MINERALOGY OF ALKALINE-SALINE SOILS ON THE WESTERN SLOPES OF NORTHERN NEW SOUTH WALES

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INTRODUCTION

Alkaline soils are the dominant type of salt-affected soil in Australia (and Europe), occupying almost one quarter of the continent (Northcote & Skene 1972). Alkaline-saline seepage scalds are particularly widespread in inland northern New South Wales and Southern Queensland, where they are commonly associated with Vertosols formed from Cainozoic basalt. These soils are much more challenging to manage than neutral (Cl & SO_4) saline soils because of their high pH (often ca. 10), very high sodicity, aluminate toxicity, organic-matter eluviation, silica accumulation and, possibly, irreversible clay mineralogical changes. Despite these facts and the ever-growing concern about declining soil and water quality due to salinisation, alkaline-saline soils, especially those associated with seepage scalding, are scarcely mentioned in the Australian literature.

The stability of clay minerals in alkaline-saline soil environments is unclear. In particular, the literature is divided over whether inherited (residual or detrital) clay minerals are destroyed and/or authigenic (transformed or neoformed) clay minerals are formed under such conditions. Sodic clay-mineral destruction via hydrolysis is regarded by many (e.g., Barshad 1960, Kamil & Shainberg 1968, Shainberg 1973) as the governing process of soil alkalinisation. Conversely, the formation of clay minerals is thought to occur during the evaporative concentration of Mg-rich ground waters that have a positive residual carbonate alkalinity (Hardie & Eugster 1970). Smectite, in particular, is typically described as the dominant clay mineral present in, and a characteristic product of, alkaline-saline soils (e.g., Kovda & Samoilova 1969, Szabolcs 1989). However, Kohut & Dudas (1994) found that clay mineralogy of alkaline-saline soils in Alberta, Canada, varied little from non-saline soils. Any significant changes in clay mineralogy will have a major bearing on the extent to which alkaline-saline soils can be reclaimed. Clay-mineral stability and the associated process of alkalinisation in these soils must therefore be determined to underpin best-management practices.

The chemistry and mineralogy of alkaline-saline Vertosols and an active spring mound are currently being examined as part of an investigation to determine the salt sources and the physicochemical evolution of alkaline-saline soils in the Bellata district of northern New South Wales (Figure 1). The bedrock in the district comprises Jurassic to Cretaceous sedimentary rocks of the Surat Basin, which are overlain locally by Palaeogene gravel and, in turn, Miocene basalt. The climate is warm, dry sub-humid with summer-dominant rainfall that on a mean montly basis is invariably exceeded by the mean daily potential evaporation. Preliminary findings from studies including Scanning Electron Microscopy (SEM) and X-Ray Diffraction (XRD) are reported herein.

RESULTS

The scalded Vertosols are highly saline, with electrolytic conductivities of 25-30 dS/m where rich in Cl^-. The $pH_{1:5}$ is about 9 to 9.5 throughout the solum and 10 in the surficial depositional crust. The pH_{CaCl_2} does not exceed 8.5, indicating that dissolved bicarbonate and exchangeable sodium are the main causes of alkalinity. The surface soil of the spring mound is only moderately saline (EC ca. 7 dS/m), but is highly alkaline with a $pH_{1:5}$ of about 10 and pH_{CaCl_2} of 9, indicating the presence of sodium carbonate.

A somewhat narrow range of salt minerals has been formed in these soils in which, unlike many of the previously reported alkaline-saline soils in the literature, sulphate minerals have not been found. An efflorescence of natron has developed on the spring mound (Figure 2a). Puffy, powdery saline topsoil occurs sporadically on both the spring mound and the soil scalds. The puffy texture of this soil is due to the physical parting of fine soil aggregates by the growth of elongate forms of halite (Figure 2b & c), identified by EDXA. Tubular halite, described as *fibrous* or *curly stem-like*, has been observed by a few previous authors who questioned whether this habit represented a natural field state or had grown in artificial conditions since field collection. However, in view of no other obvious reason for the puffy nature of the host soil, it is considered here as natural. Halite is also abundant as massive cement (Figure 2d). About 10% ankerite occurs as very fine rhombahedral crystals on and within the desiccated spring-mound crust (Figure 3a & b). Nodular calcite exists throughout the scalded sola and Mg-calcite has formed as nodules and fine crystals within the

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scalded topsoil and the depositional crust on both the mound and scalded soils (Figs. 2e & f). No other soluble salt minerals have been found.

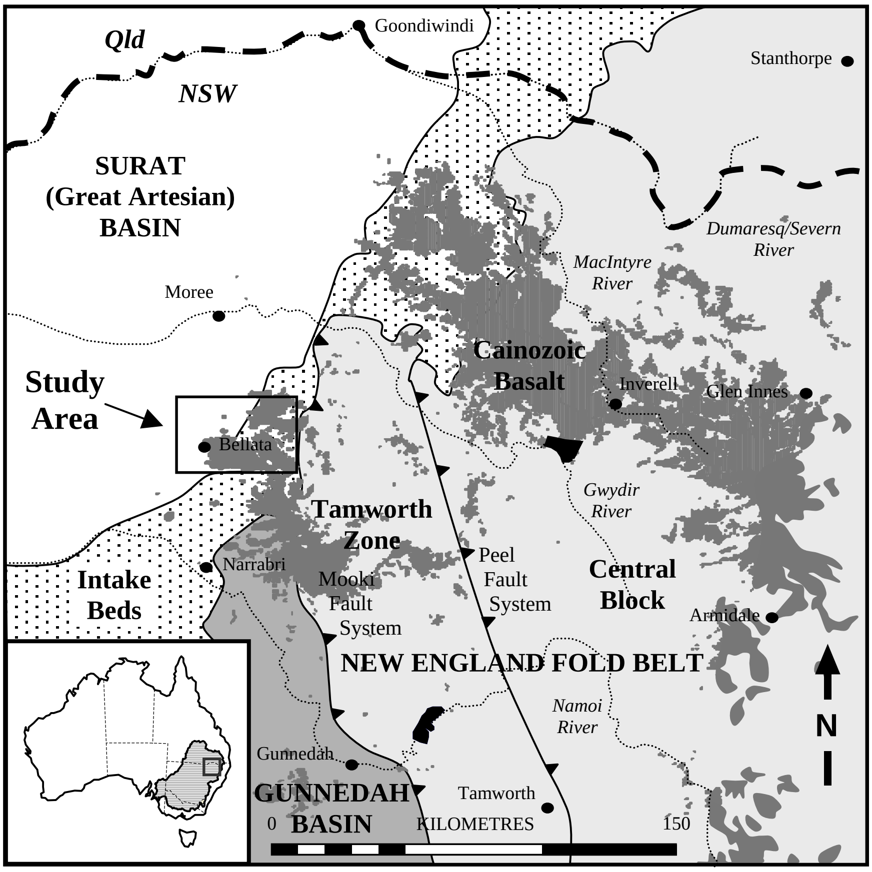

Figure 1: Bellata salinity research area, in the eastern part of the Murray-Darling Basin (shown on inset) and overlying the eastern margin of the Great Artesian (Surat) Basin. The area is located immediately west of the New England Fold Belt. All of these units are sporadically overlain by Cainozoic basalt.

Preliminary XRD analysis of the Vertosols in the Bellata district has revealed that the bulk of the clay fraction of both non-saline and saline topsoils comprises interstratified dioctahedral (d_{060} ca. 1.50Å) smectite-illite. About 10% disordered kaolin-group minerals are also present. The interstratified clay minerals in non-saline soils at the hillcrest and the footslope laterally adjacent to a scalded soil may be ordered whereas in the saline soil and spring-mound crust they are random (Figure 4). If so, this result differs from previous findings in that the alkaline-saline soil conditions have not caused substantial clay mineral formation or destruction within the topsoil, but may have contributed to the loss of order within the interstratifications.

Kaolin-group minerals identified morphologically include halloysite (Figure 3a-d and perhaps Figure 3e) and kaolinite (Figure 3d & f). Kaolinite is very rarely found as isolated euhedral crystals within and on the surface of the spring mound and has not been observed by SEM in the other soils. Halloysite, on the other hand, is particularly common on the surfaces and within the shallow horizons of the saline soils and spring mound. It occurs in a variety of intriguing habits even within a distance of several millimetres on a single soil sample. This indicates the presence of a range of geochemical microenvironments on and within the soil. The occurrence of kaolin-group minerals in the shallow soils is expected since even very saline topsoils are subjected to oxidation and seasonal or event-driven flushing with rainwater, which can cause the transformation of smectites via the removal of lattice cations and silica.

Texturally mature quartz sand and silt clasts are abundant and ubiquitous, even in soils at relatively elevated landscape positions and where developed *in situ* directly from basalt. Heavy minerals of the same size range are also present and have been concentrated as distinct laminae within the depositional scald crust. As many of these clasts are too coarse to have been transported long distances by aeolian activity, the sediment source might have been now-removed alluvium associated with palaeodrainage that had developed following disruption of previous drainage by volcanic extrusion. Alternatively, the gravel road on the hillcrest may supply sediment by sheet wash during intense rainstorms.

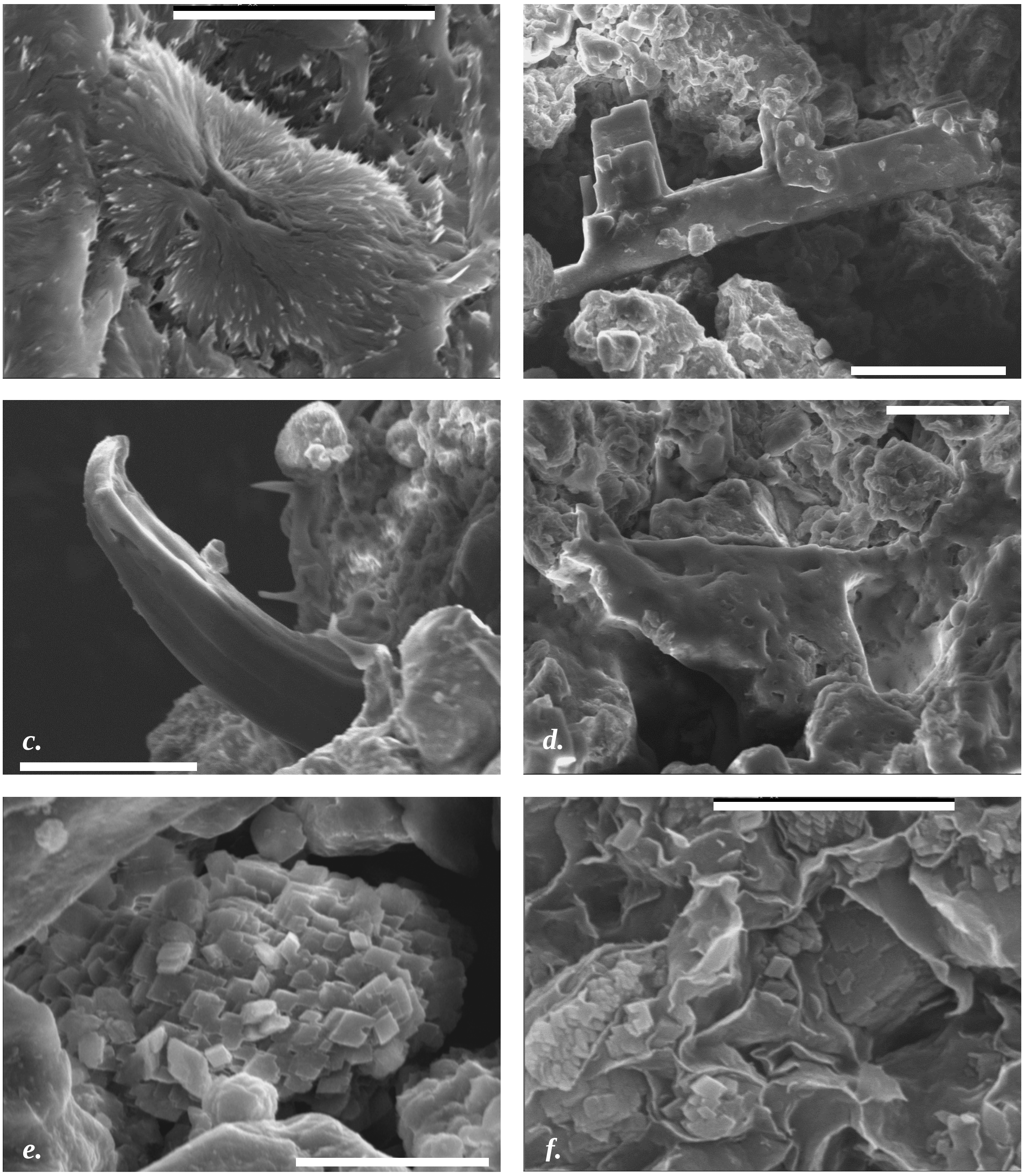

Figure 2: Salt minerals found at Bellata: **a.** Natron efflorescence formed on an active spring mound (scale bar is 10 µm); **b**. Halite in rare cubic form in the puffy, powdery saline topsoil (scale bar is 50 µm); **c**. Common habit of halite in the puffy saline soil (scale bar is 50 µm); **d.** Massive halite in the puffy saline soil (scale bar is 20 µm); **e**. Nodular Mg-calcite in the depositional crust of the spring mound (scale bar is 10 µm); **f.** Abundant rhombahedral Mg-calcite crystals filling pores between sheets of inherited smectite within the depositional crust of the spring mound (scale bar is 4 µm).

FUTURE WORK

Some basic findings from the early stage of an investigation into the mineralogy of alkaline-saline Vertosols in eastern Australia are presented here. Substantial further work is required to adequately describe the detailed mineralogy and mineral stability within this soil environment. In particular, clay minerals will be further analysed via XRD following various chemical and heat pre-treatments. This will be supported by soil physical measurements, soil chemistry, bulk and mineral geochemistry, pore-water chemistry, isotopes, geochemical modelling, chemical extraction techniques and, perhaps, TEM studies of soil cores. This work will support the interpretation of the salt sources and the geochemical processes responsible for alkalinisation.

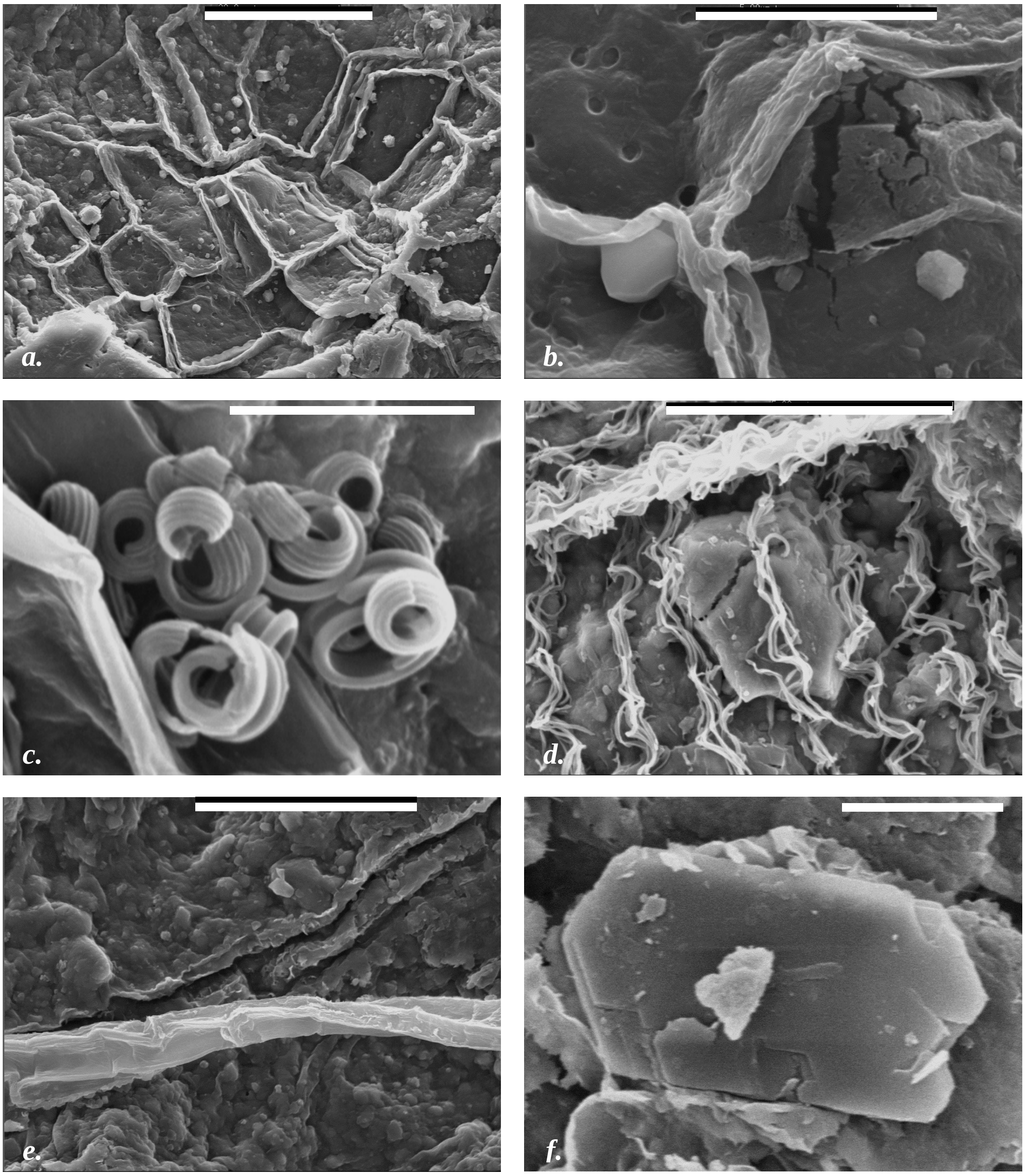

Figure 3: Kaolin-group minerals observed under SEM: **a**. Smectite-illite converting to halloysite on the spring mound crust surface; scattered ankerite rhombs are also present (scale bar is 20 µm); **b**. Close up of Figure 3a showing the substrate rolling into halloysite, ankerite, an unidentified mineral (lower left), numerous holes and a dome with synaeresis? cracks (scale bar is 10 µm); **c**. Halloysite? on the spring mound crust surface (scale bar is 5 µm); **d**. Thread-like halloysite draped over a substrate of smectite and a solitary kaolinite crystal on the spring mound crust surface (scale bar is 10 µm); **e**. One of many elongate structures partially ripped up from the spring-mound crust surface to leave a channel of altered clay. Channels locally dominate the soil surface and multiply overprint other channels (scale bar is 40 µm); **f**. Rare euhedral kaolinite crystal within the spring mound crust (scale bar is 5 µm).

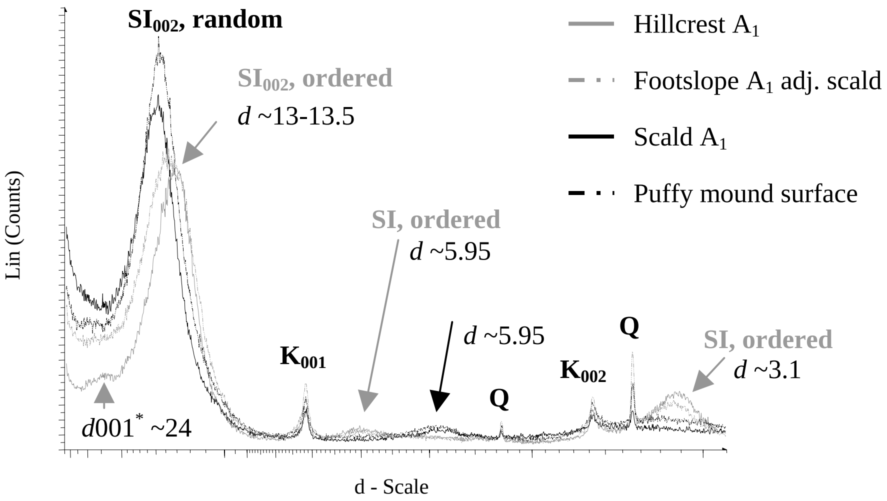

Figure 4: X-ray diffractogram of Mg-saturated clay-size fractions of saline and non-saline topsoils.

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