Soil Chemical Properties at Historical Archaeological Sites of Inner Sydney, New South Wales

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This paper reviews the analysis of historic soils undertaken in inner Sydney. It presents background information on the type of soils found in inner Sydney and the chemical properties of undisturbed soils. It then examines how soils on archaeological sites are different through examining the pH, salinity, exchangeable cations, organic matter, phosphorus and trace elements.

Interest in soil properties during field studies of the historical period mainly arises from the need to distinguish between the soils and soil materials disturbed by occupation and the undisturbed soil profile below. Erection, alteration and demolition of buildings, particularly foundations and drains, seldom leave the original profile intact. Topsoil is stripped away, subsoil from trenches and footings is spread around on the surface, extraneous soil material is brought in for use as fill, and the original soil is contaminated or mixed with debris and building rubble. In between these episodes other activities such as refuse and wastewater disposal, fires, gardening, burial of animal and human remains and changes to the pattern of water movement also leave their mark on the soil.

In most instances detailed examination of particular soil morphological features is useful in assessing the degree of disturbance, particularly when an undisturbed profile is available for inspection close by.[1] Laboratory analyses of soil properties can be useful if such a comparison is not available. Soil chemical testing usually helps to confirm conclusions reached in the field, and also to characterise soil profile features. The test results sometimes are unexpected and may yield new information on the soil's properties, including those inherited from the natural processes of soil formation as well as those acquired as a result of human activities in the past 200 years.

The amount of soil chemical data from historical sites in Sydney has been steadily accumulating since the 1970s and continues to increase. Soil chemical properties are affected, to a greater or lesser extent, by spatial and temporal variation, and this has the effect of masking underlying trends or patterns. A large volume of data often needs to be interpreted to search for particular trends or unifying features. If soil chemical properties can be interpreted and better understood, then future studies of the historical period will be enhanced by their investigation.

Some properties can act as indicators of particular types of land use, but only if their impact is large enough to overcome the natural, inherent properties of the soil. Usually, the surface soil experiences the most pronounced impact, with subsoil properties responding more slowly to activities on the surface. Soils vary in their ability to respond to external impacts, some having a natural buffering capacity that resists changes. Others, including some in Sydney, experience significant changes to their most basic chemical properties.

The main chemical properties of interest are those which can be readily analysed by most commercial and government testing laboratories, namely pH, salinity, organic carbon, exchangeable cations, phosphorus, nitrogen and some trace elements. The interpretation of the results to produce meaningful conclusions is critical. The main requirement is to distinguish between the natural inherited features, and those acquired from landuse activities at the site.

SOIL IN SYDNEY

In Sydney's central business district and suburbs in its immediate vicinity (Fig. 1) the soil pattern in this area is strongly controlled by the parent material, the type of weathering it has undergone, and the position in the landscape. Inspections of undisturbed soil profiles in many of Sydney's parks has revealed their main features.[2]

The dominant parent rock is Hawkesbury Sandstone, which varies from coarse gravelly to fine sandstone with occasional shale lenses. Alteration of the sandstone by weathering has covered the fresh rock with a crust or rind up to several metres thick. This mantle of weathered rock is typically sandy and shallow, with topsoils of grey sand and yellow or light grey sand to sandy clay subsoils, with a varying amount of gravel. Deep weathering in places has produced resistant iron-indurated dark bands adjacent to pallid iron-depleted zones. These erosion-resistant crusts form a capping on many of the broader ridges and upper slopes. Thicker soils occur here, many with iron-indurated gravel in the profile.

Clayey yellow subsoils also occur in the elevated parts of the landscape where shale lenses are more common. They are also found where interfingering of sandstone and shale bands occur at the upper boundary of the Hawkesbury sandstone with the overlying Ashfield shale. Elsewhere, the sandy soils represent the Hawkesbury series, and those with clayey subsoil the Hammondville series of Walker.[3] The Gymea soil landscape of Chapman and Murphy covers most of the inner Sydney area and harbour foreshores.[4] Many variations in profile morphology arise from differences in the depth to rock and the thickness and properties of the weathered sandstone.

The lower areas of the landscape are where depositional rather than erosional processes are the dominant soil-forming factors. Soil eroded from higher upslope accumulates in depressions and lower slope areas, producing deeper profiles, occasionally with shallow fresh water tables below the surface. These are zones of accumulation, and occur along drainage lines and swampy depressions, often at the head of tidal inlets, and occasionally on more level areas higher up. Deep sandy and clayey soils with grey or pallid subsoils and occasionally with thick dark topsoils, rich in organic matter, are found here.

Similar soils are also found in depressions in the sand dune terrain of Sydney's inner-southern and eastern suburbs. Windblown sand up to many metres thick covers the underlying bedrock in a landscape often without a connected drainage pattern. Blown out of Botany Bay, 10 km south of Sydney, during periods of lower sea level the sand supports characteristic podsol soil features seen along Australia's eastern coastline. The surface soil is darkened by accumulated organic matter, but becomes pale and almost white underneath. The bleached zone which may be over a metre thick in the more elevated parts of the landscape, abruptly overlies a dark cemented sandy hardpan layer known locally as Waterloo rock or coffee rock. This hardpan is brown and black and often has a wavy or contorted upper surface. It becomes less cemented with depth and in elevated positions often changes to a bright

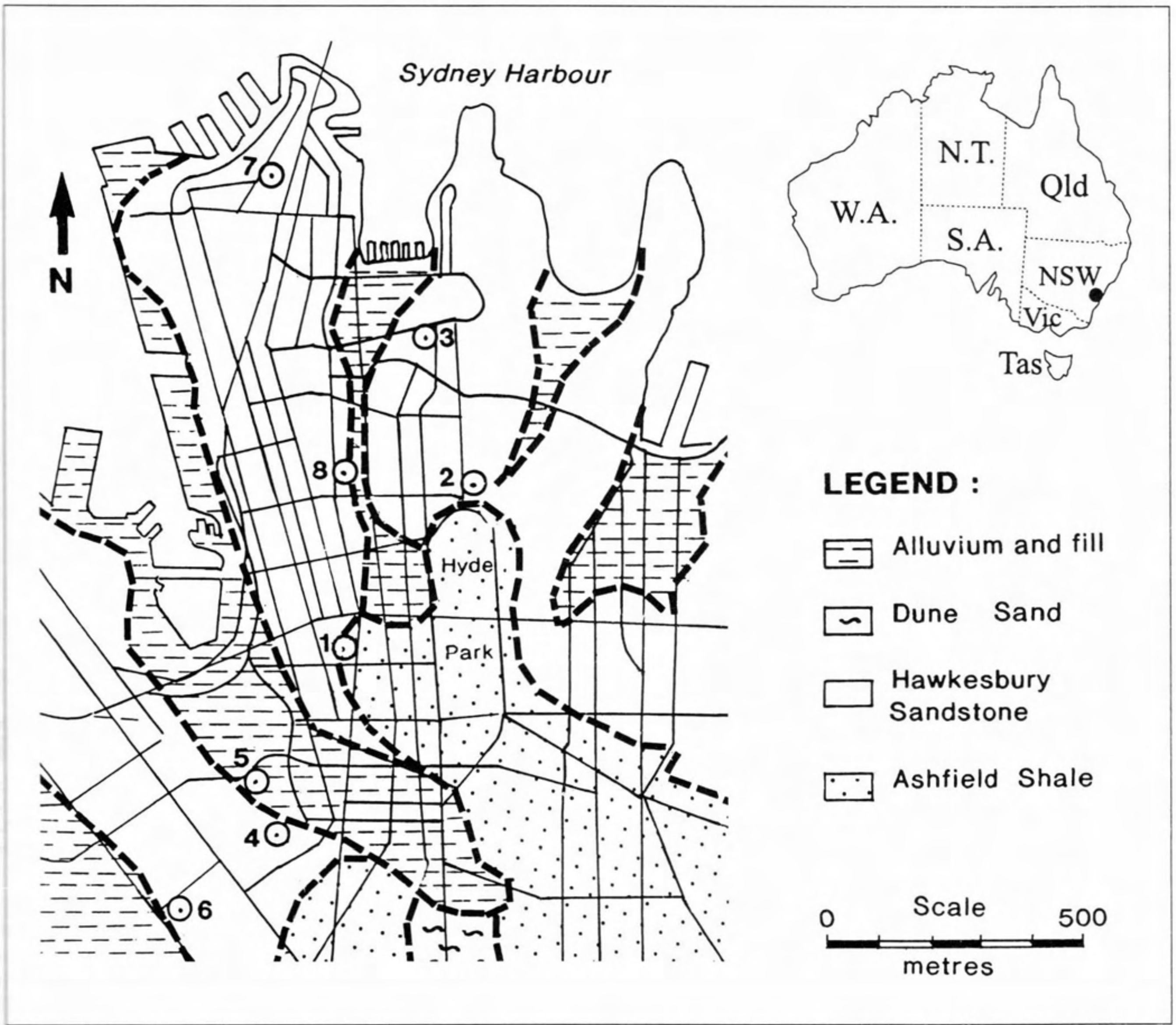

Fig. 1: Location map of archaeological sites in inner Sydney.

1.	*Old Sydney Burial Ground*	4.	*Paddy's Market*	7.	*Cumberland Street, the Rocks*
2.	*Hyde Park Barracks and the Mint*	5.	*Little Pier Street, Darling Harbour*	8.	*GPO, Martin Place*
3.	*First Government House*	6.	*May Ann Street, Ultimo*		

Two other sites mentioned (Cremorne and Prince of Wales Hospital) lie outside the map area. The geological boundaries are from General Geology, Eastern Suburbs Railway, *Snowy Mountains Hydroelectric Authority, 1969.*

yellow colour, with brown or red mottles. The mottled zone can continue for several metres before rock is encountered, or can be underlain by a second coffee rock layer. In depressions the sand below the hardpan is often grey or pallid, and usually waterlogged.

Chemical properties of undisturbed soils

Salinity

Sydney's rainfall (annual average around 1200 mm) is high enough to have a major impact on soil chemical properties. The more mobile constituents such as soluble salt (derived from the sea and delivered by aerial deposition) are quickly leached down through the permeable sandy profiles. This means that soil salinity is generally very low in undisturbed profiles. Electrical conductivity (e.c.) measurements of 1:5 soil/water suspensions are generally below 0.1 deciSiemens per metre (dS/m). Drier areas 30-40 km inland have greater soil salinity, notably in poorly drained clay subsoils.

pH

The high rainfall strips alkali cations like calcium, magnesium, sodium and potassium out of the profile. Most bushland or farmland soils are acidic, with a surface pH (measured in calcium chloride solution) around 5, usually decreasing in the subsoil to around 4. The exception is where depositional processes become dominant, allowing the alkali cations to accumulate. The windblown sand profiles exhibit this characteristic in the coffee rock layer. Elsewhere, along drainage lines, and in swampy areas and depressions, the soil is often less acidic than on elevated areas nearby. The pH rarely exceeds 7.5 at any depth in the profile. Calcium carbonate is not found naturally in inner Sydney soils, except in the form of marine shells in some estuarine areas.

Exchangeable cations

The positively-charged alkali cations, instead of being leached out, can be retained by the soil if it has enough negatively-charged exchange sites. These exchange sites are

found on particles of clay and organic matter, two constituents which are in limited supply in many Sydney soils. The cation exchange capacity in sandy soils is low, irrespective of pH. In loamy or clayey acid soils many of the exchange sites are occupied by aluminium, rather than the alkali cations. The cation exchange capacity can be measured directly, or by totalling up the concentration of the five major exchangeable cations, calcium (Ca), magnesium (Mg), potassium (K), sodium (Na) and aluminium (Al). Totals below 3 milliequivalents per 100 g, or meq/100 g (sometimes expressed as centimoles of positive charge per kilogram) are common in bushland and farmland soils around Sydney; some horizons of the sand podsols have totals less than 1. High values (over 10 meq/100 g) may be found in topsoils with a high organic matter content. In these topsoils, calcium is the dominant exchangeable cation (generally occupying 70-80% of the total of exchangeable cations). Magnesium is the next highest (10-15%), followed by potassium, then sodium. The exchangeable aluminium percentage is generally zero if the pH (in calcium chloride solution) exceeds 5. These proportions change with increasing depth below the surface. The percentages of exchangeable calcium and potassium fall, and magnesium increases to become the dominant cation, except in very acid soils where aluminium becomes dominant. The sodium percentage, which is usually small may also increase with depth, especially in parts of the landscape where depositional processes influence soil properties. Only in the sand podsol profiles is the decline in calcium arrested to some extent, and there may be a slight peak in the coffee rock layer. The individual concentrations (rather than the percentages) vary widely, generally according to the clay content of the particular layer or horizon. Exchangeable potassium concentrations may be the exception here, because plant debris is high in potassium. The exchangeable potassium concentration in a particular layer often reflects the amount of organic matter present. The distribution of exchangeable cations down the profile is often linked to cycling of these major nutrients by the native vegetation. Many plants, such as the smooth barked eucalypts and angophoras, accumulate calcium in their bark.[5] Calcium, taken up from the subsoil by the roots, is delivered to the surface when the bark is shed. These natural processes are interrupted when the vegetation is removed. Clearing and burning of these native species can leave pockets of high calcium concentrations in the soil.

Organic matter

In their undisturbed state Sydney's topsoils are reasonably well-supplied with organic matter. Carbon, the main constituent, is present in amounts commonly around 2-3%, with larger quantities in accumulation zones such as peaty swamps. There is a steep decline in the content of carbon with depth, often falling to around 0.1 percent in the deep subsoil. Organic matter rich topsoils in their undisturbed state are sometimes preserved in Sydney's parks, usually through burial under fill or top-dressing. Elevated carbon contents in the subsoil of the dune landscape are a natural feature of the dark hardpan layer. In other landscapes naturally buried topsoils are rare, and usually confined to deposition zones along drainage lines and depressions.

Phosphorus

Phosphorus, a major nutrient, is not abundant in Australian soils. In most soils only a low proportion of the total soil phosphorus content is held in plant-available forms. This severely restricts the growth of introduced pastures and crops, but native plant species have adapted to the situation. Various soil tests have been developed to estimate the amount of plant-available phosphorus, the most commonly used in acid soils being the Bray test.[6] In unfertilised profiles topsoil Bray test levels over 20 mg/kg are rare, while in the subsoil any result over 5 mg/kg is unusual. Total phosphorus concentrations are much higher and can range up to 500 mg/kg, or more if there is plenty of organic matter. Some subsoils in the sand dune country are very low in phosphorus, containing as little as 50 or 100 mg/kg total; their Bray P content is often below the limit of detection. The ability of many soils to absorb or retain phosphorus is considerable, especially if they are acidic and clayey. Phosphorus sorption tests provide a relative measure of this ability, which can vary down the profile. Low sorbing undisturbed soils are rare in Sydney, except in the thick bleached subsurface horizons of the sand dune landscape.

Nitrogen

Nitrogen is a major constituent of soil organic matter and exists in soils in several forms. There are two measures of interest in Sydney, total (Kjeldahl) nitrogen, or TKN, and nitrate-nitrogen. Up to 0.3% TKN may be present in many undisturbed topsoils, although it may be higher in some peaty swamps. The content declines dramatically in the subsoil, where a typical figure may be 0.02%, or even lower in the sand dune country. A small proportion of soil nitrogen is present in the nitrate form, which is soluble in water and consequently prone to considerable temporal variation. Although virtually no data are available for Sydney soils the nitrate-nitrogen content of many topsoils is low, around 10 mg/kg, with even less in the subsoil. There are major exceptions to this situation, particularly where nitrogen fertiliser has been freshly applied, or where nitrogen-rich organic wastes have been deposited.[7]

The trace element content of Sydney soils has received little attention, one problem being to determine baseline levels in uncontaminated soils. Many industrial processes leave a characteristic suite of contaminating trace elements in the soil profile, chromium from tanneries being one example. Some limited information has shown that heavy metal concentrations in suburban parkland are higher than in bushland or farmland areas of Sydney's urban fringe, but are much lower than in the backyards of some inner city suburbs.[8] Large amounts of confidential data have been collected in relation to rehabilitation of land contaminated by industrial activities around Sydney, and environmental thresholds have been set by regulatory authorities.[9] An improved ability to interpret trace element data is needed if there are to be useful inferences drawn for important historical sites.

Many soil chemical properties thus are closely linked to morphological features and their particular position in the profile. Soil chemical data must be interpreted with these factors in mind, the context of the sample having a critical bearing on most inferences that may be drawn. The scale of most soil maps does not allow the details of the soil pattern to be depicted. The main profile features and chemical properties will be described and summarised, but maps will seldom be able to present these data with great precision at any particular site, even where there has been no disturbance.

The chemical properties described in the following section are to some extent site specific, but they help to indicate how the soil's inherited properties have been modified by human activities during the past two centuries.

Soil properties of historical sites

The soils are inspected and sampled using a number of techniques, but collection of large undisturbed cores provides samples of sufficient size for most purposes (Fig. 2). The soils are usually sampled from representative layers or horizons recognised in the core or pit. The results for a number of sites in Sydney are arranged in Tables 1-3 according to the nature of the soil parent material.

pH

A marked contrast in pH between the natural undisturbed soil and the overlying disturbed layers is observed in many sites. Possibly the first record of this was at the Old Sydney Burial

Fig. 2: Features of the undisturbed soil core retrieved from the floor of this pit at Little Pier Street demonstrated that the site was once on the shoreline of Sydney's Darling Harbour (Photograph by Richard Mackay.)

Ground, near St. Andrews Cathedral (Fig. 1).[10] Buried under 90 cm of disturbed soil material, the original surface soil (A_1 horizon) had a pH (in water) of 5.0. The pH of the other deeper horizons of the natural profile were very similar (4.9 or 5.0). This profile, developed on a small area of Ashfield Shale, had the typical duplex profile form, i.e. a marked increase in clay content below the A horizon boundary. Covering the natural profile was a disturbed layer 15 cm thick consisting of soil from the upper three horizons (A_1, A_2 and B_1), mixed together, and having a pH of 5.1. In the layer of introduced soil material above this, the pH jumped to 7.9, and in the nine other overburden layers of introduced soil material the pH ranged between 7.3 and 8.5. The reason for this remarkable contrast could not be explained, except for the suggestion that lime, or slaked lime, may have been incorporated at the time of burial.

In other sites the change in pH does not always correspond to the break with the natural to the disturbed layers, and is much less pronounced. At the First Government House site not only the disturbed material had an elevated pH, but the underlying natural profile as well.[11] The undisturbed profiles had a pH as high as 7.8 in calcium chloride solution which is about three units higher than would normally be expected. Profiles with a subsoil pH of 7 or more are rare in Sydney. The most likely explanation suggested for this anomalous situation is the disposal of alkaline calcium-rich ash from the fireplaces of the House, and its subsequent leaching down the profile. Charcoal was a common contaminant of the overburden, and the soils, formed on Hawkesbury Sandstone, are very porous. Downward penetration under Sydney's rainfall for over a century and a half has allowed the alkaline material sufficient time to leach down deep into the soil. Agricultural trials with surface-applied lime have demonstrated that downward movement occurs slowly under natural rainfall, raising the pH of acidic sub-surface soils.[12]

A similar effect has been observed in Sydney's Hyde Park , where the sandy soil profiles have been affected by the deposition of alkaline material on the surface (Lawrie 1988).[13]

Salinity

Two nearby sites with contrasting soil salinity levels illustrate how the original landscape leaves its imprint, even though human activity has brought major changes to the terrain. At the old Paddy's Market site soil coring at a very low, gently sloping to level footslope area encountered a shallow water table, the level of which rose rapidly in the borehole.[13] The question of the proximity to the original shoreline of Darling Harbour was raised. Salinity measurements of the waterlogged grey sandy soil showed a very low electrical conductivity (0.06 dS/m). This indicated that this site was not a beach or sandy tidal shore adjoining Darling Harbour. The waterlogged, swampy nature of this site was also indicated by rusty mottles, a foul sulfidic odour and bluish streaks in the soil. All these features would normally be found along boggy, seasonally or permanently wet drainage lines at the base of sandstone ridges.

At Little Pier Street 200 m to the north high soil salinity positively indicated the position of the original shoreline.[14] Under the disturbed overburden a waterlogged black sticky silty clay loam was found which had an e.c. 1:5 of 0.89 dS/m. This covered a grey coarse sand (e.c. 1:5 0.60 dS/m) that contained a shell deposit at a depth of 30 cm below the black layer. Mangrove pollen was found in the core recovered from this site.[15] The present shoreline lies 450 m further north. The intervening area was filled in to create the Darling Harbour Goods Yard.

Exchangeable cations

At the Paddy's Market site exchangeable cation concentrations show the influence of depositional rather than erosional processes. The disturbed dark former topsoil had an organic matter content (4.6%) four times higher than the underlying grey waterlogged layer (1.16%). The total of exchangeable cations consequently was much higher (15.0 meq/100 g), although the proportions of each of the four major cations were similar in both samples. The waterlogged layer (a grey sand) had a much lower total exchangeable cation level (2.5 meq/100 g), similar to sandy soils in more elevated locations dominated by erosional processes. The accumulation zone here is in the organic matter rich topsoil, above the water table.

The relative proportions of each cation, expressed as a percentage of the total, are typical of many neutral to weakly acidic topsoils, i.e. calcium 79%, magnesium 12%, potassium 8% and sodium 1%. Moderately acidic topsoils have some exchangeable aluminium and less calcium. At this site the exchangeable potassium content is elevated, probably due to the presence of decayed vegetation, which is rich in potassium.

On the other side of the city, in Macquarie Street, the exchangeable cation concentrations in undisturbed soils of the Hyde Park Barracks and the Mint have been altered as a result of human activity.[16] At the site of the Mint kitchen, a clayey profile had a very high exchangeable calcium percentage in the A_2, B_1 and B_2 horizons (about 90% of total cations). Soils in these upper slope positions dominated by erosional processes are normally acidic and while calcium may be the dominant cation in the A_1 horizon, the percentage in undisturbed soils normally falls steeply in the subsoil, often to as low as 5%.[17] Many of the profiles tested at this site have elevated calcium percentages. This is a drastic change to a major soil chemical property, particularly in the subsoil, a zone in the profile normally immune from such major impacts. The change is thought to be the result of the use of native Australian trees which, when burnt for fuel, produce a calcium-rich ash. A similar impact was subsequently reported at several other

Table 1. Soil properties at typical sites on Hawkesbury sandstone terrain

Landscape description	Soil horizon	Soil description	Depth (cm)	pH (Ca)	Salinity (ec 1:5,dS/m)	P (Bray, mg/kg)	Organic carbon (%)	Exchangeable cations				
								Ca	Mg	K	Na	Al
Cremorne:	A	Very dark grey sand	10-20	5.6	0.06	17	2.78	8	0.68	0.09	0.14	0.03
Convex upper slope	A_2	Light grey sand	30-40	5.9	0.03	1	0.64	2.9	0.24	0.02	0.07	0.01
on hilly sandstone terrain	?B	Grey medium clay with sand	70-75	5.1	0.06	2	0.63	8.1	0.88	0.08	0.26	0.02
The Rocks:	?A_1	Very dark grey sand	0-10	6.4	0.04	78	0.93	8.5	0.42	0.26	0.05	<0.01
broad ridge crest on	A_2	Very light grey sand	16-21	6.5	0.03	61	0.27	3.4	0.2	0.18	0.03	0.02
hilly sandstone	B	Yellowish grey sand	25-30	6.6	0.03	130	0.21	4.4	0.21	0.21	0.04	<0.01
terrain (site 1)	C	Light yellow grey sand	35-40	6.4	0.03	20	0.18	2.8	0.18	0.23	0.03	<0.01
Upper slope on hilly	Mixed A+B	Greyish brown sandy clay with gravel	10-20	6.3	0.15	271	0.69	6.1	1	0.51	0.31	<0.01
sandstone terrain (site 4)	B_2	Yellowish brown sandy clay with gravel	28-38	5.7	0.14	70	0.39	7.5	0.68	0.39	0.12	<0.01
	C	Light grey coarse sand	38-41	5.5	0.13	39	0.5	7.8	0.73	0.43	0.15	<0.01
Paddy's Market: at the base of gentle	Disturbed A	Dark grey brown coarse sandy clay loam	50-56	6.4	0.1	-	2.6	1.8	1.8	1.24	0.18	<0.01
rocky slope	C	Grey sand waterlogged	80-90	6.2	0.06	-	0.66	0.9	0.37	0.13	0.07	<0.01
Little Pier Street, Darling Harbour	A	Black silty clay loam, weakly laminated	135-140	7.3	0.89	11	2.62	10	5.8	1.1	0.4	<0.01
lower intertidal estuarine flats (Site	estuarine sediment	Dark grey coarse sand	140-148	6.8	0.6	21	<0.5	23	1.1	0.18	0.04	<0.01
3)	estuarine sediment	Dark grey coarse sand	160-170	5.7	0.61	14	<0.5	27	0.92	0.13	<0.02	<0.01

Table 2a. Soil properties at typical sites on interbedded sandstone and shale terrain

Landscape description	Soil horizon	Soil description	Depth (cm)	pH (water)	Salinity (ec 1:5,dS/m)	Organic carbon (%)	Exchangeable cations				
							Ca	Mg	K	Na	TOTAL
Old Sydney Burial	A_1	layer 12	90-120	5	-	1.44	-	-	-	-	-
Ground	A_2	layer 13	120-135	4.9	-	0.94	-	-	-	-	-
St Andrew's Cathedral;	B_1	layer 14	135-150	5	-	0.05	-	-	-	-	-
broad ridge crest on thin	B_2	layer 15	150-160	4.9	-	0.25	-	-	-	-	-
shale capping over sandstone	C	layer 16	160+	4.9	-	0.28	-	-	-	-	-
Mint kitchen, Macquarie Street;	A_2	Very light yellowish brown gravelly clay	0.18	7.8	0.05	-	2.99	0.13	0.08	0.22	3.42
broad lane ridge crest on interbedded sandstone	B_1	Yellowish and reddish brown medium clay	18-30	7.4	0.08	-	11.37	0.58	0.13	0.2	12.28
and shale	B_2	Yellow brown and red brown medium clay	30-41	7.6	0.06	-	12.37	0.79	0.14	0.27	13.57
	B_2	Yellow and red brown mottled clay	41-48	7.3	0.07	-	11.19	0.67	0.12	0.35	12.53
	B_3	Light grey and dark red brown medium clay	48-55	6	0.04	-	12.2	1.09	0.09	0.26	13.64
	B_3	As above	55-68	5.1	0.06	-	5.11	0.65	0.06	0.14	5.96

Table 2b. Soil properties at typical sites on interbedded sandstone and shale terrain

Landscape description	Soil horizon	Soil description	Depth (cm)	pH (Ca)	Salinity (ec 1:5,dS/m)	P (Bray, mg/kg)	Organic carbon (%)	Total N %	Exchangeable cations Ca	Mg	K	Na	Al
First Govt House site, Phillip and Bridge Streets (Site 13)	Lower A	Yellowish brown clayey sand	0-5	7.1	0.11	12	0.4	0.03	2.95	0.46	0.32	0.26	<0.01
	Upper gravel	As above, with iron-indurated gravel	10-15	7	0.1	7	0.24	0.02	2.73	0.43	0.27	0.22	<0.01
	Lower gravel	As above	30-35	7.1	0.1	4	0.24	0.02	2.87	0.69	0.35	0.2	<0.01
	B	Mottled sandy clay	40-45	6.7	0.12	2	0.13	0.02	6.13	1	0.4	0.29	<0.01
	C	Pallid sandy clay	60-65	7.1	0.15	3	0.15	0.02	11.06	1.33	0.46	0.31	<0.01
Ultimo Mary Ann and Jones Streets	A_1	Dark greyish brown fine sandy loam	0-20	3.8	0.14	32	2.75	-	1.1	0.22	0.4	0.31	1.78
	A_2	Light yellowish brown loamy sand	25-40	4.4	0.08	6	1.62	-	1.21	0.42	0.28	0.2	0.46
	B_1	Yellow brown sandy clay loam	40-45	5.7	0.08	1	0.38	-	2.15	1.11	0.41	0.24	<0.01
	B_2	Yellow brown medium clay with sand	45-55	6.9	0.14	1	0.47	-	4.71	1.47	0.66	0.38	<0.01

Table 3. Soil properties of sites with natural accumulations of organic carbon in the subsoil

Landscape description	Soil horizon	Soil description	Depth (cm)	pH (Ca)	Salinity (ec 1:5,dS/m)	P (Bray, mg/kg)	Organic carbon (%)	Exchangeable cations Ca	Mg	K	Na	Al
Sydney GPO Site 4 Site 2	1A	Grey brown light clay with coarse sand	20-30	5.4	0.18	11	1.4	11.1	0.9	0.67	0.4	<0.1
	$1B_1$	Light grey light clay, with rusty mottles	80-90	4.3	0.17	<3	0.25	4.8	1	0.78	0.2	1.5
Layered alluvial soils adjacent to channel of the tank stream; buried under 1-2 m of recent fill	$1B_2$	Light grey light medium clay, with gravel	110-120	4	0.14	<3	0.2	2.6	0.8	0.59	0.3	2.7
	$1B_3$	Grey light medium clay, with fine sand	150-160	4.1	0.11	<3	0.42	2.3	0.9	0.57	0.2	2.7
	IIA	Dark grey light medium clay	190-200	4.1	0.07	4	0.98	1.4	0.5	0.38	0.1	2.5
	IIB	Light grey light medium clay with coarse sand	210-220	4.1	0.06	10	0.32	1.4	0.5	0.42	<0.1	1.8
Prince of Wales Hospital, Randwick upper slope on sand dune blown over sandstone terrain; profile covered by 60 cm of sandy fill	A_0	Black sand	0-3	4.5	0.04	9	2.51	2.2	<0.3	<0.05	0.2	0.4
	A_1	Grey sand	5-10	4.6	0.01	<3	0.27	0.4	<0.3	<0.05	<0.1	<0.1
	A_2	White sand	20-30	4.5	0.01	<3	0.17	0.1	<0.3	<0.05	<0.1	<0.1
	A_2	white sand	40-50	4.7	0.01	<3	0.13	<0.1	<0.3	<0.05	<0.1	<0.1
	A_2	White sand	60-70	4.8	0.01	<3	0.14	<0.1	<0.3	<0.05	<0.1	<0.1
	A_2	White sand	80-90	4.8	0.01	<3	0.07	<0.1	<0.3	<0.05	<0.1	<0.1
	B1 coffee rock	Dark brown, black and yellow brown sand	95-105	4.9	0.03	15	0.61	1	<0.3	<0.05	0.1	0.1
	B_2	Yellow brown sand	120-130	5.1	0.01	4	0.22	0.2	<0.3	<0.05	<0.1	<0.1
	B_2	Yellow brown sand	160-170	4.9	0.01	5	0.1	0.1	<0.3	<0.05	<0.1	<0.1
	C	Very light yellow sand	215-225	4.8	0.01	<3	0.08	<0.1	<0.3	<0.05	<0.1	<0.1

Sydney sites, including First Government House, Cumberland Street in the Rocks and at the GPO. The mechanism for introducing large amounts of calcium into otherwise undisturbed clay subsoil is uncertain. One possibility is the construction of lateral sub-surface drains through the subsoil. A number of these drains were found at the First Government House site. Seepage of calcium-rich drainage and surface run-off into the surrounding soil may have increased the penetration into the subsoil, not only in the sandy soils of the First Government House, but also in the less permeable clays inspected at the Barracks and Mint.

Organic matter

A shallow sandy profile, equivalent to the Hawkesbury series of Walker, in the grounds of an old cottage at Cremorne on the north shore of Sydney Harbour, had chemical properties that had not been significantly modified by human activity.[18] Its organic matter content at the surface was only 4.9% (i.e. 2.78% carbon), falling to about 1% (0.63% carbon) at a depth of 70 cm.

Another relatively undisturbed buried profile, a more clayey one representative of the Hammondville series, had a similar decreasing trend in the carbon content down the profile. Located at Ultimo, on the western outskirts of Sydney's CBD, the profile had remarkably well-preserved earthworm channels in the lower A horizon.[19] The worm channels had been infilled with darker topsoil, raising the organic matter content. Carbon content of the B horizon was 0.4%, and 2.7% in the topsoil. The intervening subsurface horizon where worm activity was greatest had a carbon content of 1.6%.

Any interruption in the strongly decreasing trend in carbon content with depth can usually provide a clear indication of disturbance in the profile. The association between human activity and increased soil organic matter or carbon contents has long been recognised.[20] Natural processes can also interfere with this trend, producing elevated carbon contents in otherwise undisturbed subsoil, and potentially affecting archaeological interpretation.

Two examples where this type of natural interruption have been observed are at the GPO, in the centre of Sydney, and at the Prince of Wales hospital site, 7 km to the south east. The latter location is in a sandstone landscape covered by windblown sand to a depth of several metres. The profile is a podsolised sand, with a coffee rock horizon a metre below the surface.[21] This dark hardpan layer is a natural feature of these profiles and, compared to the horizons above and below it, is enriched with carbon. The old topsoil is richest, with 2.5% carbon, and is almost black. The level falls by a factor of 10 a few centimetres below the surface, reaching a minimum of 0.07% at 80-90 cm where the sand is bleached almost pure white, just above the coffee rock layer. This dark subsoil horizon contains 0.6% carbon, and elevated levels of phosphorus and calcium as well. Below the coffee rock, the carbon content falls again, back to 0.08% by a depth of 220 cm. Although this site had been used as a burial ground, and signs of Aboriginal use were revealed no evidence of disturbance to the coffee rock layer was observed during soil inspections.[22] Its chemical properties appear to have been unaffected by human activities, at least at the test location.

A buried carbon-rich layer was also encountered at the GPO site.[23] The natural soil profile features varied widely across this site, mainly due to its location beside the Tank Stream. The stream appears to have flowed in a channel which traversed from one side of a sandstone gully to the other. Older stream channels followed slightly different tracks that were filled in later by flood-derived sediments. At one point this process appears to have buried an older soil with a layer of clayey alluvial material. This suggests that floodwaters were slow-moving, perhaps in a quiet backwater swamp environment. A new soil formed on top of the alluvial sediments, with a carbon content of 1.4% in the surface, falling to a low of 0.2% at a depth of 110-120 cm. In the buried topsoil the carbon content increased to 0.98%, falling again with depth to 0.32%. Various features of the overlying clayey alluvium and red and yellow mottling pointed to natural deposition rather than human activity (eg weak banding of rounded ironstone gravel). The burial process was initiated much earlier than the colonial period as evidenced by a carbon date of 16,900 ± 700 years BP in a charcoal-rich layer stratigraphically equivalent to the buried topsoil.[24] The context of the sample within a sequence of horizons must be known when soil samples are submitted for carbon or organic matter analyses. Often soil profiles are truncated by excavation and lose their upper horizons. Human activities then introduce carbon to these previously low-carbon layers. Truncation of profiles containing subsoil horizons naturally enriched with carbon may not have been exposed to human activities to produce similar depth trends in carbon content.

Phosphorus

Like carbon, phosphorus is relatively immobile in soils, and remains close to the site of deposition. It is a constituent of organic debris associated with human habitation, and also occurs in various mineral forms produced by weathering of the soil parent material. Much of the plant-available phosphorus is associated with soil organic matter, and for this reason soil tests which estimate the plant-available fraction are useful in assessing whether human activity has affected the soil's properties. Analysis of total phosphorus includes all the mineral forms inherited from the parent material, and is not as sensitive an indicator of human-induced changes as the more widely used tests that estimate the amount of phosphorus available for plant growth. The Bray No. 1 test measures the phosphorus loosely bonded to clay surfaces and organic matter, and a proportion of the iron and aluminium phosphates in acidic soils.[25] Its use at the First Government House site demonstrated the close relationship between disturbance of the soil and the available phosphorus content.[26]

A total of 53 soil samples, both disturbed and undisturbed, were described and tested at the First Government House site. Thirty were from undisturbed soils, and this group had a median value of Bray P of only 4.2 mg/kg, compared to 34 mg/kg in the group of 23 samples from disturbed soils. Among the reasons for the difference is the low natural level of phosphorus in Sydney's soil, a situation first noted a century ago.[27] The high levels in the disturbed material were variously ascribed to activities such as contamination with burnt vegetation (a typical dry matter phosphorus content in grass is 0.2%, or 2000 mg/kg).[28] A piece of burnt wood from an old post hole had a Bray P content of 62.5 mg/kg. This contrasted with a level of only 3 mg/kg in a lime-rich piece of weathered mortar, which obviously was not a contributing source.

Gardening activities, possibly involving the use of animal manures as fertiliser was another reason suggested for elevated phosphorus levels. Five such samples recorded Bray P levels ranging between 14 and 42 mg/kg. Much higher levels were recorded in sandy sediments found in the drains. Human and animal wastes are thought to have contaminated these layered grey sandy soils, which had a Bray P content of 130 mg/kg. Samples from three adjoining layers in a drain near the privies recorded the site's highest levels, ranging up to 428 mg/kg.

Undisturbed soils by comparison recorded maximum Bray P levels in the original topsoil. Two old topsoils had only 12 and 4 mg/kg, levels which might be considered typical.

One reason for the poor mobility of phosphorus is the soil's natural ability to bind or retain it. An index is used to compare this retention, or sorption, capacity. Measurements from profiles at the First Government site showed that this capacity

varies according to the position in the profile. The A horizons have a medium to high capacity, but the B horizons are even more strongly sorbing, with a very high sorption index; levels may fall back at greater depths to medium-high. This characteristic is, to some extent, affected by soil pH and clay content. Recently it has been demonstrated that heavy applications of phosphorus-rich organic wastes can significantly reduce sorption.[29] This offers the potential that P sorption measurements could assist in detecting whether such activities had occurred in previous years. Combined with other soil tests, the keeping of livestock such as pigs, cows or horses in a confined space (yards or stables) could be confirmed if P sorption is found to be depressed.

Nitrogen, another major constituent of organic debris, has not been tested as frequently as phosphorus. Work with total (Kjeldahl) nitrogen tests at the First Government House site yielded little useful information, mainly because, like total phosphorus, TKN levels include nitrogen in many forms. Recent work with soils receiving organic wastes has shown that nitrate-nitrogen is a more sensitive indicator of this type of activity.[30] When combined with tests for soil potassium, it promises to be useful in detecting the presence of plant-rich wastes, such as those produced by domestic livestock.

Animal dung is a possible contributor to the high Bray P levels found in a shallow sandy profile in a site at Cumberland/Gloucester Street, in the Rocks.[31] The pH has been raised to 6.6 in this profile, and this has probably decreased the soil's initially high phosphorus sorption capacity. Reduced retention by the soil of phosphorus in surface-applied wastes has allowed greater penetration down the profile, increasing Bray P concentrations up to 130 mg/kg at a depth of 25-30 cm below the original surface. Phosphorus in organic forms is less easily retained by the soil than inorganic phosphate, and the higher mobility usually means movement is deeper. Bray P concentrations in untreated subsoils are normally below 3 mg/kg.

Two other profiles, both shallow and sandy, also had high Bray P contents at the Cumberland Street site. Total phosphorus was also determined at these two profiles, with levels ranging between 170 and 1210 mg/kg. The maximum total P level was recorded in a disturbed surface soil, which had the peak Bray P content of 271 mg/kg. The ratio of Bray P to total P is very high (0.22) compared to farmland or bushland soils (usually 0.05-0.1) and indicates considerable additions of phosphorus.

Trace elements

A range of trace elements was determined in the Cumberland/Gloucester Street samples with a view to check for possible heavy metal pollution associated with any industrial activities. Heavy metal levels were low, with the exception of one sample where the cadmium content (4.5 mg/kg) was in the very high range for inner city soils. This dark humus-rich sample had a high content of organic matter (which can retain cadmium) and occurred in a depositional location, separated from the other samples. These had cadmium concentrations of 0.7 mg/kg or less and lead 16 mg/kg or less (Table 4). Much higher trace element concentrations have been recorded in Australian cities and in towns with mineral processing industries.[32]

DISCUSSION

A simple surface activity such as waste disposal can affect a combination of soil properties. The organic matter in kitchen refuse contains carbon, nitrogen, phosphorus and potassium, with smaller but significant quantities of calcium, magnesium and sodium. Ashes from fireplaces may be rich in alkali cations like calcium, magnesium and potassium, as well as carbon and phosphorus. Manure from the stables, house cow or domestic poultry, contains carbon, nitrogen and phosphorus, and has a neutral to alkaline pH.

When material containing these elements is applied over a long time to soils with inherently very low concentrations, levels may be raised by an order of magnitude or more. Such increases can extend well beyond the normal range imposed by natural variation. Significant changes like this allow inferences to be drawn about previous land use activities, provided the mobility of each element is considered together with the natural distribution of the elements within the soil profile. Information on soil chemical properties is used mainly to support inferences drawn on the basis of examination of soil profile features. Physical alteration of soil morphology at or near the surface can affect chemical properties in the undisturbed subsoil. Most of the soils at the sites inspected in Sydney have experienced this invisible impact.

Soil chemical testing, on its own, is rarely able to diagnose a specific activity. Instead the information supports inferences drawn from other evidence, which may often be fairly tenuous without it. Better characterisation of soil properties in future years will further enhance the use of soil testing. More information on the impact on soil properties of non-agricultural activities will enable more specific identification of a particular activity. Detailed studies of the environmental impact of industrial activities are yielding information on soil properties, as a result of regulatory requirements. Studies are needed on soil properties of much more mundane locations such as cemeteries, school yards, urban parks and gardens, and roadside nature strips. Studies of eroded sediment accumulated in various small catchments are becoming more common, particularly in rural areas, because of concerns about water quality. If this information can be linked to specific land use activities then it may be used to detect such activities even after a period of 200 years.

Table 4: Trace element concentrations (mg/kg; hot acid extract) in three sites at Cumberland Street (Lawrie 1994).

Trace	Site 2	Site 3		Site 4		
	(Humic)	?B1	B2	Mixed	B2	C
Arsenic	<4	<4	4	8	<4	<4
Cadmium	4.5	0.7	<0.6	<0.6	<0.5	<0.6
Chromium	6	8	8	17	11	8
Copper	7	11	7	<2	<2	<2
Lead	25	16	8	12	<7	<7
Manganese	11.4	9.5	16.6	11.3	3	2.1
Mercury	<2	<2	<2	<2	<2	<2
Molybdenum	<3	<3	<3	<3	<3	<3
Nickel	<3	<3	<3	<3	<3	<3
Selenium	<7	<7	<7	<7	<7	<7
Zinc	5.8	5.3	6.5	2.9	1	<1

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NOTES

1 Lawrie 1982.
2 e.g. Lawrie 1988.
3 Walker 1960.
4 Chapman and Murphy 1989.
5 Lambert 1981.
6 Bray and Kurtz 1945.
7 Lawrie 1998.
8 Lawrie *et al.* 1992.
9 Tiller 1992.
10 D. J. Plowman, in Birmingham and Liston 1976.
11 Lawrie and McLennan 1987.
12 Conyers and Scott 1989.
13 Lawrie 1991.
14 Lawrie 1992.
15 Mike Macphail, pers. comm.
16 Davey and Geering 1981.
17 Lawrie and McLennan 1987.
18 Walker 1960; Lawrie 1994a.
19 Lawrie 1994b.
20 Cook and Heizer 1965; Limbrey 1975.
21 Lawrie 1996a.
22 Godden Mackay 1998.
23 Lawrie 1996b.
24 Casey & Lowe 1998: Appendix 1.
25 Bray and Kurtz 1945.
26 Lawrie and McLennan 1987.
27 Guthrie 1898.
28 Lawrie 1983.
29 Holford *et al.* 1997.
30 Lawrie 1998.
31 Lawrie 1994c.
32 Tiller 1992.

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