protein, low calorie diet. Sub-clinical deficiency, characterised by low production rates, is very common and causes considerable economic losses. Co-deficient cattle respond quickly to Co supplementation. Co deficiency should be assessed using livestock growth data, haemoglobin and cobalt/vitamin B₁₂ together with Co supplementation trials (C.F. Mills, pers.comm.)

4.2 Copper and molybdenum

Copper (Cu) is probably the second most deficient trace element for grazing livestock in the tropics although most cases are related to constituents such as Mo, S and other factors which produce a "conditioned" Cu deficiency even though normal amounts of Cu (6-16 mg kg⁻¹) occur in forage. In general, Cu deficiencies usually occur when forage Mo exceeds 3 mg kg⁻¹ and Cu is below 5 mg kg⁻¹. Ward (1977) recognised four categories of Cu deficiency in which feed contained (1) high Mo (> 20 mg kg⁻¹), (2) low Cu but relatively high Mo in a ratio of 2:1, (3) very low Cu (< 5 mg kg⁻¹) and (4) normal Cu and low Mo but with high levels of soluble protein related to high intake of fresh pasture. In this situation, Cu deficiency results from the high levels of sulphide produced in the rumen which in turn produces high levels of copper sulphide from which the Cu cannot be absorbed. The clinical signs of Cu deficiency include scouring, rough and bleached hair, slow growth and loss of body weight, pale membranes of the eyes and mouth and in some case heart lesions. All symptoms are not shown by all Cu deficient animals and many may have other causes. Cu toxicity is thought to be largely confined to sheep.
4.3 Fluorine

Although fluorine (F) is an essential element for animals, the requirements are extremely low and only toxic effects are likely to be important for grazing livestock. Chronic fluorosis in grazing livestock is usually associated with either drinking high F water (3-15 mg kg$^{-1}$ or more), continuous consumption of high-F mineral supplements and grazing F-contaminated forages adjacent to industrial plant emitting F-rich fumes, such as Al smelters. Plant F rarely exceeds 1-2 mg kg$^{-1}$ as most plants cannot absorb larger amounts. Cattle are less tolerant to F than other animals. Defluorinated phosphates should be fed to cattle rather than fertilizer rock phosphates which are commonly very rich in F (2-3%). Fluorine toxicity is a widespread and major problem (C.F. Mills, pers. comm).

4.4 Iodine

Iodine deficiency is characterised by general weakness, stunted growth, still born animals with goitre, suppression of oestrus periods in the female and lack of libido in the male. Iodine deficiency remains a very serious problem in many tropical countries, both for livestock and humans. Low intake of I is the primary cause of I deficiency but the intake of goitrogens, that interfere with I utilisation, also causes I deficiency problems. Goitrogenic substances are common in Brassica species (eg. rape, kale and turnips) as well as soyabean meal. Diagnosis of severe I deficiency is based on the clinical evidence of goitre; sub-clinical I deficiency may be detected by low levels of the thyroid stimulating hormone (thyroxine) in serum or milk I concentration which is very sensitive to dietary intakes. Marginal I deficiency is difficult to detect because of the poor relationship to feed I concentration. In addition a relationship to Se deficiency is becoming evident (C.F. Mills, pers.comm.)

4.5 Iron and manganese

Acid tropical soils are generally rich in Fe and Mn so that forage levels are generally in excess of requirements and deficiencies are unusual in the tropics. Clinical signs suggesting a Mn deficiency have been reported from Costa Rica and the Mato Grosso region of Brazil. Detection of Mn deficiency is aided by liver analysis and Fe by haemoglobin and percent saturation of transferrin. Excesses of Fe and Mn may interfere with the metabolism of other minerals. High Mn in forages on volcanic soils in a region of Costa Rica are considered to have resulted in low reproductive rates of cattle.
4.6 Magnesium

Magnesium deficiency has been recorded in at least 19 countries in the tropics (McDowell et al., 1984). Mg exerts a strong influence on neuromuscular activity. Hypomagnesemic tetany is encountered in grazing ruminants and susceptibility to grass tetany is increase in older ruminants. Up to 20% of animals in individual herds may have tetany although in most endemic areas only a small proportion of cattle (1-2%) are affected. Non-clinical hypomagnesemia is much more common than clinical tetany and this has substantial economic consequences. Grass tetany is usually prevented by Mg fertilization of pastures, adding Mg to feed or salt blocks and avoiding the use of high K fertilizers. Mg deficiency is best monitored through analysis of urine which tends to be a more reliable than pasture analysis.

4.7 Phosphorus

Phosphorus is the most deficient mineral in grazing cattle in the tropics where soils and plants are low in P. For much of the year, cattle graze on mature forages containing less than 0.15% P. Total soil P is often quite high in tropical soils but much of it is held in insoluble Al and Fe complexes and therefore not available to plants. Bovine botulism and apophosphorosis result from severe P deficiency with cattle exhibiting subnormal growth, low reproduction and a depraved appetite that may lead to bone chewing. Bovine botulism results when phosphorus-deficient cattle chew bones on which accompanying tags of flesh contain the toxin Clostridium botulinum. This has been observed in South Africa, Senegal and Brazil (McDowell et al., 1984).

4.8 Potassium

K deficiency is not considered to be a major problem for grazing livestock in tropical countries since young forages generally contain adequate levels of K. However, it is possible that K deficiencies may occur during extended dry seasons as K decreases with increasing forage maturity. K deficiency is difficult to diagnose as it is characterised by non-specific "signs" such as slow growth, lowered feed efficiency, nervous disorders, emaciation, stiffness, and muscular weakness. Dietary K concentration is the best guide to K status as evaluation based on tissue analysis is not reliable.
4.9 Selenium

Forage with >5 mg kg\(^{-1}\) Se is usually toxic to grazing livestock whereas deficiency symptoms commonly occur when Se is below 0.1 mg kg\(^{-1}\). Selenium toxicity is usually associated with seleniferous soils, especially where these are alkaline. Liming can increase Se toxicity by increasing plant concentrations. Chronic Se poisoning is characterised by dullness, emaciation, rough hair coat, soreness, stiffness and lameness caused by erosion of the joints, atrophy of the heart and cirrhosis of the liver. Remedial measures include soil treatment to reduce availability, treatment with As to reduce adsorption and increase excretion and modification of the diet by rotation to low-Se pastures. Seleniferous areas have been identified in Colombia and Se toxicity in more than 20 tropical countries (Table 2).

Se deficiency in ruminants can cause reduced growth and nutritional muscular dystrophy (commonly known as white muscle disease) in lambs and calves and poor reproductive performance in older animals. White muscle disease is characterised by subnormal Se and GSH-Px concentrations in the blood and tissues and by abnormally high levels of serum glutamic oxaloacetic transaminase (SGOT). High incidence of retained placentas in cattle in Brazil has been reduced by the administration of adequate dietary Se (McDowell et al., 1983). Subnormal growth rate and "unthriftiness" with rapid loss of weight and sometimes mortality can be prevented by Se treatment after which marked increases in growth are usually recorded. Selenium deficiency has been recognised in 20 tropical countries (Table 2) and can be treated by a Se mineral supplement, Se fertilization of forage producing areas, Se injections or Se-ruminal pellets. Various aspects of selenium diseases and their prevention in animal husbandry are reviewed in Låg (1991).

4.10 Sodium and chloride

Na deficiency is very common amongst grazing livestock in the tropics and can easily be overcome by the provision of common salt licks. Natural forage is generally deficient in Na and in the tropics high Na losses occur in sweat. Lactating animals suffer most from lack of salt.

4.11 Sulphur

Sulphur is involved in the synthesis of protein so S deficient animals show signs of protein malnutrition. Blood lactate and dietary S levels are considered to be the most reliable indicators of S status. Deficiencies have been reported in Brazil, Colombia, Equador and
Uganda (McDowell et al., 1984). Sulphur is implicated in Se toxicity and also in Cu deficiency, where high levels of sulphide produced in the rumen generates high levels of copper sulphide from which the Cu cannot be absorbed.

4.12 Zinc

Zinc deficiency in grazing livestock is characterised by reduced feed intake, growth rate and feed efficiency followed by skin disorders (parakeratosis skin disorder), hair loss, inflammation of the nose and mouth and stiffness of the joints. Zn deficiency also affects various stages of the reproductive process and development in both males and females. All animals with these deficiency symptoms respond positively to Zn administration. 15 countries in Latin America have reported Zn deficiencies on the basis of clinical and/or serum and forage concentrations. It has also been recognised as being a problem in India (Arora, 1988).

Supplemental Zn can be provided by feeding mineral salts containing 20 to 30 mg kg⁻¹ Zn.

5 FACTORS INFLUENCING MINERAL (TRACE ELEMENT) REQUIREMENTS

A wide variety of factors influence mineral requirements of grazing livestock including type and level of production, age, chemical form of elements, mineral intake, breed and adaptation, element inter-relationships (Ca-P, Fe-P, Al-P, Ca-Zn, Cu-Mo, Cu-Fe, Se-As-S, K-Na-Mg) as well as vitamins D, E, B₁₂, goitrogenic substances, oxalic acid and phytic acid. Mineral deficiencies vary with season, in some cases being lower in the wet season whereas in other cases they are more common during the dry season.

6 SOURCES OF MINERALS (TRACE ELEMENTS) TO GRAZING LIVESTOCK

In the absence of mineral supplements, except, perhaps for common salt, grazing livestock in many tropical countries depend almost exclusively on forage and ingested soil for their trace element (mineral) requirements. Unfortunately tropical forages rarely satisfy trace element requirements with the result that deficiencies are recorded in many countries (Table 2 and Figs. 1-3). Although some minerals are ingested through water and soil, mineral contents are very variable, and in the case of soil may not be adsorbed in the digestive tract. Soil ingestion may lead to higher trace element intakes (especially of Co, I, Fe and Mn) but
these may not be in an available form as Co and Fe are usually held in insoluble primary and secondary minerals. Annual soil ingestion may reach up to 600 kg for grazing livestock. Toxic elements may also be ingested in soil whilst in other cases soil ingestion may decrease the apparent and true P adsorption and, depending upon soil composition, the utilisation of Ca (Rosa, 1980; C.F.Mills, pers.comm.).

7 FACTORS AFFECTING THE MINERAL (TRACE ELEMENT) CONTENT OF SOILS AND PLANTS

A comprehensive review by Reid and Horvath (1980) of the main factors that control the transfer of trace elements from rocks to soils, plants and then to animals includes 334 references. The main sources of trace elements and the pathways to plants, animals and man are illustrated in Figure 4. Rocks are the parent material from which trace natural element concentrations are derived and it has been recognised for many years that there is a close relationship between trace element concentrations in rocks, the drainage sediments and soils derived from them, plants and trace element deficiency problems in cattle (Webb and Atkinson, 1965). Wu and Låg (1988), for example, showed that the geographical distribution of selenium deficiency diseases in Norway corresponds well with the distribution of selenium levels in soils. In some cases, low Se is associated with high Fe (C.F.Mills, pers.comm.).

The characteristic concentrations of elements in the major rock types are summarised in Table 3. Low levels of Co associated with granites and low Cu, Co and Zn in sandstones frequently result in animal trace element deficiencies whereas high Mo in black shales often produces Mo-induced Cu deficiency in ruminants.
Fig. 4 A diagram of the main sources and pathways of transfer of trace elements (minerals) to animals and man (Allaway, 1968 and Reid and Horvath, 1980).

The major geochemical factors controlling baseline levels of elements in drainage sediments and soils include the composition of the parent rock or superficial drift, chemical mobility, climate, topography, together with dispersion and dilution of metals during transport (Plant and Raiswell, 1983). In the temperate regime in Scotland, Ure (1985) showed that soil trace element contents closely correspond to parental geological materials (either bedrock or drift, depending on various factors) although there was in general considerable small scale geographical variation. Further details on mineral concentrations in soils and the factors that determine mineral uptake by plants are given by Reid and Horvath (1980).

The most important factors governing trace element concentrations and availability in plants are (1) soil acidity (pH), (2) soil moisture and drainage conditions, (3) soil temperature
and seasonal variations, (4) plant species and (5) fertilization. Weathering and soil forming processes and chemical speciation within soil control the release of trace elements to plants. In tropical and sub-tropical areas, for example, laterisation, rapid destruction of organic matter and extensive leaching exert a significant influence. Other important factors controlling mineral intake by ruminants include soil ingestion and the relationship between mineral concentrations in plants and animal requirements. Plants generally provide adequate supplies of K and possibly also Mn and Zn whereas animal demands for Cl, Co, I, Na, and Se frequently can not be satisfied by plants and may lead to deficiency problems.

McDowell et al. (1985b) briefly reviewed soil-plant relationships as determinants of the geographical distribution of trace element related diseases in animals in tropical regimes. In general, only a fraction of the total trace element (mineral) concentration in soils is taken up by plants. Soil, plant species, maturity stage, yield, pasture management and climate all affect forage trace element concentrations. It is generally accepted that most natural examples of trace element deficiencies in animals are associated with specific regions and can be directly related to soil characteristics. Older, more acid, coarse and sandy geological formations especially in tropical regions where high rainfall and temperature produce rapid weathering and extreme leaching are associated with trace element deficiencies in ruminants. In addition, trace elements held in relatively insoluble iron hydroxides in laterite and lateritic soils are relatively unavailable to plants. The availability and uptake of Fe, Mn, Zn, Co and Cu decrease as the soil alkalinity increases whereas Mo and Se uptake increases (Mitchell, 1971; Maskall and Thornton, 1991). Liming can increase Se or Mo toxicity by increasing plant concentrations and at the same time cause Co and Mn deficiencies by lowering plant available concentrations. In addition, the availability of some elements (such as Mn and Co) may increase under poor drainage conditions. Increased crop yields through fertilization may also produce deficiencies by dilution and removal of trace elements due to increased growth rates. Trace element concentrations in plants vary considerably in different species growing on the same soil and also vary with maturity.
<table>
<thead>
<tr>
<th>Elements</th>
<th>Ultramafic igneous</th>
<th>Basaltic igneous</th>
<th>Granitic igneous</th>
<th>Shales and clays</th>
<th>Black shales</th>
<th>Deep Sea clays</th>
<th>Limestones</th>
<th>Sandstones</th>
<th>Phosphorites</th>
<th>Coals (ash)</th>
</tr>
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<tbody>
<tr>
<td>Calcium</td>
<td>2–100</td>
<td>30–150</td>
<td>4–30</td>
<td>18–120</td>
<td>20–200</td>
<td>0.02–2.0</td>
<td>0.01–0.22</td>
<td>0.001–0.3</td>
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<td>2–40</td>
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<td>46 000</td>
<td>1500–9400</td>
<td>15 000</td>
<td>7000</td>
<td>21 000</td>
<td>47 000</td>
<td>7000</td>
<td>1800</td>
<td>5670</td>
</tr>
<tr>
<td>Phosphorus</td>
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<td>1190</td>
<td>600–920</td>
<td>700</td>
<td>b</td>
<td>1500</td>
<td>400</td>
<td>170</td>
<td>133 000</td>
<td>400</td>
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<tr>
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<td>0.2–13.8</td>
<td>0.2–10</td>
<td>0.2–10</td>
<td>0.2–10</td>
<td>0.6–9.7</td>
<td>0.4–188</td>
<td>0–2000</td>
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<td>20</td>
<td>20</td>
<td>20</td>
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<td>10</td>
<td>2</td>
<td>20</td>
<td>200</td>
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<td>0.001–0.004</td>
<td>0.001–0.004</td>
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<tr>
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<td>0.005</td>
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<td>0.005</td>
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<td>Chromium</td>
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<td>40–600</td>
<td>2–90</td>
<td>30–590</td>
<td>26–100</td>
<td>b</td>
<td>b</td>
<td>b</td>
<td>30–3000</td>
<td>10–1000</td>
</tr>
<tr>
<td>Cobalt</td>
<td>90–270</td>
<td>24–90</td>
<td>1–15</td>
<td>5–25</td>
<td>7–100</td>
<td>b</td>
<td>b</td>
<td>b</td>
<td>30–300</td>
<td>2–200</td>
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<tr>
<td>Copper</td>
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<td>30–160</td>
<td>2–30</td>
<td>18–120</td>
<td>20–200</td>
<td>b</td>
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<td>b</td>
<td>10–100</td>
<td>2–40</td>
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<td>Fluorine</td>
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<td>0.005–0.05</td>
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<tr>
<td>Iodine</td>
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<td>0.5</td>
<td>0.5</td>
<td>0.5</td>
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<tr>
<td>Iron</td>
<td>94 000</td>
<td>86 500</td>
<td>14 000–30 000</td>
<td>47 200</td>
<td>20 000</td>
<td>65 000</td>
<td>38 000</td>
<td>7000</td>
<td>7000</td>
<td>3500</td>
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<tr>
<td>Lead</td>
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<td>2</td>
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<td>b</td>
<td>b</td>
<td>&lt;1–31</td>
<td>1–150</td>
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<td>5</td>
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<td>15</td>
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<tr>
<td>Mercury</td>
<td>0.004–0.5</td>
<td>0.002–0.5</td>
<td>0.005–0.05</td>
<td>0.005–0.05</td>
<td>0.005–0.05</td>
<td>0.005–0.05</td>
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<td>0.005–0.05</td>
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<td>Molybdenum</td>
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<td>0.05</td>
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<tr>
<td>Nickel</td>
<td>270–3600</td>
<td>45–410</td>
<td>2–20</td>
<td>20–250</td>
<td>10–500</td>
<td>b</td>
<td>b</td>
<td>b</td>
<td>10–1000</td>
<td>3–100</td>
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<td>Selenium</td>
<td>200</td>
<td>140</td>
<td>8</td>
<td>2</td>
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<td>2</td>
<td>20</td>
<td>20</td>
<td>3–100</td>
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<tr>
<td>Vanadium</td>
<td>17–300</td>
<td>50–360</td>
<td>9–90</td>
<td>30–200</td>
<td>50–1000</td>
<td>b</td>
<td>b</td>
<td>b</td>
<td>10–100</td>
<td>0–700</td>
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<tr>
<td>Zinc</td>
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<td>48–240</td>
<td>5–140</td>
<td>18–180</td>
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<td>165</td>
<td>20</td>
<td>20</td>
<td>20–300</td>
<td>7–100</td>
</tr>
</tbody>
</table>

*The upper figure is the range usually reported, the lower figure the average. **Not available. ***Early single step spectrographic reporting. ****Not including anomalies with contents 10–1000 times the average, particularly those from the Donets Basin, Kerch-Taman, and Crimea, U.S.S.R. Table compiled by M. Fleischer and H.L. Cauvin. Reproduced from Geochemistry and the Environment, Vol. III (1978), with permission of the National Academy of Sciences, Washington, DC.
A comprehensive survey by Russell and Duncan (1956) of the relationship between mineral levels in pastures and soils and the occurrence of mineral deficiency and toxicity diseases in grazing livestock led the authors to recommend that an integrated investigation of soil, plant and animal factors was needed for diagnosing and resolving mineral imbalance diseases in livestock. This approach was further developed by Kubota and Allaway (1972), Allaway (1975), Reuter (1975) and Underwood (1977). Reuter (1975) outlined a diagnostic approach involving (1) determination of water and exchangeable trace elements concentrations in soils, (2) plant analysis as an indicator of the plant available trace element status of soils, (3) blood and tissue analysis and (4) determination of enzyme activity and metabolite accumulation in plant and animal tissues.

Whereas the most reliable method of confirming deficiencies is probably by mineral (trace element) supplementation trials, the problem with this is its high cost in time and resources. Clinical, pathological, biochemical, soil, water, plant, animal tissue and animal fluid analyses have all been used to diagnose trace element deficiencies and excesses. Although extreme cases of trace element deficiency and toxicity are often readily diagnosed on the basis of clinical or pathological characteristics, diagnosis of sub-clinical cases is complicated by the fact that many of the symptoms of mild and transient trace element imbalances, such as unthriftiness, subnormal growth and reproduction, may also be caused by energy and protein deficiencies and the effects of parasites. Diagnosis of sub-clinical cases must rely on chemical and biological analyses. Critical concentrations in tissues and forage indicating mineral deficiencies or toxicities for cattle have been summarised by McDowell (1976) and McDowell et al., (1983, 1984) but no values are given for soils (contrary to the statement in McDowell et al, 1985b).

8.1 Sampling media

8.1.1 Animal tissue and fluids

Mills (1970) and Underwood (1977) described the use of blood and enzyme analysis in detecting trace element imbalances in cattle and sheep. In tropical regimes, McDowell et al., (1983, 1985b) considered that forage and tissue analyses are the best predictors of mineral
problems and reported the use of Se, Co, Ca and P forage analyses, together with Co and Cu in liver and P in serum. Tissue analysis appears to be a reliable indicator for Se and Cu deficiency or excess, but is more problematic with Mn and Zn in so far that few tissues reflect well the dietary intakes of these minerals (McDowell, pers.comm.)

McDowell et al. (1984) considered that animal tissue and fluid analyses reflect more accurately the total dietary environment (soil, water, pasture) than soil or forage analyses. In general, animal tissue and fluid mineral values significantly and consistently below or above critical (normal) levels should be considered as suggestive but not conclusive evidence of dietary excess or deficiency. However, there appears to be a considerable potential for misinterpretation of animal tissue and fluid analyses (McDowell et al., 1984). As mineral (trace element) analyses, especially of animal tissue and fluid samples, are expensive and complicated, the selection of the minimum number of samples of the optimum type is critically important.

8.1.2 Forage

The use of forage analysis to assess trace element status may be confused by problems of defining the plant species, amounts consumed, element availability and also by soil contamination of forage samples. Mineral concentrations in plants vary considerably in different species growing on the same soil. In addition, Cu, Co, Fe, Se, Zn and Mo tend to decline with maturity: as is also the case with the macrominerals P, Mg, K, Na, and Cl (Underwood, 1981). These are important factors to consider when using plant mineral concentrations as a guide to potential animal deficiencies because the species and degree of maturity will significantly affect mineral concentrations. In general, McDowell et al. (1984) considered that forage was a more diagnostic sampling medium than soil.

8.1.3 Soils

There is a long chain of processes between soil mineral content and effects of mineral deficiency/imbalance on cattle productivity, which could either remove or enhance the chance of mineral deficiencies becoming economically important. This chain starts with differential uptake by different plant species; continues with variation in partitioning between different parts of plants; selection of species and parts of plants by ruminants in general and also differences between animal species in their selectivity; different susceptibilities to mineral deficiencies between animal species; and different requirements for different physiological
states (lactation, growth etc.). Thus it is not surprising that correlations among soil, plant and animal tissue trace element concentrations are highly variable and often low or non-existent (McDowell et al., 1983). Conrad et al. (1980) reported soil-forage correlations for Fe (r=0.12), Mn (-0.12) and Zn (0.30) in Brazil, although these values are difficult to interpret as no significance limits are given. Forage-tissue correlations of up to 0.5 were reported by Mtimuni (1982) in Malawi, although the significance levels are again not known. Lower correlations coefficients are reputed to have been determined in Bolivia (McDowell et al., 1982). In Guatemala, 94-100% of forage, plasma and liver samples indicated copper deficiencies while all soil samples contained supposedly adequate concentrations (McDowell, pers. comm.). Similar discrepancies have been noted in eastern Bolivia (CTVM, 1992). This implies that the soil chemical extraction procedures may not provide a good indication of plant available mineral concentrations.

Whereas in some areas it has been shown that there is a lack of correlation between soil and plant chemistry, a soil survey can often provide a reasonably accurate indication of potential livestock deficiencies. The close relationship between trace element concentrations in rocks and the soils derived from them to trace element deficiency problems in grazing livestock has been described by Webb and Atkinson (1965), Kubota et al. (1967), Allaway, (1975), and Wu and Låg 1988).

Ure (1985), evaluated the use of soil trace element data in the assessment of trace element supply to plants and animals in temperate regimes. An assessment of the trace element status can be attained by analysis of total trace element contents of the B horizon soils. Ure (1985) gave the diagnostic levels for deficiency or excess as 5-10 ppm Co, 5-15 ppm Cu and >3 ppm Mo in B-horizon soils. The equivalent levels in Ap horizons of mineral soils (pH 6) are <0.6 ppm Co (acetic acid extractable), <3 ppm Cu (EDTA extractable) and >0.08 ppm Mo (NH₄ acetate extractable). All levels refer to the < 2 mm soil size fraction so if a finer fraction is analysed, or if <150 micron drainage sediment samples are used as a guide to soil concentration, then these diagnostic levels might be significantly higher due to the enrichment of Co, Cu, Mo in the fine fraction of soils and sediments.

In the discussion to Ure (1985), it was pointed out that there was no international agreement on chemical extractants and that the value of the extractants varied with soil type. Research into the use of extractant soil trace element levels as indicators of plant uptake dates
back to the 1950's when Mitchell et al. (1957) suggested that the EDTA extraction was a promising tool for the assessment of copper status of crops and that EDTA was probably superior to acetic acid for the determination of cobalt status. Ure (1985) considered that acetic acid extraction is appropriate for plant available Co determinations whereas EDTA is more appropriate for Cu. Ure (1985) concluded that B horizon trace element data may be more effective for long term mapping because liming or drainage will influence extractable trace element contents in surface soils. In general, the determination of extractable ("available") mineral concentrations in soils does not allow confident predictions to be made of plant uptake. When it does, available and total mineral concentrations are equally good (e.g. for Mo). In addition, while soil pH can greatly affect plant uptake, the use of extractants which standardize pH at a level removed from that in the field is unlikely to be helpful (N. Suttle, pers. comm.)

It is, therefore, apparent that although determination of trace element availability from soils may provide indications of livestock trace element (mineral) deficiencies, they may be unreliable and difficult to interpret. The overall lack of correlation between soil mineral concentrations and those in forage or animal tissues suggests that the extraction procedures being used do not provide a true indication of plant available mineral concentrations.

8.1.4 Drainage sediments

Whereas soil samples have been used to detect animal mineral deficiency problems in tropical countries (Arora, 1986; 1988; McDowell et al., 1985b), the use of drainage sediment geochemical maps for animal studies has not been widely investigated. The composition of a drainage sediment sample reflects the chemistry of a much wider area than a soil sample so it is a more appropriate sample medium for regional surveys. The overall chemical equivalence of drainage sediment and soil samples has been demonstrated in many areas including the UK (Appleton et al., 1991) and the tropical regime of eastern Bolivia (Appleton and Greally, 1992). In eastern Bolivia, statistical analysis of soil and drainage sediment trace element data from various sectors and for a variety of catchment rock types has confirmed the broad correlation between soil and stream sediment geochemistry, although in some cases soils contain significantly higher trace element concentrations (Appleton and Greally, 1992). Variations both within and between sample types is largely controlled by quartz dilution and secondary adsorption effects indicated by variation in Fe, and to a lesser extent Mn, concentrations. An additional evaluation of the link between the chemistry of drainage
Sediments and soils is being carried out in the Harare area of Zimbabwe. Soil samples have been collected from interfluvial areas of a drainage basin having an area of 2-3 km² and relatively low concentrations of Cu, Co, Mn and Zn. The results of this study will be presented elsewhere (Ridgway, in prep.)

Although the effectiveness of using drainage geochemical data for trace element deficiency and excess prediction has been disputed (see for example discussions in Mills et al., 1985), it has been demonstrated that drainage sediment geochemistry is a useful guide to animal health problems in temperate regions (Thornton, 1983; Aggett et al., 1988), even though much of the animal food is imported. Drainage sediment data were used to detect areas of Mo-induced Cu deficiency in sheep and cattle (Thornton et al., 1969; Thornton et al., 1972), Mn deficiency in cattle (Thornton and Webb, 1970) and Co deficiency in sheep (Thornton, 1972). Lewis (1985) showed that areas with high risk of Co deficiency may be predicted from soil and drainage geochemical surveys, although local variations are likely to be common, especially in temperate regimes. Lewis (1985) described examples in the UK where regional geochemical data from mineral exploration surveys provided a good indication of Co, Cu, Mo, and Se trace element problems. However, trace element problems in developed countries are probably also related to changes in agricultural practices resulting in increased production of modern herbages that tend to be deficient in Cu, Se and I and have increased levels of Mo and possibly other antagonists. In developing countries, where most animals are almost totally dependent on local forage, the association between drainage geochemistry and animal trace element status ought to be clearer.

In discussion of Ure (1985), Suttle observed that whereas he preferred the predictive value of determining extractable trace element contents for soils, he did accept that regional stream sediment geochemical data reflected a much more stable definition of trace element levels as management practices (such as liming or drainage) exert a considerable control on extractable trace element contents in surface soils. Ure (1985) noted that trace element speciation studies were not the prime requisite for identifying regional variations in developing countries as these could be detected using more economical drainage sediment and soil surveys to detect potential risk areas. In discussion of Ure (1985), Plant observed that many areas in developing countries have data available from mineral exploration studies which might also be suitable for mapping areas with potential trace element imbalances.
8.2 Discussion

In discussion of McDowell et al. (1985b) and Lewis (1985) it was observed that compositional changes during plant development caused sampling and data interpretation problems. McDowell commented that on approaching a new area, soil analysis is requested whenever possible but where animal productivity is known, liver biopsy and forage concentrations are used to develop an area map. Suttle appeared to be convinced that animal tissue composition was the best indicator of potential and actual problems and considered that (1) McDowell had not produced convincing evidence for the use of forage and tissue analyses as predictors of potential deficiencies and/or toxicities and (2) that Lewis had shown that Cu deficiency could only be predicted from geochemical data when Mo in sediment, soil or in pasture was also considered. Mills suggested that although the use of soil and plant data may be imprecise they did have a value in view of the relatively low cost of obtaining the data and especially in situations where animal tissue studies are precluded.

McDowell observed that all approaches had their limitations and it was necessary to proceed to supplementation trials. However, even with supplementation trials, a consistent result can not be guaranteed. For example, during a trial with sheep in Australia carried out over a period of 13 or 14 years, there was no response at all from Co supplementation for five of the years. In some years there were some mild responses and in other years there were severe production losses as a result of not providing cobalt (McDowell, pers. comm.).

Mills pointed out that the validity of many of the criteria used for animal mapping can be questionable because of the frequent absence of a clear relationship between, for example, blood inorganic composition and pathological effects. McDowell confirmed this by stating that tissue analyses are not all that good a guide to the definite existence of a deficiency or toxicity but merely indicate what supplementary treatments should be used in therapeutic trials. Hartmans suggested that if associations were found with soil or geological variables this would provide a justification for the application of preventive measures in an area. Finally, Phillippo observed that the significance of some variables at present considered irrelevant may be revealed by multidisciplinary approaches and may resolve presently inexplicable aspects of the aetiology of trace element related problems.
8.3 Conclusions

(1) Trace element deficiencies and toxicities in grazing livestock can be predicted by a systematic mapping survey or regional reconnaissance based on appropriate soil, forage and animal tissue analyses although results have to be interpreted with caution. Although McDowell et al., (1985b) considered that forage and tissue analyses are the best predictors of mineral problems, none of the methods can be considered definite in their conclusions. A mineral supplementation scheme can only be arrived at after the consideration of a range of different indicators (McDowell, pers.comm.). In many cases, where there is a reasonable indication of which microminerals are limiting, it may be justifiable to include them with macromineral supplements (P, Na, Cl) as a type of insurance, until analysis and production data verify that a particular micromineral is required.

(2) There appears to be some potential for misinterpretation of animal tissue and fluid analyses

(3) When using plant mineral concentrations as a guide to potential animal deficiencies, the species and degree of maturity will significantly affect trace element concentrations.

(4) Whereas determination of trace element availability from soils may provide indications of livestock trace element (mineral) deficiencies, the soil data may be unreliable and difficult to interpret.

(5) Regional drainage sediment geochemical data provide a relatively stable indication of trace element levels as management practices (such as liming or drainage) exert a considerable control on extractable trace element contents in surface soils. Drainage sediments probably provide a reasonable indication of long-term potential trace element availability and limitations.

(6) The diagnosis and mapping of areas with deficiency or toxicity problems in grazing livestock by mapping forage, animal tissue or fluid compositions is an expensive procedure and may be unsuitable for mapping of large areas. In addition, data obtained from livestock may also reflect previous nutritional history before livestock entered an area.
Regional drainage sediment geochemical mapping is a relatively rapid, cost-effective and reliable method of providing information on the levels of trace elements in the environment. In temperate regions, the method has been used to delimit areas characterised by trace element linked degenerative diseases in animals and also in crops.

9 APPLICATION OF DRAINAGE SEDIMENT GEOCHEMICAL MAPS FOR ANIMAL MINERAL STATUS INVESTIGATIONS IN TROPICAL COUNTRIES

Regional drainage sediment geochemical mapping surveys designed to identify mineral deposits have been carried out in many developing countries including Bolivia, Kenya, Sierra Leone, Solomon Islands, Sumatra, Swaziland, Uganda and Zimbabwe. This report examines the potential for the application of this existing mineral exploration regional geochemical data for animal health studies. Data processing was carried out using the UNIMAP interactive mapping system (UNIRAS, 1990).

9.1 Samburu-Marsabit region, Kenya

Associations between trace element concentrations in soils and plants and trace element deficiencies in pastures, crops and livestock and more recently wildlife have been identified in Kenya (Howard, 1970; Maskall and Thornton, 1989, 1991). Maskall and Thornton (1991) recognised a correlation between soil, plant and wildlife trace element deficiencies in certain species in some of the Kenya wildlife reserves, including the Lewa Downs, Ol Pejeta and Solio reserves that fall within or on the boundary of the area covered by the Samburu-Marsabit regional drainage geochemical mapping project (Fig. 3a and Ridgway, 1987a,b,c; 1988). In the absence of data for wildlife, Maskall and Thornton (1991) applied criteria developed for domestic ruminants to wildlife and showed that 20% and 30% of black rhino from the Solio Wildlife reserve had blood plasma levels deficient in copper and vitamin B12 respectively. As ruminants are generally less tolerant of Cu and vitamin B12 deficiencies than non-ruminants (Mertz, 1986; Langlands, 1987) it is possible that ruminant wildlife such as impala may be more at risk than non-ruminants including the black rhino. It is important to note that these wildlife data will require verification of their physiological and pathological relevance (C.F. Mills, pers.comm.).
Copper and Co in drainage sediments and soils for the three wildlife reserves are broadly the same (Table 4) thus confirming the potential for using regional drainage sediment geochemical maps to identify areas where mineral deficiencies might be a problem. The large areas with < 15 ppm Cu and Co shown on the geochemical maps (Figs 4 and 5) indicates that trace element deficiency problems in wildlife and cattle may be quite extensive in the Samburu-Marsabit area and that further investigations may be merited. Mn and Zn deficiencies may also characterise extensive areas underlain by generally acid basement gneisses (Figs. 6, 7, 8). Livestock (cattle, sheep and goats) are quite common in the Samburu-Marsabit area although their distribution mainly depends on the availability of grazing and access to water.

Elevated Co and Cu concentrations are associated with Quaternary volcanics in the southeast sector and mafic gneisses in the north-central sector whilst both the Quaternary and Tertiary volcanic terrains are characterised by high Mn and Zn.

Table 4. Comparison of drainage sediment and soil geochemistry for wildlife reserves in the Samburu-Marsabit area, Kenya

<table>
<thead>
<tr>
<th>Wildlife reserve</th>
<th>Cu (ppm)</th>
<th>Co (ppm)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Sediment</td>
<td>Soil</td>
</tr>
<tr>
<td>Lewa Downs</td>
<td>25-35</td>
<td>32-49</td>
</tr>
<tr>
<td>Ol Pejeta</td>
<td>10-15</td>
<td>10-20</td>
</tr>
<tr>
<td>Solio</td>
<td>10-15</td>
<td>7-18</td>
</tr>
</tbody>
</table>

30
Fig. 3a. Location map for the Samburu-Marsabit drainage geochemical survey, Kenya (area of geochemical maps outlined)
Fig. 4. Copper (ppm) drainage geochemical map of the Samburu-Marsabit region, Kenya (Wildlife reserves: LD=Lewa Downs, OP=Ol Pejeta, S=Solio; locations from Maskall and Thornton, 1991).
Fig. 5. Cobalt (ppm) drainage geochemical map of the Samburu-Marsabit region, Kenya (Wildlife reserves - see Fig. 4 caption)

Fig. 6. Manganese (ppm) drainage geochemical map of the Samburu-Marsabit region, Kenya
Fig. 7. Zinc (ppm) drainage geochemical map of the Samburu-Marsabit region, Kenya

Fig. 8. Geological map of the Samburu-Marsabit region, Kenya
9.2 Swaziland

In Swaziland, possible Cu, Zn and Mn deficiencies have been reported together with positive response to Cu supplementation to calves (Butterworth and Presswood, 1978). Magnesium, Na, P, Cu, and Zn deficiencies have been identified in pasture, and P, Zn, Cu and Mn deficiencies in cattle liver and serum analyses, at nine sites in the middleveld topographic zone which runs from north to south through the central sector of Swaziland and carries more than one third of the total cattle population (Fig. 9 and Ogwang, 1988). Drainage sediment values of < 15 ppm Cu (Fig. 10), < 25 ppm Zn (Fig. 11), <15 ppm Co (Fig. 12) and < 200 ppm Mn (Fig. 13) occur over a large part of the middleveld where these deficiencies have been reported. Ogwang (1988) reported mean wet season and dry season acetate extractable soil Cu, Mn and Zn concentrations of 0.9-1.1, 3.5-3.8 and 0.9-1.3 respectively. On the basis of the soil, pasture and biopsy analyses, Ogwang (1988) suggested that supplementation of K, P, Na, Cu, and Zn is essential for grazing livestock in the middleveld. Mills (pers. comm.) notes that Mn deficiency is very rare and very difficult to identify unequivocally, so the validity of Mn deficiencies identified by Butterworth and Presswood (1978) and Ogwang (1988) need to be confirmed.

Similarly low levels of Co, Cu, Mn and Zn in drainage sediments also characterise other sectors of the highveld and also the lowveld to the west of the Karroo basalts indicating that animal trace element deficiencies might also occur in these areas. Although Co deficiencies were not reported by Ogwang (1988) on the basis of limited pasture, cattle liver and serum analyses, the geochemical map for Co indicates low Co (< 15 ppm; Fig. 12) over approximately the same areas as for Cu (Fig. 10) implying that Co deficiencies in cattle may also occur in these areas. Coincidence of elevated Mo associated with biotite-hornblende gneisses and molybdenite mineralisation in granites and granite pegmatites, and low Cu in the western and north-central sectors of Swaziland (Figs. 14 and 10) suggest that there may be cases of Mo-induced Cu deficiency in these areas. This problem is most likely to occur in areas where the water table might be high, such as in the Komati River valley SW of Tshaneni and in the Ngwempisi River valley, to the S. of Mankayane.

The areas of high Co, Cu, Mn and Zn (Fig. 10-13) correlate with the outcrop of the greenstone belt in the northwest of Swaziland (Barton, 1982) and Karroo basalts in the east. Low Co, Cu, Mn and Zn are generally associated with granites and biotite gneisses in the
central and western parts of the country.

In contrast to the restricted veterinary data, the national geochemical maps (Forgeron, 1979) are based on 6850 drainage sediment samples collected at a density of 1 sample per 2-3 km² and provide a comprehensive data base for further animal health studies. Whereas the areas with Cu, Mn and Zn deficiencies in cattle indicated by the exploratory veterinary survey are broadly coincident with areas of low Cu, Mn and Zn indicated by the drainage sediment geochemical maps, the maps should not be considered to provide a definitive indication of areas with potential deficiency problems. They do, however, provide a useful indication of areas where further veterinary investigations are justified. In addition, it is important to remember that in many developing countries, energy, protein or P deficiencies may mask trace element deficiencies and the effects of these will not appear until the more limiting deficiencies have been rectified.

Fig. 9 Generalised topography and main drainage system of Swaziland (from Forgeron, 1979).
Fig. 10  Copper (ppm) drainage geochemical map of Swaziland (adapted after Forgeron, 1989).

Fig. 11. Zinc (ppm) drainage geochemical map of Swaziland (adapted after Forgeron, 1989).
Fig. 12. Cobalt (ppm) drainage geochemical map of Swaziland (adapted after Forgeron, 1989).

Fig. 13. Manganese (ppm) drainage geochemical map of Swaziland (adapted after Forgeron, 1989).
Fig. 14. Molybdenum (ppm) drainage geochemical map of Swaziland (adapted after Forgeron, 1989).

Fig. 15 Simplified geological map of Swaziland (adapted from 1:250,000 Geological Map of Swaziland, 1982)
9.3 Northern Sumatra

In northern Sumatra both drainage sediment and soil chemistry are broadly controlled by bedrock lithology as shown by the association of high Cu with the intermediate to mafic volcanic rocks of the Woyla Group (Figs 16 and 17 and Land Resources/Bina Programme, 1988). The regional geochemical maps, based on 1 drainage sediment sample per 10 km² (Stephenson et al., 1982), also effectively outline areas with low Co (<15 ppm, Fig. 18), Cu (<15 ppm, Fig. 17), Mn (< 500 ppm, Fig. 19) and Zn (< 40 ppm, Fig. 20) over the intensively farmed hills and plains east of the Barisan Mountains (Fig. 16). Limited soil data for this area (Land Resources/Bina Programme, 1988) confirm the deficiencies in trace nutrients such as Cu and Zn indicated by the drainage sediment data and suggest that low soil fertility would be the chief limiting factor for mixed and wet land arable farming in these areas and that trace element deficiencies may be encountered in livestock. Soils in northern Sumatra are mostly very acid, ferruginous and low or very low in available nutrients so that the agricultural development of many areas has failed because of low soil fertility (Land Resources/Bina Programme, 1988). Potassium, which occasionally causes mineral deficiency problems in grazing livestock, is present at high levels over the central sector of northern Sumatra (Fig. 21), where it is derived from the rhyodacitic Toba Tuffs (Fig. 16). In contrast, low levels of K occur in the southeastern sector of northern Sumatra overlying Pleistocene sands and gravels and Holocene alluvium.

Of the 35 Recommended Development Areas (RDA's) outlined by the Regional Physical Planning Programme for Transmigration [RePPProT] (Land Resources/Bina Programme, 1988) (Fig. 16), mixed farming (pasture and livestock) was suggested for various areas in the Barisan Mountains underlain by Cu-deficient Toba Tuffs. The relatively high K levels in these areas was recognised (Land Resources/Bina Programme, 1988) but potential trace element deficiencies of Co and Cu, and to a lesser extent Mn and Zn, were not recognised even in those areas being especially recommended for mixed farming. Coincidence of high Mo with low Cu in the centre of northern Sumatra (Figs. 17 and 22) indicate a potential for Mo-induced Cu deficiency in livestock in this mixed farming region.

In addition to the broad agreement between soil and drainage sediment geochemistry in northern Sumatra (Stephenson et al., 1982 and Land Resources/Bina Programme, 1988)
equivalence of drainage sediment and soil trace element levels has also been identified in
detailed geochemical surveys in the northwest of Sumatra (unpub. data). Drainage
geochemical data, therefore, appear to give a reasonable indication of potential trace element
deficiencies in soils, pastures and animals in northern Sumatra.

Fig. 16. Geology, topography and recommended development areas in northern Sumatra
(after Stephenson et al., 1983 and Land Resources/Bina Programme, 1988).
Fig. 17. Copper (ppm) drainage geochemical map of northern Sumatra

Fig. 18. Cobalt (ppm) drainage geochemical map of northern Sumatra
Fig. 19. Manganese (ppm) drainage geochemical map of northern Sumatra

Fig. 20. Zinc (ppm) drainage geochemical map of northern Sumatra
Fig. 21. Potassium oxide (%) drainage geochemical map of northern Sumatra.

Fig. 22. Molybdenum (ppm) drainage geochemical map of northern Sumatra
9.4 Northeast Zimbabwe

Drainage geochemical maps for 9000 km² of tropical, seasonally wet-dry, terrain in northeast Zimbabwe indicate some areas with low levels of trace elements that are essential for animal health and productivity. The maps are based on a regional drainage geochemical survey carried out by sampling at a density of approximately 1 sample/km² (Dunkley, 1987). Although northeast Zimbabwe is generally thinly populated and not intensively grazed by animals, the geochemical maps do indicate areas where trace element deficiencies may occur. The highest population density occurs in the southwest sector of the area mapped, especially in the relatively flat lying area underlain by the Grey Gneiss terrain (Baldock, 1986; Dunkley 1987) where most of the Communal Lands are used for subsistence farming by small family groups. Cattle grazing is common within this area and water appears to be the main restricting factor for agricultural development. The Mutoko Granite in the extreme south west of the area is characterised by more rugged terrain with extensive areas of bare rock outcrop. Habitation is restricted to valleys between the granite hills.

The soils of the area are mostly fersiallitic, with high Fe and Al (Thompson and Purves, 1978) although greyish brown, coarse sands and sandy loams characterise areas underlain by granitic rocks and brown to reddish-brown sandy loams overlying sandy clays are more common over siliceous gneisses and schists. Reddish-brown granular clays occur over the Makaha Greenstone belt and basic and ultrabasic intrusive rocks, such as those that intrude the Mutoko Granite in the southwest. Lithosols are found in areas of rugged terrain.

Comparison of the Co, Cu, Mn and Zn geochemical maps (Figs. 24, 25, 26, 27) with the geological map (Fig. 23) show the Makaha Greenstone belt (marked M in Fig 23) is characterised by elevated levels of Co, Cu, Mn and Zn and the Middle-Upper Proterozoic metasediments of the northern part of the area has high Mn, Cu and Zn with some sectors also characterised by high Co. The Communal Land areas underlain by Grey Gneiss terrain located in a belt lying between the northern and southern greenstone belts (Fig. 23), tend to be characterised by very low levels of Co, Cu, Mn and Zn, reflecting the low levels of these trace elements in the parent rocks and the sandy, infertile soils derived from them. Similarly low levels of Co, Cu, Mn and Zn are associated with those sectors of the Mutoko Granite in the southwest of the area that are not intruded by basic rocks. The geochemical maps indicate areas where animals and crops might be expected to be deficient in Co, Cu, Mn and Zn. Co
especially appears to be low over much of northeast Zimbabwe. Further investigations are required of the agricultural significance of the geochemical maps, including more detailed soil, pasture and veterinary investigations.

Fig. 23  Simplified geological map of northeast Zimbabwe (after Dunkley 1987 a,b)
Fig. 24. Cobalt (ppm) drainage geochemical map of northeastern Zimbabwe

Fig. 25. Copper (ppm) drainage geochemical map of northeastern Zimbabwe
Fig. 26. Manganese (ppm) drainage geochemical map of northeastern Zimbabwe

Fig. 27. Zinc (ppm) drainage geochemical map of northeastern Zimbabwe
9.5 Harare region

The 4,400 km² covered by the Harare geochemical survey (Dunkley, 1987 c) includes the industrial and suburban areas of Harare, extensive areas of commercial and small-scale farmland and also communal lands in the north and east, especially around Chinamora and Chikwakwa. Farmland covers a large part of the area and indigenous vegetation is confined to less easily cultivated ground which is often used for grazing of livestock. Commercial maize, winter wheat, beef and dairy farming is carried out over the relatively fertile reddish-brown clay loams of the greenstone belt (Fig. 28) whilst farming in the granitic areas, with their shallow, greyish-brown coarse-grained sands and sandy loam soils (Thompson and Purves, 1978), is usually dominated by tobacco and grazing (Dunkley, 1987).

Contrasts in bedrock geochemistry are strongly reflected in the drainage geochemistry maps. Basic metavolcanics, iron formation strata and metasediments of the Harare Greenstone Belt are characterised by high As, Co, Cu, Mn, Ni and Zn (Figs. 29 to 34). High Ni may cause phytotoxicity in crops over parts of the greenstone belt and arsenic (Fig. 34) reaches levels that may be prejudicial to human and animal health. In contrast, the Late Granites (comprising the Nyabira Complex granodiorite and gneiss in the west; granite and tonalite of the Harare Complex to the south of the greenstone belt; leucogranite, tonalite and granodiorite of the Chikwakwa Injection Complex in the east; gneissic tonalitic and granodioritic plutons and gneisses and late porphyritic granites of the Chinamora Igneous Complex in the north and northeast) are characterised by low to very low levels of Co, Cu, Mn and Zn (Figs. 29,30,31 and 33). Such low levels have been shown to be associated with animal trace element deficiencies in grazing animals in Kenya and Swaziland. On this basis, the geochemical data indicate that similar deficiency problems might be anticipated over the granitic terrains within the Harare area.
Fig. 28  Simplified geological map of the Harare region (after Dunkley 1987 c; boundaries of the geochemical maps (Figs. 29-34) are the same as this geological map)
Fig. 29. Cobalt (ppm) drainage geochemical map of the Harare region

Fig. 30. Copper (ppm) drainage geochemical map of the Harare region
Fig. 31. Manganese (ppm) drainage geochemical map of the Harare region

Fig. 32. Nickel (ppm) drainage geochemical map of the Harare region
Fig. 33. Zinc (ppm) drainage geochemical map of the Harare region

Fig. 34. Arsenic (ppm) drainage geochemical map of the Harare region
9.6 Eastern Bolivia

The results of a regional drainage geochemical survey covering 220,000 km² of pre cambrian terrain in eastern Bolivia were published in a geochemical atlas by Appleton and Llanos (1985). The area is mainly underlain by Precambrian crystalline rocks and geomorphologically it is an up-domed Tertiary lateritised planation surface buried in Quaternary alluvial basins at the shield margins (Fig. 35; after Litherland et al., 1986). The climate is tropical varying from wet-dry in the south to wet in the north; vegetation varies from semi-deciduous in the south to tropical rain forest in the north. Lowland savannas occur over some seasonally-flooded and poorly drained alluvial valleys, especially in the Quaternary alluvial areas of the shield margins. The population of about 100,000 persons is mainly restricted to the southern half of the area. Cattle rearing occurs in an extensive form, especially on the savanna areas.

Very extensive areas of eastern Bolivia are characterised by levels of Co, Cu, Mn and Zn (Figs. 36 to 39) that in Kenya and Swaziland are known to be associated with trace element deficiency problems in grazing livestock. Mo (Fig. 40) is generally low and unlikely to cause Mo-induced Cu deficiency in grazing ruminants, except perhaps in the Velasco alkaline province which is characterised by slightly elevated Mo and low Cu. Trace element determinations in the Bolivian samples were determined by AAS after a hot nitric acid digestion whereas the Kenya samples were digested in hot 50% hydrochloric acid and the Swaziland samples in a hot concentrated 3:1 nitric/perchloric mixture. There may be differences in the efficiency of these three acid extractions as hydrochloric acid is generally more efficient than nitric or nitric/perchloric at releasing elements from iron oxides (Ridgway and Dunkley, 1988). Because the less effective 50% hydrochloric acid digestion was used for the Kenya samples it is probable that sample digestion efficiency was approximately equivalent in the three surveys. However, it is emphasised that the drainage geochemical maps should not be considered to provide a definitive guide to areas with potential deficiency problems but merely a useful indication of areas where further veterinary investigations may be justified.

Bauer et al. (1981) evaluated the mineral status of cattle on a ranch in the Beni Lowlands of north eastern Bolivia, located to the northwest of the area covered by the geochemical maps (Figs. 36-40). The majority of the forage samples were below critical levels for P, Na.
Cu and Zn; liver Cu and Zn also indicated deficiencies but no trace element data were presented for the alluvial clay soils. Mineral supplementation trials showed that cattle receiving salt and bone phosphate (including Cu 4.8 ppm, Mn 3.6 ppm and Zn 36 ppm) gained 22% greater weight compared with the control. The response is most likely to be related to phosphorus as the concentrations of Cu, Mn and Zn in the mineral supplement would be unlikely to produce significant effects. Cattle receiving only salt gained an average of only 4% more weight than the control. Pregnancy rates were 13% higher for the bone phosphate + salt supplemented cattle compared with cattle given only salt. In the absence of soil or stream sediment geochemical data it is difficult to assess the relevance of the Beni supplementation trial to the area covered by the regional geochemical survey (Appleton and Llanos, 1985). It is worth noting that some of the Recent-Quaternary alluvial clay soils of eastern Bolivia, such as those west of Ascensión de Guarayos (Appleton and Llanos, 1985) contain elevated concentrations of Cu, Co, Zn and Mn compared with the more sandy deposits in the San José de Chiquitos and San Matias areas. Some of the veterinary data for the tropical lowlands area covered by the regional geochemical survey have been reviewed by CTVM (1992) and additional information is being reviewed by Dr Armando Peducassé (University of Santa Cruz, Bolivia) and will be reported elsewhere.
**Fig. 35** Regional map of Cenozoic geology, structure and geomorphology (After Litherland et al., 1986)

**Fig. 36.** Cobalt (ppm) drainage geochemical map of eastern Bolivia
Fig. 37. Copper (ppm) drainage geochemical map of eastern Bolivia

Fig. 38. Manganese (ppm) drainage geochemical map of eastern Bolivia
Fig. 39 Zinc (ppm) drainage geochemical map of eastern Bolivia

Fig. 40 Molybdenum (ppm) drainage geochemical map of eastern Bolivia
9.7 Northern Sierra Leone

A regional drainage geochemical survey covering 23,000 km² of Precambrian terrain in northern Sierra Leone is described in Macfarlane et al. (1981). Trace elements were determined by optical emission spectrography. The area surveyed can be divided into two physiographic zones: a low lying coastal plain rising to 50m and an interior upland region of deeply dissected hills and broken plateaus increasing in altitude eastwards from 100 to 600m. Residual hills such as the Sula and Loma Mountains rise 200 to 800m above the interior upland region. The area has a tropical wet-dry climate with and less than 250mm annual rainfall. Savannah woodland with a thick undergrowth of elephant grass is the characteristic vegetation. The area is mainly underlain by Precambrian crystalline rocks comprising infracrustal gneisses and granitoids, supracrustal metasediments, andesitic, basic and ultrabasic volcanics cut by basic to ultrabasic intrusions (Fig. 41).

Fig. 41 Simplified geological map of northern Sierra Leone (after Macfarlane et al., 1981)
Fig. 42. Water resources in northern Sierra Leone (after Macfarlane et al., 1981)

Fig. 43. Cobalt (ppm) drainage geochemical map of northern Sierra Leone
Fig. 44. Copper (ppm) drainage geochemical map of northern Sierra Leone

Fig. 45. Manganese (ppm) drainage geochemical map of northern Sierra Leone
Compared to the rest of Sierra Leone, the region is sparsely populated although villages are seldom more than 10 km apart. Cattle farming is widely practised by nomadic Fula pastoralists in much of northern Sierra Leone. Macfarlane et al. (1981) suggested that larger herds of cattle could be established in areas where pasture and water could be guaranteed throughout the year, such as the area underlain by the Rokel River Group and the Marampa Group (Fig. 42).

Very extensive areas of northern Sierra Leone are characterised by low levels of Co, Cu, and Mn in drainage sediments (Figs. 43 to 45). Similarly low trace element levels in Kenya and Swaziland are known to be associated with trace element deficiencies in grazing livestock. No veterinary information has been encountered for the area but the drainage geochemical maps could be used to indicate areas with potential trace element deficiency problems where further veterinary investigations would be justified.

9.8 Uganda and Solomon Islands

Geochemical maps are being prepared for Uganda (Uganda Government, 1973; Reedman and Gould, 1970) and the Solomon Islands (Dunkley, 1986; Ridgway and Coulson, 1987). The significance of the maps for animal health studies and descriptions of areas where potential trace element deficiency problems may occur will be described in a subsequent report.

10. CONCLUSIONS

Although undernutrition is accepted as the most limiting factor to grazing livestock production in tropical areas, Co, Cu, I, Fe, Mn, Se and Zn deficiencies together with excesses of Cu, F, Mn and Mo in soils and forages have long been known to be responsible for low production and reproduction problems among grazing livestock in many developing countries. In addition, As, Pb, Cd, Hg and AI are toxic to animals.

There have been numerous studies of increased productive performance related to mineral supplementation. Assuming that the costs of mineral (trace element) supplements are proportionally small compared with production gains, the economic benefits of
supplementation should be significantly high. It is, therefore, critically important to identify those areas where mineral deficiencies or toxicities are negatively affecting cattle productivity. The diagnosis and mapping of areas with trace element deficiency or toxicity problems in grazing livestock has generally been executed by mapping forage, animal tissue or fluid compositions although results have to be interpreted with caution and none of the methods can be considered definite in their conclusions. There appears to be some potential for misinterpretation of animal tissue and fluid analyses. With plant mineral concentrations, the species and degree of maturity will significantly affect trace element concentrations. Whereas determination of trace element availability from soils may provide indications of livestock trace element (mineral) deficiencies, the soil data may be unreliable and difficult to interpret. It has been suggested that regional drainage sediment geochemical data provide a relatively stable indication of trace element levels and a reasonable indication of long-term potential trace element availability and limitations.

The diagnosis and mapping of areas with deficiency or toxicity problems in grazing livestock by mapping forage, animal tissue or fluid compositions is an expensive procedure and may be unsuitable for mapping of large areas. In addition, data obtained from livestock may also reflect previous nutritional history before livestock entered an area.

In comparison, regional drainage sediment geochemical mapping is a relatively rapid, cost-effective and reliable method of providing information on the levels of trace elements in the environment. In temperate regions, the method has been used to delimit areas characterised by trace element linked degenerative diseases in animals and also in crops. There is a need to increase awareness of the potential for inter-disciplinary studies in this field and to illustrate that the prudent use of regional geochemical data can be of value in predicting the risks of trace element deficiencies and/or toxicities in grazing livestock.

Regional drainage sediment geochemical mapping surveys designed to identify mineral deposits have been carried out in many developing countries including Bolivia, Kenya, Sierra Leone, Solomon Islands, Sumatra, Swaziland, Uganda and Zimbabwe. This review has demonstrated how this existing mineral exploration regional geochemical data may be used for animal trace element deficiency and toxicity studies.
Comparison of the results of local soil-plant-animal studies with regional drainage sediment geochemical maps in the Samburu-Marsabit region of Kenya showed that Cu and Co in drainage sediments and soils are broadly the same in three wildlife reserves where trace element deficiencies had been identified. This confirm the potential for using regional drainage sediment geochemical maps to identify areas where mineral deficiencies might be a problem.

In Swaziland, drainage sediment values of < 15 ppm Cu, < 25 ppm Zn, < 15 ppm Co and < 200 ppm Mn occur over a large part of the middleveld where Cu, Zn and Mn deficiencies have been reported in grazing livestock. In contrast to the restricted veterinary data, the national geochemical maps provide a comprehensive data base for further animal health studies.

The regional geochemical maps of northern Sumatra, eastern Bolivia, northeast Zimbabwe, the Harare region of Zimbabwe and northern Sierra Leone all indicate extensive areas where trace element deficiencies may prejudice the health of grazing animals.

Many regional geochemical surveys have been carried out for mineral exploration purposes with a restricted range of elements which rarely include some of the environmentally more important elements such as Cd, Mo, Se, F and I. Comprehensive data on F is also required for aquifers.

Investigation of the effects of sample density reduction through sample selection (Ridgway et al., 1991) suggests that in many cases significant geochemical patterns can be detected through either the analysis of a relatively small sub-set of samples from sample archives, thus providing significant savings over re-analysis of all samples or by low-density resampling. Time and cost considerations dictate that the preparation of systematic surficial geochemical maps in many countries with limited financial resources is only likely to be achieved if a low sample density is used. However, the scale of the geological features and the sample density appear to be the most significant factors in determining the level at which meaningful geochemical patterns can be mapped. For example, in cases where the original sampling density was low (eg. 1 sample per 10-16 km$^2$ in northern Sumatra and eastern Bolivia), geochemical patterns reflect bedrock composition with a fair degree of accuracy even with densities reduced as low as one sample per 500 km$^2$. In contrast, the high density
data set for Zimbabwe yielded distorted patterns at a density of 1/36 km$^2$ and grossly misleading patterns at 1/100 km$^2$ and 1/300 km$^2$ (Ridgway et al., 1991). Further work on the development of a cost-effective low density sampling strategy is being carried out (see section 11).

As farming systems in developing countries progress and farmers are encouraged to seek higher levels of productivity from forage fed livestock, the deficiencies or imbalances of minerals in their forage will become more important and more necessary to correct even if they do not present obvious clinical symptoms. Screening large numbers of animals for evidence of mineral deficiency without first recognising which areas to target, would be an expensive and laborious process and would probably be subject to variations due to season, climate and physiological status at the time of sampling. Whereas geochemical maps often indicate areas where deficiencies in cattle might occur, the maps should not at this stage be considered to provide a definitive indication of areas with potential deficiency problems. If follow-up veterinary studies recommended in this report verify that drainage geochemical maps correlate well with dietary mineral deficiencies confirmed by mineral supplementation trials for productive livestock, then this should confirm the value of geochemical mapping as a cost effective method of identifying areas and elements where deficiency or toxicity might occur. The maps could, therefore, be used to indicate the need for further specific veterinary investigations and correction (through supplementation) in the interests of achieving higher levels of animal productivity. Finally, it is important to remember that in many developing countries, energy, protein or P deficiencies may mask trace element deficiencies and the effects of these will not appear until the more limiting deficiencies have been rectified.
11. FUTURE INVESTIGATIONS (1992-93)

It is proposed that the following activities will be carried out during 1992/93 as part of the ODA funded Environmental Geochemistry project:

1. The Centre for Tropical Veterinary Medicine (CTVM), Edinburgh University was commissioned to carry out a one month literature search and study of the mineral status of livestock and pastures in the tropical countries covered by the current report. The objective of the review was to investigate the potential for correlating existing documented reports of mineral status in these countries with the geochemical distributions given in the current report. The CTVM review (CTVM, 1992) should be read in conjunction with the current report. In addition, university theses on macromineral and micromineral status of three areas within eastern Bolivia are being assessed by Dr Armando Peducassé (University of Santa Cruz).

2. The negative effects of minerals on animal productivity can be either direct, due to a simple excess, deficiency, or to an imbalance between different minerals. The effect can be manifested through decreased growth rate, milk yield, impaired reproduction, or in extreme circumstances animals may die. Initially it would be useful to compare veterinary records of such problems which have been linked to minerals, in areas for which geochemical maps are available. This will be attempted by contacting the relevant veterinary organisations, although first indications from Bolivia and Zimbabwe are that this information is probably not readily available.

3. Arrange and execute multidisciplinary studies in areas where trace element deficiencies are indicated by the geochemical maps. This work will seek to confirm a close relationship between stream sediment, soil, forage and animal tissue chemistry with the aim of demonstrating the validity of using regional stream sediment geochemical mapping for identifying areas that may be subject to Cu, Co, Mn, Zn, Se and I deficiencies or toxicities in animals. Suspected deficiency is probably more accurately indicated by samples of animal fluids or tissues, although there does appear to be some hereditary variation in normal (or supportable) mineral and trace element levels between breeds and strains of livestock originating from different background environments. The final test
should probably be specific mineral supplementation and dose/response trials
(G.G.Freeland, C.F.Mills, pers.comms.).

These follow-up studies will only be instigated if they meet with the approval of the
ODA Senior Animal Health and Production Adviser. It has been suggested (M. Gill,
NRI, pers. comm.) that in order to meet ODA's emphasis on demand-led research and
the importance of socio-economic/cultural factors in affecting successful uptake, it might
be best to concentrate further studies in areas where:
(a) productivity is generally low, without a specific cause such as lack of fodder, having
been identified, and (b) it is clear that farmers wish to increase productivity and would
be prepared to pay for additional inputs. Conversely, it has been observed that it may be
difficult or impossible to verify farmer's willingness to pay for supplements and that if
mineral (trace element) deficiencies were proven to exist, controlled trials would be
required to prove the economic viability of mineral supplementation (pers. comm. Dr J
McGrane and D. Brown, ODA/LIDIVET, Santa Cruz, Bolivia).

4. Develop cost-effective strategy for low density sampling through use of high-order
drainage geochemical sampling. High order drainage channels with catchment areas of
50 to 100 km² will be sampled and the geochemical patterns compared with those derived
from a high density data set firstly by mathematical reduction with moving-average
techniques and by sample selection and secondly by analysis of composite samples. The
procedures to be used for compositing samples will be investigated using ANOVA. In
order to carry out this programme in a cost effective manner, sampling will be carried
out in areas where BGS already hold high density stream sediment data sets. Sampling
has been carried out initially in the Harare district of Zimbabwe. Samples will be
analysed for a suite of environmentally important elements including Cu, Pb, Zn, Co, Mn,
Fe, Cr, Se, Mo, I, F and P.

5. In order to convince veterinary, agricultural and other specialists that drainage
geochemical maps provide a good indication of soil mineral concentrations, two studies
will be carried out to evaluate the link between the chemistry of drainage sediments and
the chemistry of soils in the drainage basin(s) which they represent. In the Harare area
of Zimbabwe, soil sampling has been carried out within a drainage basin having an area
of 2-3 km² and relatively low concentrations of Cu, Co, Mn and Zn. This study will also
provide an indication of the variability of trace element concentrations within one drainage basin. In eastern Bolivia, statistical analysis of soil and drainage sediment trace element data from various sectors and for a variety of catchment rock types has confirmed the broad correlation between soil and stream sediment geochemistry, although in some cases soils contain significantly higher trace element concentrations (Appleton and Greally, 1992). Variations both within and between sample types is largely controlled by quartz dilution and secondary adsorption effects indicated by variation in Fe, and to a lesser extent Mn, concentrations.

6. Develop a sensitive hydride generation Atomic Absorption Spectrometry analytical method for the detection of low levels of Se including development of preconcentration techniques and relevant sample dissolution protocols, validation against standard reference material and development of QA protocols. Development of Se analytical procedure required to underpin animal health and low density sampling investigations. A review of current analytical methods for the determination of Se in geochemical samples has been prepared (Cave and Blackwell, 1992).

Geochemical maps are being prepared for Uganda and the Solomon Islands. The significance of the maps for animal health studies and descriptions of areas where potential trace element deficiency problems may occur will be described in a subsequent report.
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13. REFERENCES


Department, Overseas Development Natural Resources Institute, Overseas Development Administration, London, United Kingdom; and Direktorat Bina Program, Direktorat Jenderal Penyiapan Pemukiman, Jakarta, Departemen Transmigrasi, Indonesia.


