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TRACE ELEMENT CONCENTRATIONS IN CERTAIN SOILS OF THE LOWER SOUTH EAST OF SOUTH AUSTRALIA

BY

G. BLACKBURN AND J. B. GILES

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SUMMARY

Spectrographic analyses for total cobalt, copper, iron, manganese, molybdenum, nickel, vanadium, zinc, and zirconium are reported for surface soil samples at 45 sites in the lower south-east of South Australia, an area of well-known trace element deficiencies. The soils represented (terra rossa, rendzina and ground-water rendzina, podzols and krasnozems) are several of the characteristic great soil groups of this area. Owing to the general lack of notable changes in clay content or trace element concentrations in these profiles the analyses of surface samples are satisfactory for comparisons between soils.

Provided due attention was given to differences of parent material, topography and drainage, as well as to profile features, in classifying the soils, the trace element concentrations were found to be consistent within the groups.

The absolute levels of all trace elements except molybdenum were very low for most soils of this region compared with average levels for normal soils from other parts of the world. Various soils developed on basaltic parent materials were found to have the highest contents of those trace elements essential for plants and animals. Moderate concentrations of cobalt, manganese and nickel were found in some other soils which were not obviously developed on volcanic parent materials but which occurred on well-drained sites. Corresponding soils of similar clay content, on poorly drained sites, were much lower in these elements.

INTRODUCTION

The occurrence of trace element deficiencies involving cobalt, copper, manganese and zinc in different soils of south-eastern South Australia has received much attention but until recently there had been few determinations of trace element concentrations for soils of this region. Several determinations of manganese in particular soils had been given by Samuel and Piper (1928) and by Prescott and Piper (1929). A microbiological assay of trace elements by Donald et al (1952) included several deficient soils from this district. More attention had been given to determining concentrations of trace elements in plant material (Piper and Beckwith 1951, Lee 1951a).

Data on concentrations of nine elements are now available on soils from 45 sites representing characteristic soils of this part of Australia. The sources of information are

1. Tiller (1957a, b, c,) who studied 78 samples from 10 profiles in reference to the influence of volcanic materials on soil fertility and the growth of Pinus radiata.

2. McKenzie (1958) for 41 samples from 8 profiles of terra rossa and rendzina soils examined by Stace (1956).

3. Giles (1960) for 102 samples from 27 profiles, mainly terra rossa and rendzina soils.

In all three enquiries spectrographic determinations were made of the total amounts of various trace elements. Zinc was determined by x-ray spectrometry and other elements (cobalt, copper, iron, manganese, molybdenum, nickel, vanadium and zirconium) by optical spectrography, using methods developed in the Division of Soils, C.S.I.R.O.

The present paper compares the trace element status of the different soils, by reference to the determinations on the surface soils to a depth varying from 3 to 8 inches, - the layer of most direct interest for plant growth. Generally this top-soil layer was found to be quite representative of the trace element status of the entire profile, probably because few of the sites showed major variations in clay content down the profile.

SOILS

Seven great soil groups as described by Stephens (1956) are represented. The main features of soil profiles and environment are given in Table 1 and the locations in Fig. 1. The majority of the samples were collected during reconnaissance soil mapping in County Grey (Blackburn 1959). The soils represent the range from the most fertile - developed on volcanic rocks, to the least fertile - the ground-water podzols. Calcareous sands, peats, and those profiles of sand over clay known as solodized solonetz and solod have not yet been examined.

The fine-textured ground-water rendzinas and podzols are probably the most widely distributed soils in this area, followed by terra rossas and ground-water podzols. The shelly types of ground-water rendzina are important only on a comparatively small area near the coast. Various soils on volcanic materials are confined to restricted areas near the small extinct volcanoes mostly referred to as mountains in this region of subdued relief.

Most samples were taken on roadsides and other uncleared land, but eleven sites refer to improved pasture or pine plantations and these are indicated in Table 1.

The parent materials have been designated by reference to geological reports (Sprigg 1952) and information obtained during soil surveys. Although there is generally no difficulty in distinguishing dune limestone, estuarine or lacustrine marls, basalt, and basaltic tuff as parent materials, there are several sites where parent materials were not readily classifiable owing to variations in deposition of marine, estuarine of aeolian sediments, including volcanic ash. Two of the ground-water podzols (180 and 366) and the podzol (184), are formed on sandy parent materials, but overlie volcanic material at depth (Tiller 1957a). Four soils (182, 185, 189 and 351) have formed directly on basalt or basaltic tuff, and one soil (339) contained volcanic glass yet was apparently derived mainly from underlying fossiliferous limestone.

The textures represented in the profiles vary from sands to clays; in all but four (189, 268, 426, 15906) there were no internal contrasts of texture, as from sand to clay.

RESULTS

Concentrations of cobalt, copper, iron, manganese, molybdenum, nickel, vanadium, zinc and zirconium in the top soil are given in Table 1, together with values for soil pH and clay content; the samples are classified according to great soil group and parent material.

The original results (Tiller 1957a, McKenzie 1958, Giles 1960) for all horizons indicate that the concentrations given in Table 1 equal or exceed the respective mean concentrations for entire profiles except for the following:-

a) profiles with distinct texture changes (189, 268, 426, 15906)
b) profiles overlying volcanic ash deposits (180, 184, 366)
c) certain ground-water rendzinas (308, 318, 16464 and 16484) in which cobalt is higher in the deeper horizons.

The concentration of elements in the surface horizon exceeds that of the whole profile by 10 per cent for copper and zinc in terra rossas and rendzinas, by 20 per cent for manganese in terra rossas and by about 50 per cent for manganese in ground-water podzols. In sixteen profiles the copper and zinc concentrations were considerably higher in the surface than sub-surface samples; this does not appear to have been due to applications of trace element fertilizers, for only five of these sites were covered by improved pastures or pine plantation to which such fertilizers might have been applied. Six other sites, with either improved pasture or pine plantations showed no difference in copper and zinc contents between surface and sub-surface layers.

In Table 2 the mean contents of the specified elements in each group of soils are compared as a ratio with the means established for the soils of the world by Vinogradov (1959). The latter are regarded as useful standards of comparison and trace element contents equal to these means will be referred to in this paper as normal.

DISCUSSION AND CONCLUSIONS

(a) Comparison of Soil Groups

Satisfactory comparisons of trace element status can be made only where the great soil groups are represented by several individuals showing some similarity of concentrations. The terra rossa on dune limestone, ground-water rendzinas on marls, ground-water rendzinas on marine shells and estuarine deposits, ground-water podzols, and the rendzinas and krasnozems formed on volcanic deposits are the groups for which satisfactory comparisons can be made.

The greatest contrast in trace element contents is between those soils formed on volcanic rocks and others formed on highly calcareous or siliceous parent materials. The terra rossa on dune limestone, ground-water podzol, and the two kinds of ground-water rendzina, each show some degree of deficiency for several of the elements determined and the concentrations are consistent with the pattern of deficiencies already established from field experiments (Tiver 1955). The samples from volcanic areas, and several other soils, were found to have higher contents of several elements, particularly copper and zinc.

The terra rossas on dune limestone are distinguished from the ground-water rendzinas on marls by a number of features visible in the field, yet both have low concentrations of trace elements other than molybdenum. However, two (16475, 16491) of the terra rossas on miscellaneous limestones are similar to the two rendzinas (16470, 16479) on marls in regard to both their trace element concentrations and their field characteristics excluding colour. These four soils have quite different trace element contents from either the terra rossas on dune limestone or the ground-water rendzinas. A similarity of certain terra rossas and rendzinas, including these particular four soils, has been referred to by Stace (1956), Norrish and Rogers (1956) and McKenzie (1958, 1959), all of whose work pointed to the lack of clear-cut chemical differences between these two groups. However, Oertel (1960) showed, by using a statistical technique, that the two groups could be discriminated by chemical features. The results of the recent examination by Giles (1960) of a much larger number of terra rossas and ground-water rendzinas showed the former to contain more manganese than the latter, especially in the surface layers.

Table 2 shows that the terra rossas on dune limestone and the two kinds of ground-water rendzinas have contents of cobalt, copper, manganese and zinc that are distinctly low compared with the soils of the world (Vinogradov 1959). Despite this similarity each of these three groups, as represented by this sample of soils, has its characteristic pattern of trace element concentrations. Thus the terra rossas on dune limestone are distinguished from the other two groups by having the highest contents of manganese and molybdenum and the lowest zinc; the ground-water rendzinas on marls by the highest contents of copper, iron, nickel, vanadium and zinc; and the ground-water rendzinas on shells by the lowest contents of copper, iron, manganese, molybdenum and zirconium. Concentrations of cobalt exceeding 2 p.p.m. occurred only in the group of ground-water rendzinas on marls.

There are some points of similarity in the trace element contents of the ground-water podzols and the ground-water rendzinas on shells, but the iron, manganese, nickel and zinc contents are outstandingly low in the former while the molybdenum content is normal.

The trace element status of five groups of soils is summarised in Table 3.

(b) Occurrence of Higher Concentrations of Trace Elements

The results given in Table 1 for the determinations by Giles and by Tiller confirm the deficiencies of certain trace elements essential for plant or animal growth in several quite distinct soils of this area, previously referred to by Tiver (1955) and by Stephens and Donald (1958). But there are also several soils with moderate to normal contents of the essential trace elements. These soils include those developed on volcanic rocks; the remainder may owe their higher content of these elements either to distribution of volcanic ash or to introduction of alluvium transported from volcanic rocks. Such distribution of volcanic material is not easily established but in one of the soils (339) volcanic glass was identified (K.G. Tiller, personal communication) following the recognition of an unusually high phosphorus content. Although this soil contains very little cobalt, its nickel content is high in proportion to the clay content, and its copper, manganese and zinc contents are comparatively high for this area. The determinations for samples 331 and 336 also attract attention due to their variation from terra rossas on dune limestone. The sample 331, from the Glencoe district, occurs apparently on calcareous dune or beach limestone, yet its cobalt and nickel contents are unusually high for comparable soils on dune limestone; this site may have received volcanic ash from a nearby volcano. The sample 336 is associated with the system of stranded coastal dunes near the present coastline, but its iron, manganese, and nickel contents are much higher than for the soils on dune limestone. There is no known volcanic centre near this site to suggest as a source of its higher nickel and molybdenum contents. It may be significant, however, that it differs from the other terra rossas sampled on dune limestone, in having more than 30% silt compared with not more than 10 per cent in the sandy terra rossas; this soil is thought to be developed on a more recent deposit carried by wind from the adjacent coastal flats.

The only remaining soils with trace element contents comparatively high for this region, are the two finer-textured terra rossas (16475, 16491) and the two rendzinas (16470, 16479) referred to above. These have relatively high cobalt and nickel contents in comparison with other terra rossas and with the ground-water rendzinas; the contrast with the latter group is more impressive in view of the comparable clay contents. These differences may result from variations in parent materials or in soil processes. Three of these four soils lie within 6 miles of volcanic centres which may have supplied the higher contents of cobalt and nickel, but the fourth sample (16491) near Penola is regarded as outside the range of significant volcanic ash distribution. An explanation of its composition from parent material differences alone would probably have to depend on uneven distribution of alluvium on a prior course of the Glenelg River draining areas to the east where certain basic igneous rocks might provide cobalt and nickel. No effort has yet been made to examine this possibility but it seems likely that more is involved than variations in parent materials. These four distinctive soils - two terra rossas and two rendzinas - are well-drained soils not subject to flooding or invasion by ground-water, and contrast with ground-water rendzinas which have been flooded or water-logged, especially before the installation of artificial drains. It is suggested therefore that certain elements, including cobalt and manganese, have been leached more from at least the surface layers of soils subject to flooding than from those well drained terra rossa or rendzina soils apparently leached only by rainfall _in situ_. A particular comparison is given in the Penola district by the samples 16491, a terra rossa, and 16484/5 and 308, both ground-water rendzinas. The first two of these three samples were examined by Norrish and Rogers (1956) who reported on their similar clay minerals and underlying limestone. Nevertheless, the surface soil of the ground-water rendzina was found to have very much less cobalt and manganese than the related terra rossa. A further point of interest concerning these two ground-water rendzinas is that both have higher cobalt contents in the deeper layers than at the surface (Giles 1960).

(c) Soil Contents of Trace Elements and Distribution of Deficiency Disorders in Plants or Animals.

Comparison of the data in Table 1 with results of field trials on nutrient deficiencies and other reports of such deficiencies suggests that analyses for total trace element concentrations if considered in conjunction with soil variables which may affect availability, such as pH, can be used to indicate tendencies to deficiencies.

Cobalt concentrations of less than 2 p.p.m. in the surface soils occur generally in the localities where cobalt deficiencies have been reported by Lee (1951b) and Fearn (1958). Areas of volcanic soils in this region have been reported as free from such deficiency (Kelly 1958) but according to Fearn (J.T. Fearn, personal communication) no precise evidence can be obtained on this point due mainly to the lack of widespread sheep grazing on the volcanic soils. Certainly all those soils with less than 2 p.p.m. cobalt should be regarded as potentially deficient.

Copper deficiency is known to occur on terra rossa soils on dune limestone, the ground-water rendzinas and ground-water podzols, for all of which the copper concentrations are below 20 p.p.m. and generally below 10 p.p.m. Soils of this area, with less than 10 p.p.m. may be regarded as potentially deficient, especially under alkaline conditions. The fact that some variation in copper deficiency has been noted in ground-water rendzinas (Lee 1951b) suggests that those with the higher copper contents, more than 10 p.p.m., may not be seriously deficient in this element.

The absolute amounts of manganese in the soils may show very little relation to the appearance of deficiency symptoms; these have been found in soils with from 50 p.p.m. at Penola to more than 400 p.p.m. in the Mount Gambier area (Samuel and Piper 1928). The occurrence of manganese deficiency in soils is known to be controlled to a great extent by the forms of manganese and by the pH, hence it might be concluded that the total content of manganese has little value in assessing the probable occurrence of such a deficiency. A better interpretation may be that soils with manganese concentrations of less than about 400 p.p.m. are to be suspected as manganese deficient under particular conditions of pH, soil management, and crops.

No deficiencies of molybdenum have been proved in this region and it is regarded as significant that this is the one trace element that is frequently present in these soils in approximately normal concentrations. However, attention is drawn to the shelly ground-water rendzinas which have the lowest contents of this element.

Zinc concentrations of less than 20 p.p.m. probably indicate soil deficiencies of this element, but even higher concentrations may be associated with a deficiency, for the ground-water rendzinas of fine texture are regarded by Tiver (1955) as liable to show responses to zinc. Such soils usually have more than 20 p.p.m. zinc.

For a preliminary assessment of possible soil deficiencies of copper and zinc it seems that concentrations less than about half the world soil averages, i.e. copper <10 p.p.m. and zinc <25 p.p.m. may become critical depending on various soil and plant conditions, including soil pH and drainage.

(d) Conclusions

For soils similar in respect to profile features, parent materials and drainage conditions, each trace element maintains some consistency in its total content in the soil. This was shown particularly in relation to the terra rossas and rendzinas, including those of the ground-water type. The group of terra rossas on dune limestone is distinguished by higher contents of manganese and molybdenum from the ground-water rendzinas on marls, which have higher cobalt, copper, zinc and iron. The ground-water rendzinas on shells have low contents of all elements. The ground-water podzols contain normal amounts of molybdenum but their manganese, zinc and iron contents are exceptionally low.

The contents of several trace elements, especially cobalt, copper and zinc, are significantly higher in the comparatively small area of soils developed on volcanic rocks than in other soils.

Some variations in cobalt content in well-drained terra rossa and rendzina soils, on the one hand, and poorly-drained ground-water rendzinas, on the other hand, are regarded as related not to parent material composition or to profile features such as clay content, but to differences in the natural drainage status of these soils.

Comparison of the results presented here with the world averages given by Vinogradov (1959) is a useful way to rate the trace element status of the soils. It emphasizes that a low status in all elements except molybdenum is common to many of the soils except those associated with basic volcanic rocks.

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TABLE 1. SOIL CHARACTERISTICS AND CONCENTRATIONS IN SURFACE LAYERS OF COBALT, COPPER, MANGANESE MOLYBDENUM, NICKEL, VANADIUM, ZINC AND ZIRCONIUM

SOILS	TOPOGRAPHY, DRAINAGE	PARENT MATERIAL	SAMPLE No.	CLAY	pH	DEPTH (ins)	Co	Cu	Fe	Mn	Mo	Ni	V	Zn	Zr
							(concentrations in p.p.m. except for Fe - %)								
A. TERRA ROSSA															
Undifferentiated porous reddish-brown soils. Surface textures varying from sands to clay loams, depending on parent materials. Soil reaction: usually neutral. Depth 2-20 ins. overlying limestone (usually travertine). Organic matter content: 2-6% at surface 1-2% below.	Sites on hummocks, low ridges and hills not subject to flooding. Water-table not closer than 6 ft. below surface and usually 20-50 ft. below surface.	1. Dune limestone with 70-90% shell fragments. Soil textures: sand to sandy loam.	16452	7	8.4	0-5	<2.	2.2	n.d.	180	<2.	4.7	82	11	140
			16460	11	8.2	0-3	<2.	4.1	2.	570	2.0	9.1	100	24	220
			265/1	5	8.3	0-3	<2.	0.9	0.6	180	<1.	1.	39	9	23
			269/1-2	15	7.0	0-4	<2.	1.9	1.4	90	2.3	1.	47	11	47
			290/1	5	7.3	0-4	<2.	5.3	2.2	78	2.0	2.7	36	17	79
			316/1*	4	6.7	0-3	<2.	2.2	0.6	240	2.5	<1.	28	7	34
			334/1	4	7.5	0-3	<2.	4.2	1.4	390	2.0	4.7	47	26	140
			342/1	6	6.7	0-3	<2.	8.3	1.4	270	2.1	2.9	50	8	220
			15906	18	7.3	0-3	<2.	8.3	1.3	170	2.1	2.3	48	17	49
			Mean (9)	8			<2.	4.2	1.3	240	1.8	3.2	48	14	110
		2. Miscellaneous limestone. a. Estuarine or lake marls, up to 90% calcium carbonate. Surface soil textures; clay loam and clay,	16491	43	7.4	0-5	15.	9.6	4.	1200	2.8	23.	140	21	420
		b. Various types of limestone, with additions of estuarine or eolian deposits (including volcanic ash). Surface soil textures: sand to clay loam.	16475	30	6.2	0-4	11.	5.6	2.	830	3.6	46.	160	21	220
			339/1	9	8.1	0-5	<2.	9.0	2.2	860	2.2	20.	100	64	230
			331/1*	5	6.7	0-3	6.2	7.2	1.8	460	2.5	35.	64	18	180
			336/1	8	7.9	0-3	<2.	4.7	5.4	690	2.0	29.	140	20	180

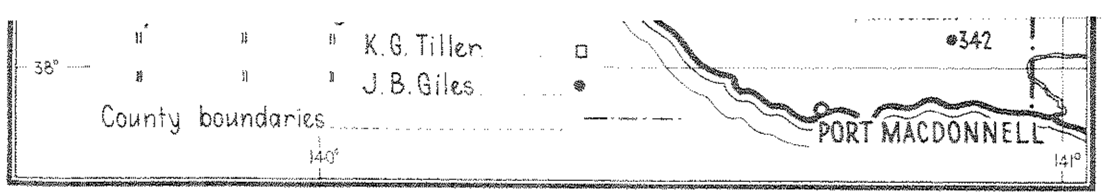

FIG. I *South-East of South Australia showing location of samples for determinations of trace elements.*

SOILS	TOPOGRAPHY, DRAINAGE	PARENT MATERIAL	SAMPLE No.	CLAY	pH	DEPTH (ins)	Co	Cu	Fe	Mn	Mo	Ni	V	Zn	Zr
							(concentrations in p.p.m. except for Fe - %)								
B. RENDZINA															
Undifferentiated porous black or dark brown sandy loams; loams clay loams or clays. Soil reaction; neutral to alkaline. Depth 8-12 ins. over lime rubble, marl or tuff. Organic matter content: up to 15% at surface, 6-7% below.	Sites mainly on hummocks and low ridges, not subject to flooding. Water table not closer to surface than 6 ft.	1. Marls. Surface soil texture: clay	16470/1	43	7.5	0-8	6.2	5.7	2.	250	2.6	18.	106	21	210
			16479/80	31	7.1	0-8	14.	9.3	1½.	1200	3.6	34.	130	54	330
		2. Tuff containing fragment of basalt and limestone. Surface soil textures: sandy loam to sandy clay loam.	182/1	19	7.	0-6	18.	45.	5.5	900	2.6	100.	170	110	420
			351/1-2*	28	8.1	0-6	5.6	12.	2.2	580	2.2	22.	78	40	117
C. GROUND-WATER RENDZINA															
Undifferentiated porous black loams clay loams and clays varying with parent material. Soil reaction: neutral or alkaline at surface, alkaline below. Depth: 3-18 ins. over shells, limestone, or lime rubble. Organic matter content: 5-20% at surface; 3-15% below.	Sites on lowlying plains subject to occasional flooding or water logging. Water-table rises into soil profile during wet seasons, sinks to 5-6 ft. in summer.	1. Estuarine or lake marls. Soil textures; clay loams and clays.	16464/5	36	8.0	0-6	<2.	9.5	2.	193	2.5	11.	82	17	430
			16484/5	71	7.6	0-8	3.5	6.8	3½.	175	2.0	21.	105	24	305
			273/1-2*	44	6.6	0-6	<2.	11.	2.6	94	2.0	8.5	65	26	101
			275/1-2	56	8.3	0-8	<2.	4.8	2.2	240	0.6	6.5	46	27	49
			289/1-2-3	53	8.1	0-8	3.7	5.4	6.0	31	1.2	22.	81	31	69
			308/1*	34	6.7	0-4	2.8	14.	2.8	290	1.4	11.	92	18	150
			311/1	73	8.8	0-4	<2.	17.	2.9	132	0.3	11.	89	40	42
			312/1	35	8.5	0-5	<2.	7.0	1.3	80	<1.	6.0	54	23	38
			318/1-2	63	7.9	0-6	3.4	7.7	6.	106	0.7	14.	95	30	86
			327/1-2*	43	8.3	0-6.5	<2.	7.9	1.8	121	<1.	4.8	66	22	39
			18628/9	40	8.3	0-7	<2.	8.3	1.3	90	<1.	2.6	43	45	26
			Mean (11)	50			C2.	9.4	2.9	140	1.1	11.	74	27	120

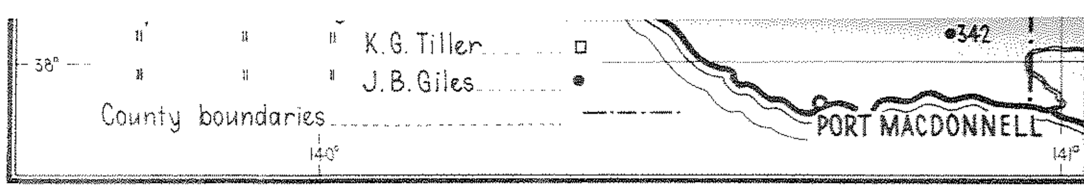

FIG. I *South-East of South Australia showing location of samples for determinations of trace elements.*

SOIL	TOPOGRAPHY, DRAINAGE	PARENT MATERIAL	SAMPLE No.	CLAY	pH	DEPTH (ins)	Co	Cu	Fe	Mn	Mo	Ni	V	Zn	Zr
							(concentrations in p.p.m. except for Fe - %)								
C. GROUND-WATER RENDZINA (Cont)															
		2. Miscellaneous shell and estuarine deposits.													
		a. Marine shells. Soil texture: Shelly loams.	279/1-2	5	8.4	0-6.5	<2.	1.4	0.2	80	<1.	<1.	37	5	5
			283/1-2	4	8.2	0-8	<2.	1.4	0.1	51	<1.	1.	37	5	4
		b. Marine or estuarine shells soil texture; organic loam.	268/1-2	3	8.2	0-8	<2.	10.3	0.6	56	<1.	4.2	46	18	34
			286/1-2	9	8.1	0-8	<2.	3.4	0.7	71	<1.	5.4	37	23	19
			287/1-2	8	8.2	0-6	<2.	1.1	0.6	56	<1.	2.4	54	34	21
		c. Mixed shelly and fine sediments. Soil texture: loam.	267/1-2	18	8.3	0-7	<2.	4.0	0.9	128	0.8	3.5	40	22	55
			281/1-2	29	8.4	0-6	<2.	1.6	1.1	71	<1.	4.2	41	15	57
			Mean (7)	11			<2.	3.3	0.6	73	<1.	3.	41	17	28
D. GROUND-WATER PODZOLS															
Deep siliceous sands with organic matter concentration at the surface and together with iron in a hardpan at 30-50 ins. Soil reaction: acid throughout. Organic matter content: 2-4% at surface, less than 1% below except in hardpan.	Sites on lowlying plains or enclosed depressions, subject to occasional flooding or waterlogging. Water-table (perched?) may rise to surface in wet seasons	Resorted siliceous sands residual from leaching of calcareous dune sands. Soil texture: sand.	180/2+	1	5.0	0-5	<2.	2.5	0.035	9	3.6	<2.	19	9	120
			366/1	5	6.0	0-3	<2.	6.5	0.16	33	2.2	<2.	21	4	n.d.
			367/1+	2	5.5	0-5	<2.	2.7	0.034	4	3.1	<2.	18	6	n.d.
			368/1	2	5.0	0-4	<2.	3.1	0.037	9	2.	<2.	28	5	n.d.
			369/1	3	5.5	0-5	<2.	3.7	0.043	11	2.	<2.	17	4	n.d.
			Mean (5)	3			<2.	3.7	0.06	13	2.6	<2.	21	5	
E. PODZOL															
Similar to ground-water podzol, but less concentration of iron and organic matter at 30-50 ins. No hardpan.	Sites on well-drained hills and dunes.	As for ground-water podzol.	184/2+	5	6.0	0-6	<2.	7.	0.78	270	2.9	10.	34	14	120

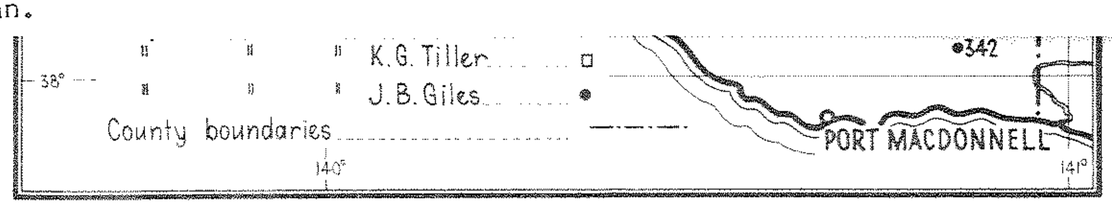

FIG. 1 *South-East of South Australia showing location of samples for determinations of trace elements*

SOIL	TOPOGRAPHY, DRAINAGE	PARENT MATERIAL	SAMPLE No.	CLAY	pH	DEPTH (ins)	Co	Cu	Fe	Mn	Mo	Ni	V	Zn	Zr
							(concentrations in p.p.m. except for Fe - %)								
F. MEADOW PODZOL															
Sand or sandy loam, 10-20 ins. deep over clay with calcium carbonate at 24-40 ins. Soil reaction: acid at surface, clay becomes alkaline at depth. Organic matter content: 2-4% at surface, 1% below	Plains on which soils are subject to water logging.	Pleistocene alluvium (?) surface soil texture: sand.	426/1+	7	6.0	0-6	<2.	4.2	½	64	4.	<2.	35	18	n.d.
G. KRASNOZEM															
Usually deep poorly differentiated, porous brown to red-brown loams or clay loams with clay subsoils. Soil reaction: acid to neutral at surface to neutral subsoil. Organic matter content: 3-5% at surface, decreasing to less than 1% at 36 ins.	Hills with adequate surface drainage.	Basalt and basaltic tuff. Surface soil texture: loam.	189/1	19	6.0	0-5	11.	22.	2.7	280	2.	94.	120	25	290
			185/1	13	6.5	0-5	73.	130.	8.3	2000	2.	400.	510	50	540

* Samples under sown pasture.
+ Samples under pine plantations.
n.d. not determined.

Laboratory data for samples 16452 - 16491 from Stace and Rogers (1954) and McKenzie (1958) and for samples 180-189, 366-369 and 426 from Tiller (1957). All other data from Giles (1960) and Laboratory records of Soil Chemistry Section, Division of Soils, C.S.I.R.O.

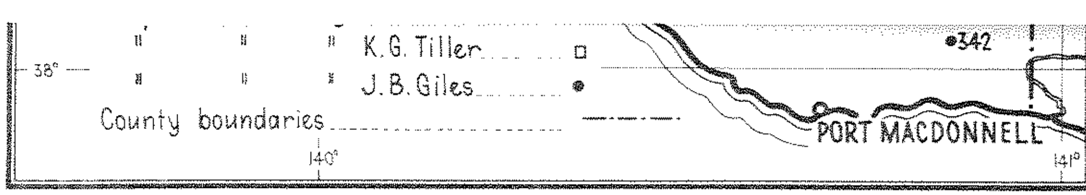

FIG. I *South-East of South Australia showing location of samples for determinations of trace elements.*

TABLE 2. MEAN CONTENTS OF ELEMENTS IN SURFACE SAMPLES OF SELECTED GROUPS OF SOILS AND RATIOS TO AVERAGE VALUES FOR SOILS OF THE WORLD

SOILS	MEAN CLAY %		COBALT	COPPER	IRON %	MANGANESE	MOLYBDENUM	NICKEL	VANADIUM	ZINC	ZIRCONIUM
TERRA ROSSA (9) on dune limestone	8	Mean	<2	4.2	1.3	240	1.8	3.2	48	14	110
		Ratio	c.1/10	1/5	1/3	1/3	1	1/12	1/2	1/4	1/3
GROUND-WATER RENDZINA on marls (11)	50	Mean	c. 2	9	2.9	140	1.1	11	74	27	120
		Ratio	c.1/5	1/2	0.9	1/6	1/2	1/4	1	1/2	1/3
GROUND-WATER RENDZINA on shelly and estuarine sediments (7)	11	Mean	<2	3.3	0.6	73	<1.	3	41	17	28
		Ratio	c.1/10	1/6	1/6	1/12	c.<1/2	1/13	1/2	1/3	1/11
GROUND-WATER PODZOLS (5)	3	Mean	<2	3.7	0.06	13	2.6	<2	21	5.3	n.d.
		Ratio	c.1/10	1/5	1/60	1/70	1	1/40	1/5	1/10	
KRASNOZEMS AND RENDZINAS ON BASALTIC MATERIALS (4)	20	Mean	27	52	5.	940	2.	150	220	66	340
		Ratio	3	2	1.3	1	1	4	2	1	1
SOILS OF WORLD Normal Concentration (Vinogradov)			c.10	20	3.8	850	2	40	100	50	300

Concentrations expressed as p.p.m.

Fe as per cent.

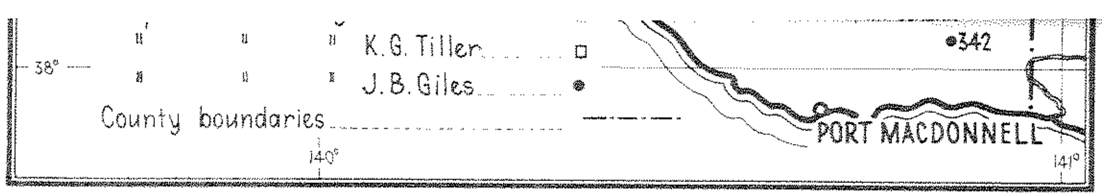

FIG. I *South-East of South Australia showing location of samples for determinations of trace elements.*

TABLE 3. SUMMARY OF TRACE ELEMENT STATUS OF DIFFERENT GROUPS OF SOILS IN LOWER SOUTH EAST OF SOUTH AUSTRALIA

Concentration relative to average normal soil (Vinogradov)	4-2	c.1	$\frac{1}{2} - \frac{1}{3}$	$\frac{1}{4} - \frac{1}{6}$	c. $\frac{1}{10}$	c. $\frac{1}{50}$
TERRA ROSSA on dune limestone	-	Mo	Fe, Mn, V, Zr	Cu, Zn	Co, Ni	-
GROUND-WATER RENDZINA on marls	-	Fe, V	Cu, Mo, Zn, Zr	Co, Mn, Ni	-	-
GROUND-WATER RENDZINA on shelly and estuarine sediments	-	-	V	Cu, Fe, Mo, Zn	Co, Mn, Ni, Zr	-
GROUND-WATER PODZOLS	-	Mo	-	Cu, V	Co, Zn	Fe, Mn, Ni
KRASNOZEMS AND RENDZINAS ON BASALTIC MATERIALS	Co, Cu, Ni, V	Mn, Mo, Zn, Zr	-	-	-	-

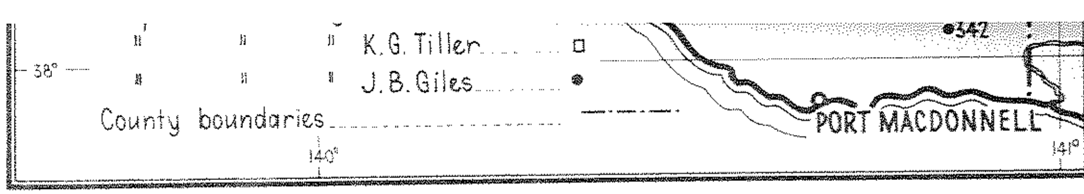

FIG. 1 *South-East of South Australia showing location of samples for determinations of trace elements.*

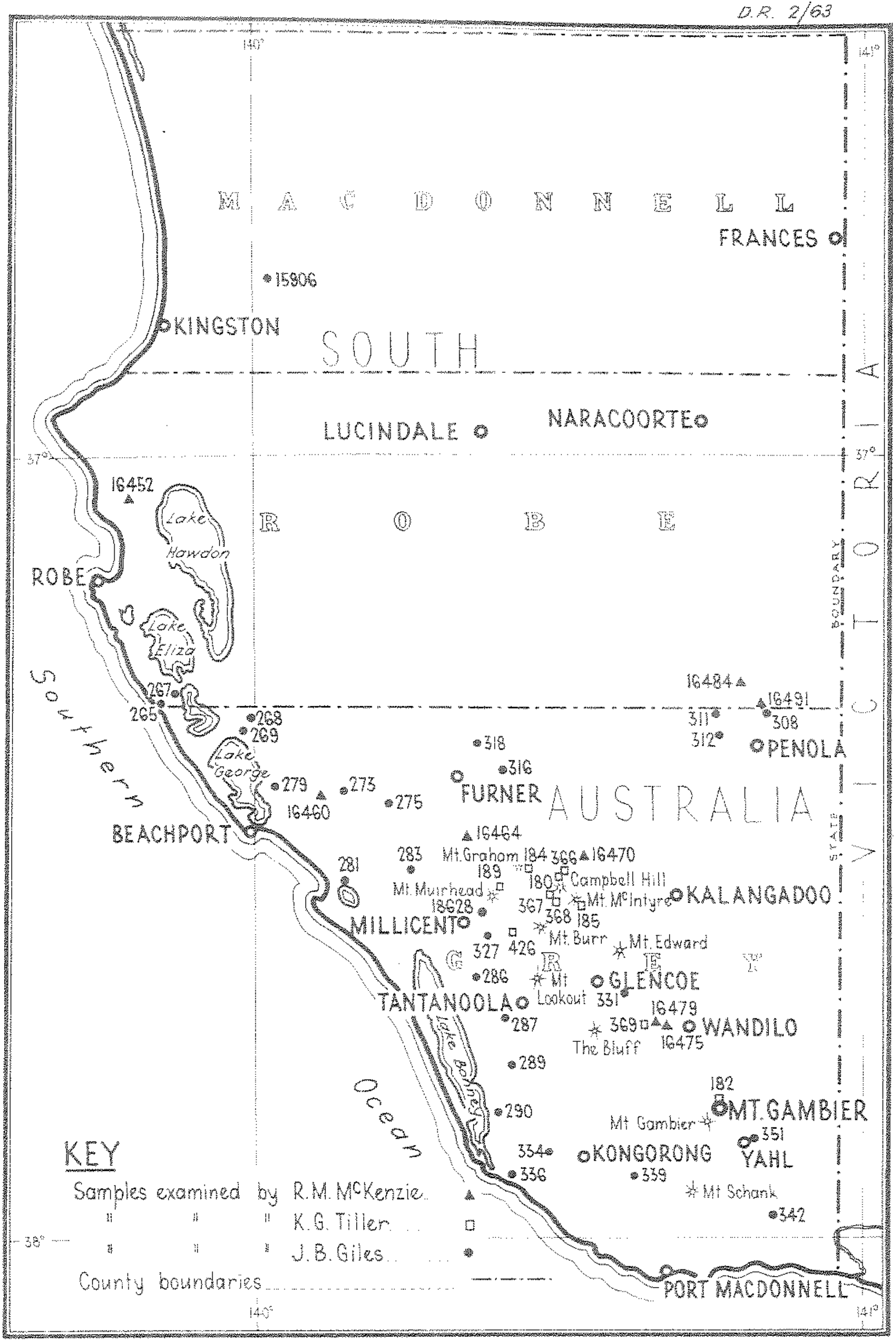

FIG. 1 *South-East of South Australia showing location of samples for determinations of trace elements.*