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CONTORTED STRATIFICATION WITH CLAY LOBES IN VOLCANIC ASH BEDS, RAGLAN - HAMILTON REGION, NEW ZEALAND

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Abstract

Contorted stratification in basal volcanic ash beds of the Pleistocene Hamilton Ash Formation incorporates halloysitic clay lobes which project upward into a bed of predominantly allophanic material. The forms produced are similar to convolute laminations described in other marine and non-marine sedimentary sequences.

The halloysitic clay lobes have been described previously as concretions and as the products of differential weathering processes.

A third hypothesis is proposed to explain the formation of the clay lobes and associated contorted stratification of these basal ash beds, namely, that the beds were deformed by plastic flowage of halloysitic clay into a sensitive allophanic bed. This deformation was possibly a result of water-saturated beds rapidly losing strength as a result of cyclic reversals of stress and strain produced by earthquake shock waves.

INTRODUCTION

Contorted stratification associated with nodular clay bodies of concretion-like form and structure occur in volcanic ash beds of the Raglan - Hamilton region some 70 to 80 miles south of Auckland (Fig. 1). The clay bodies have previously been described as "yellowish concretions" (Taylor, 1933) and as the products of differential weathering (Ward, 1967).

Fresh evidence on the nature of the contorted stratification and clay bodies was discovered during the course of soil surveys in the Raglan - Hamilton region. This region is mantled with thick deposits of volcanic ash in distinct ash beds of differing textures and clay composition. The clay bodies occur at the base of an allophanic ash bed of the ash sequence but are halloysitic in composition. Of special significance was the discovery that the clay bodies examined in detail were connected to an underlying halloysitic clay bed and could be regarded as clay lobes protruding from this bed rather than as discrete concretions. In the light of the new evidence, the origin of the contorted stratification and clay lobes is re-examined in this paper.

THE VOLCANIC ASH SEQUENCE

The volcanic ash beds which mantle the Raglan - Hamilton region are best preserved on the flat and rolling land and belong to three broad but distinct groups.

The basal group is Kauroa Ash Formation and the middle group is the Hamilton Ash Formation, both of which have been described by Ward (1967). The uppermost group is unnamed.

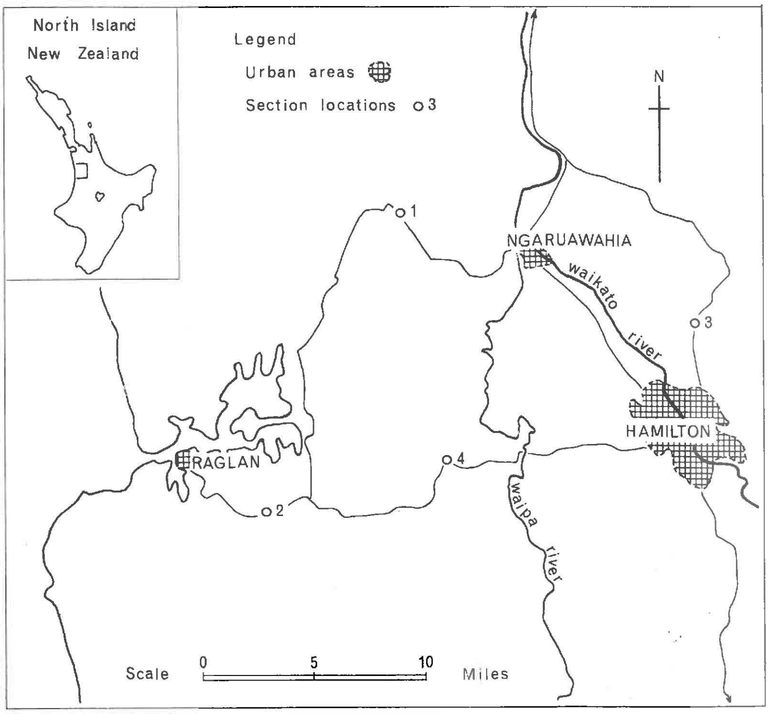


Figure 1. Raglan - Hamilton Region showing locations of sections investigated: 1. Te Akatea, N56(1965)/570461; 2. Te Uku, N64(1948)/464416; 3. Hamilton-Tauhei road, N56/796545; 4. N65(1965)/606448.

The Kauroa Ash Formation is separated from the overlying Hamilton Ash Formation by a very sharp boundary. Its uppermost bed, the Waiterimu Ash Member of Ward, consists of brown and olive grey, very firm, halloysitic material wth pronounced blocky and prismatic structure. This bed has the structure of a buried soil and is here interpreted as such and referred to as the "fossil soil" (Fig. 2).

The Hamilton Ash Formation consists, from the base, of (a) several beds of yellowish-brown friable or firm material, some of which are allophanic and of sandy loam or silt loam texture and others halloysitic and of clay texture, overlain by (b) three beds of strong brown to reddish-brown, firm, halloysitic material of clay loam or clay texture with pronouced blocky structure. Many of the beds are separated or terminated by beds or zones slightly darker than average (possibly fossil soils) or by thin beds of small, white nodules. The thickness of the formation varies from place to place with no obvious pattern; in some sections, beds appear to have been thinned or removed by erosion before they were covered by ash from subsequent eruptions, but the total thickness is in excess of 10 feet where most of the beds are represented.

The uppermost group of ash beds consists of several beds of brown, friable, allophanic ash of silt loam texture with fine crumb structure. It thickens from an average to 2 - 3 ft in the northern part of the region to over 5 ft in the southern part.

BASAL BEDS OF THE HAMILTON ASH FORMATION

The four beds at the base of the Hamilton Ash Formation (*i.e.* the lowest of the beds mentioned under (a) in the preceding section) are described in more detail here since they are associated with the contorted stratification and clay lobes under discussion. For convenience they are referred to (in order from the base) as the sandy bed, the clay bed, the allophanic bed, and the "overlying clay bed" (Fig. 2).

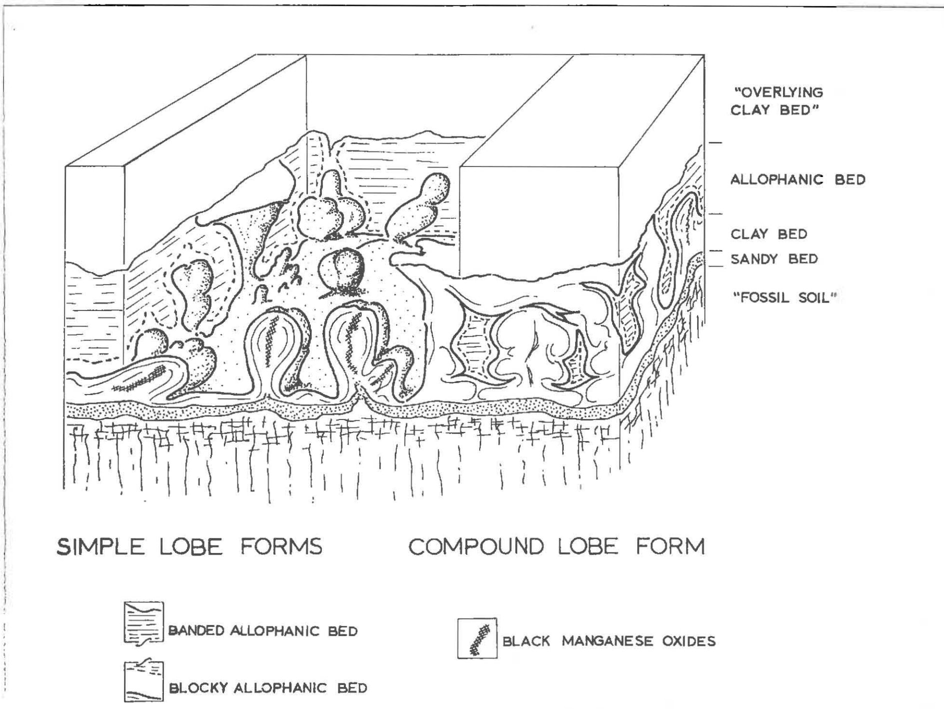


Figure 2. Diagrammatic sketch of the basal beds of the Hamilton Ash Formation illustrating the stratigraphic relationships of the beds, the contorted stratification, and the variation in shape and spatial arrangement of simple and compound lobe forms.

The Sandy Bed

The sandy bed at the base of the Hamilton Ash Formation (basal part of H1 bed of Ward, 1967) varies in consistence, texture, and colour, even within a single exposure. Its consistence and texture range from loose or weakly cemented medium sand to compact sandy loam, and its colour from grey to pale brown. It is commonly mottled with rusty, very dark brown, or black oxides of manganese and iron. Its bedding commonly follows the irregularities of the underlying "fossil soil", the surface of which is slightly irregular with many humps and hollows, giving a relief of several inches.

The Clay Bed

The clay bed overlies the sandy bed and contains greyish brown or white, firm, halloysitic material of clay texture (upper part of H1 bed of Ward) and varies from a few inches to 2 ft in thickness. Where it is only a few inches thick it is horizontally banded, porous, brittle, and white, and is commonly mottled with oxides of manganese and iron. Where it is thicker it generally has a different appearance, being greyish-brown, plastic when moist, and firm when dry. Where the overlying allophanic bed is absent, however, the clay bed is of relatively uniform thickness (Fig. 4d) and consists of two parts, an upper part resembling the thin beds and a lower part resembling the thicker beds.

The Allophanic Bed

The allophanic bed, above the clay bed, consists of yellowish-brown-friable, allophanic and gibbsitic material of clay texture (silt loam field texture) (H2 bed of Ward) and commonly varies from 1 - 2 ft in thickness. Its consistence and structure vary from section to section but it has two main forms. In one form it has an almost massive appearance on a freshly cut face, it is firm, looks waxy when scratched with the finger, shears easily between the fingers, and is non-plastic and non-sticky; on drying, it becomes hard with medium blocky structure, especially along the contact with the clay bed. This form is seen at Te Akatea (Section 1, Fig. 1). In the other form the bed has strongly developed crumb structure, is very friable, and again is non-plastic and non-sticky; throughout, it has thin, yellowish-brown, brittle, halloysitic clay rods which resemble rootlet pseudomorphs. This form is seen at Te Uku (Section 2, Fig. 1).

The "Overlying Clay Bed"

Overlying the allophanic bed is a bed of yellowish-grey, firm material of clay texture (H3 of Ward) and, in many places, with a blotchy appearance. For the purpose of this paper further description of this bed is unnecessary.

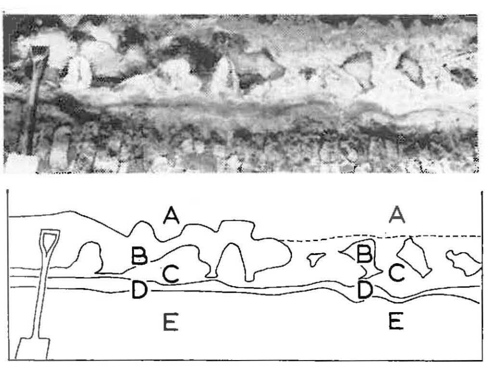
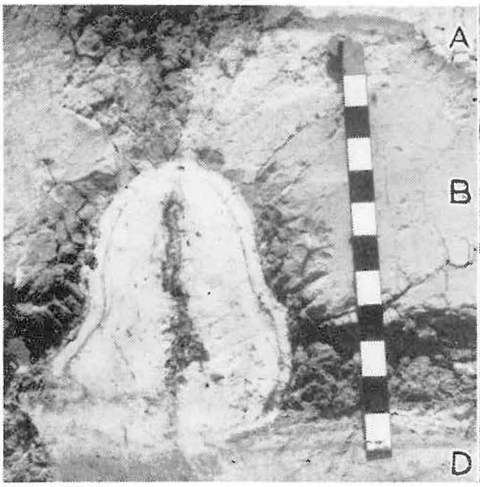


Figure 3a. Basal beds of the Hamilton Ash Formation at Te Akatea (Section 1, Fig. 1) showing simple lobe forms (left) and compound lobe forms with "eyes" of the allophanic bed (right). "Overlying clay bed" (*A*), allophanic bed (*B*), clay bed (*C*), sandy bed (*D*), and "fossil soil" (*E*).

DESCRIPTION OF CLAY LOBES

Form

Where the four basal beds of the Hamilton Ash Formation are well represented, lobes of material similar to that of the clay bed protrude upwards from the clay bed into the allophanic bed. These lobes vary in shape (Fig. 2, 3 a - c, and 4 a - d); some are almost spherical, others cylindrical with domed tops, and others oblate discs. The cylindrical forms are in places twelve or more inches in length, curved longitudinally, irregular in shape, or quite bulbous. In places some lobes appear to have merged together to produce a large compound form which in some exposures has apparently largely replaced the allophanic bed laterally for a distance of several feet but contains remnants, or "eyes" of the allophanic bed



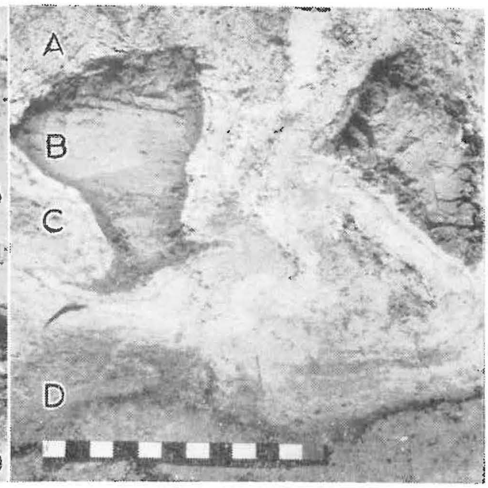
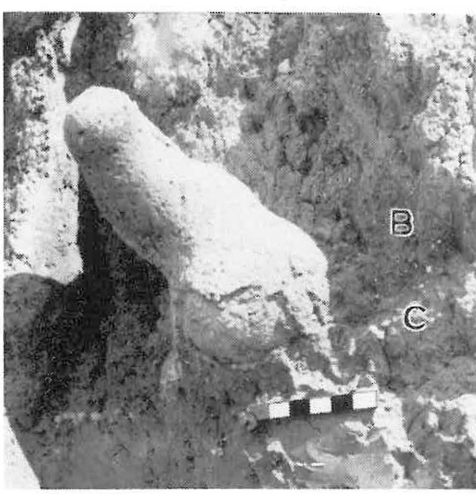


Figure 3b. Detail of simple lobe form on left of Figure 3a. Note: the outer layer of the lobe continues along the surface of the underlying sandy bed (*D*), oxides of manganese and iron located along a vertical crack through the lobe, and the blocky margin of the allophanic bed (*B*). Scale in inches.

Figure 3c. Detail of compound lobe form on right of Figure 3a, with "eyes" of the allophanic bed (*B*). Note the banding in the clay lobe (*C*). Scale in inches.



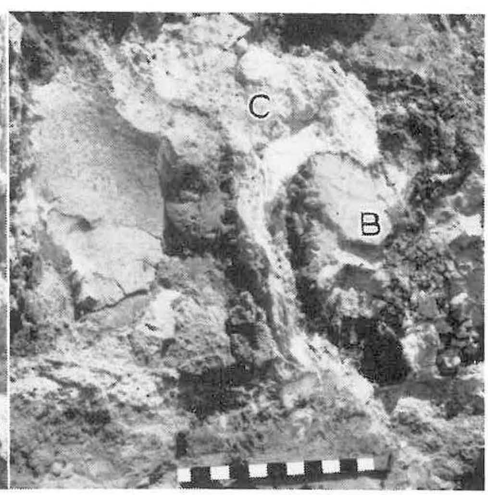
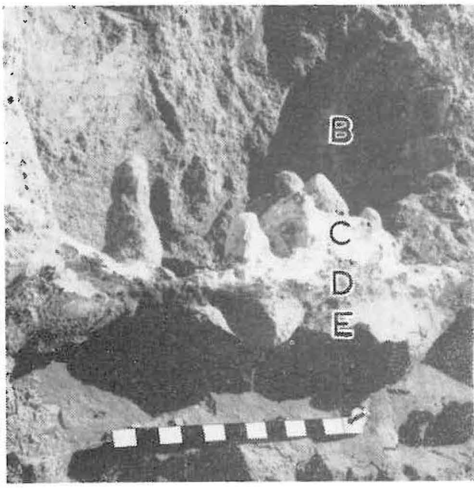


Figure 4a. Exposed simple lobe form showing the long cylindrical shape and domed top. The clay pedestal linking this lobe with the underlying clay bed is considered to have been broken into fragments, some of which lie along the contact between the allophanic bed (*B*) and clay bed (*C*). Hamilton - Raglan road (Section 4, Fig. 1). Scale in inches.

Figure 4b. Mushroom-shaped clay lobe (*C*) with a pedestal extending through the allophanic bed (*B*) to the clay and sandy beds beneath. The Akatea (Section 1, Fig. 1). Scale in inches.



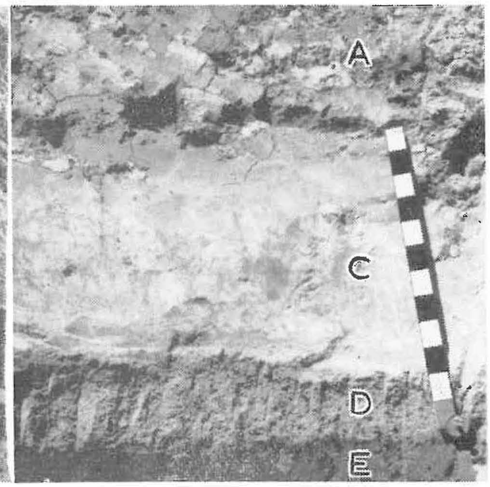


Figure 4c. Small cluster of finger-like lobe structures representing the clay bed at Te Uku (Section 2, Fig. 1). Allophanic bed (*B*), clay bed (*C*), sandy bed (*D*) and "fossil soil" (*E*). Scale in inches.

Figure 4d. "Overlying clay bed" (*A*), clay bed (*C*), sandy bed (*D*) and "fossil soil" (*E*), Hamilton - Tauhei road (Section 3, Fig. 1). In this section the allophanic bed is absent, and there are no clay lobes. Scale in inches.

(Fig. 2 and 3c). From casual inspection some of the clay lobes which appear to be merely lying on or above the surface of the underlying clay bed and thus appeared to be within the lower part of the allophanic bed, are found on excavation to be connected by a pedestal to the clay bed. Some "lobes", however, appear to lack a distinct pedestal (Fig. 4a).

Structure and Composition

Some clay lobes have a layered structure with several layers parallel with the surface of the lobe, but usually only the outer layer, which is commonly half an inch thick, is sufficiently well developed to enable it to be broken away from the others. In places the layering in the lobes continues through their pedestals into the underlying clay bed (Fig. 3b). The interior of many lobes appears to have been indurated and is stained very dark brown or black with oxides of manganese and iron (Fig. 3b).

The clay lobes are composed of white, hard, brittle material of clay texture. When broken into pieces the clayey material has an uneven surface, powders easily, and adheres to the tongue. It is plastic when moist and, after air drying, is difficult to moisten and has little of its original plasticity.

As shown in Table 1, the clay constituents of the clay lobes and clay bed, are dominantly hydrated halloysite with a little allophane. On heating to 110° C., the hydrated halloysite was irreversibly dehydrated to metahalloysite but metahalloysite was not identified in the indurated lobes. By contrast, as the table shows, the clay constituents of the allophanic bed are dominantly allophane and gibbsite.

Table 1. Clay mineralogical analyses and clay contents of clay lobes, allophanic bed, and clay bed (by R. J.. Furkert and J. S. Whitton).

* IR Infra-red absorption
XRD X-ray diffraction
DTA Differential thermal analysis

† Hydrated halloysite was the only mineral detected by XRD and DTA. Less than 1% gibbsite was found in samples Wn A76/2, /3, and /4 by all three methods of analysis.

Sample	Method of Analysis *	Allophanic Material	Hydrated Halloysite	Gibbsite	Micaceous Material	Quartz	Feldspar
Allophanic bed:	IR	50%		12%		2%	1%
Wn A76/1	XRD		——	12%	trace ?	4%	1%
	DTA	60%		13%			
Earthy clay lobe:	IR	5%	95%				
Wn A76/2	XRD		100%†	——	——	——	——
	DTA		100%†				
Clay bed:	IR	5%	95%				
Wn A76/3	XRD		90%†	——	——	——	——
	DTA		90%†				
Indurated clay lobe:	IR	5%	85%				
Wn A76/4	XRD		100%†	——	——	——	——
	DTA		100%†				

Relation to Ash Beds

Where the clay lobes are in large number, the clay bed is thin and almost discontinuous. Clay lobes are absent in sections where the allophanic bed is absent (for example, at Section 3, Fig. 1; Fig. 4d); in such sections the clay bed is of uniform thickness and its upper part is commonly faintly horizontally banded (not visible in figure) and consists of white clay material. In these respects it has some of the properties of the lobe material.

The allophanic bed in the Te Akatea section (Fig. 3a) has faint horizontal banding except in contact with the lobes where the bed has strongly developed blocky or prismatic structure (in places perpendicular to the surface of the lobe) and the banding has been destroyed (Fig. 3b). In this section the material of the larger compound forms is plastic and does not have the hard brittle consistence of the material forming the single clay lobe structures in the same section. Many of the "eyes" of allophanic bed enclosed by these compound forms exhibit the faint horizontal banding and have the blocky or prismatic marginal zone in contact with the enclosing clay material (Fig. 3c). Frequently these allophanic "eyes" have projections in one or more directions, and their irregular surfaces are parallel with the outer layer in the enclosing clay material. Some of the larger clay lobes appear to be associated with vertical cracks in the allophanic bed (Fig. 3b); these cracks frequently widen towards the top and are infilled with material from the overlying bed, but in a few rare cases the clay lobe structures protrude to the top of the allophanic bed where they appear to be mushroomed against the overlying clay (Fig. 4b).

Although many of the clay lobes are curved and irregular in shape, their curvature appears to have no preferred orientation. In a few places where the clay lobes appear to lack pedestals, the upper part of the clay bed beneath them was blocky in structure, and the lobes were resting directly on the lower part of the clay bed (Fig. 4a). In places, fragments of the upper part of the clay bed appear to have been incorporated into the underlying plastic clay by mixing.

DISCUSSION

From the evidence presented in this paper, it is clear that a satisfactory explanation of the simple and compound forms of clay lobes must explain the following features:

(a) The clay lobes are in many places directly connected to, and in cross-sectional view appear to protrude from, the clay bed.

(b) The material that forms the lobes is similar in composition to the material of the clay bed (Table 1).

(c) The layering within the lobes is parallel with their surface and is continuous with any layering that may be present in the clay bed.

(d) The allophanic bed in the vicinity of the clay lobes is apparently disrupted.

These features may be explained, at first sight, by three hypotheses:

(a) Formation by differential weathering processes within one original ash bed, aided by the movement of ground water carrying dissolved or colloidal components from the overlying ash beds.

(b) Formation by concretionary development of clay nodules by the movement of deflocculated clay from overlying beds or by chemical processes as in (a).

(c) Formation by deformation of an underlying halloysitic clay bed and its injection into an overlying allophanic bed.

Each of these hypotheses is discussed below.

(a) Differential Weathering

Ward (1967) considered the sandy bed plus the clay bed (which he named collectively Huntly Variant, H1) and the allophanic bed (which he named Te Uku Variant, H2) to be two weathering forms of the one volcanic ash bed, the Ohinewai Ash Member, produced by differential weathering; in this way he explained the complex nature of these beds. In the sections such as at Te Uku (Section 2, Fig. 1) he did not regard the thin layer of halloysitic clay material together with the numerous clay lobes (Fig. 4c), which lie between the sandy bed and the allophanic bed, as representing his Huntly Variant. In other sections such as at Te Akatea (Section 1, Fig. 1) he described the two variants occurring side by side at the same stratigraphic level (*i.e.* the allophanic bed and the compound lobe forms, Fig. 3a). Ward outlined his concept of differential weathering more fully in his development of a hypothesis to explain a similar apparent variation in the composition, consistence and regional distribution of the upper beds (Rotowaro and Dunmore Variants of Mairoa Ash Member) of the Hamilton Ash Formation. Using a weathering pathway discussed by Fieldes (1955), Ward suggested that the one parent ash weathered first to form an allophanic dominant form (Dunmore Variant) which under certain conditions persisted and under other conditions progressively weathered to form a halloysitic dominant form (Rotowaro Member). However this hypothesis as applied to these upper ash beds, is not supported by the more recent stratigraphic evidence of Pullar (1967) and Vucetich and Pullar (1969), who conclude that Ward's Rotowaro and Dunmore Variants are separate ash beds or groupings of thin marginal ash beds. The same conclusion was reached by McCraw and Tonkin (unpublished data) working in the Hamilton region.

Aomine and Wada (1962) have described two examples of differential weathering resulting in the formation of yellowish-white hydrated halloysite segregations in otherwise brownish or reddish, allophanic, volcanic ash and pumice layers respectively. From their rather brief description of the allophanic volcanic ash bed examined, it seems that the main similarity with the halloysite segregations, occurring in the ash beds of the Raglan - Hamilton region, was the development of thin vertical and horizontal veins of halloysite, similar to the halloysite clay rods occurring in some exposures of the allophanic bed. The halloysitic segregations in their pumice bed vary from "tiny granules to large blocks in size" but, from the illustration given, appear quite unlike the clay lobes described in this paper. These authors come to no definite conclusion regarding the cause of such differential weathering but suggest that local variations in both leaching and biotic factors may have an effect.

Differential weathering may have influenced the lower beds of the Hamilton Ash Formation; for example, the halloysitic clay rods that resemble rootlet pseudomorphs are possibly related to differential weathering processes conditioned by the movement of water down former root tunnels through the allophanic bed. However, it is difficult to envisage how this process alone, could produce the array of simple and compound halloysitic clay lobes that apparently originate from the base of the allophanic bed, or account for the apparent thinning or absence of the clay bed, which stratigraphically underlies the allophanic bed where clay lobe forms are developed.

(b) Concretionary Development

Taylor (1933) described as concretions the nodular clay bodies (the clay lobes of this paper) at the base of his Bed 5, in the Te Kuiti district, which is correlated with the lower beds of the Hamilton Ash Formation (Ward, 1967) in the Raglan - Hamilton region. Taylor based his concretionary hypothesis on the generally spherical external form and the internal concentric layering of the clay nodules he examined. As in the clay lobes at Te Akatea (Section 1, Fig. 1; Fig. 3a), Taylor's examples had manganese-stained interiors. He also noted that "in places the concretions are replaced by a hard whitish pan streaked with black". From re-examination of some of Taylor's sections it is concluded that this whitish pan is correlated with the clay bed and sandy bed of this paper.

The term concretion has been used widely to describe many possibly genetically distinct nodular features since Taylor's original descriptions. Pettijohn (1957) attempted to resolve some of the confusion surrounding the term and his more restricted definition was accepted and restated by Brewer (1964) as: "true concretions are concentrically laminated structures, normally subspherical, although commonly highly irregular". Brewer also accepted Pettijohn's hypothesis that most concretions are formed by accretion, but noted that a concentric fabric, of itself, provides no evidence of origin. Taylor and Pohlen (1962) in their discussion of concretions and other nodular bodies, stated that nodular concretions "commonly, though not always, have concentric bands due to non-uniform accretion".

If Brewer's definition is accepted as a basis for discussion it follows that the simple clay lobes described in this paper can be considered as concretions in both form and internal fabric, but some doubt arises as to the applicability of this definition if it is implicit that concretions are formed by an accretionary mechanism.

In most discussions on concretionary development, the cementing materials are considered to have been originally dispersed throughout the fabric of the original bed or strata, and to have been concentrated by some mechanism such as solution and subsequent redeposition about a nucleus. A feature of these concretions is that the cementing agents occupy the voids in the original fabric and so the original material is preserved within the concretionary feature. The most common concretionary cements are: carbonates, silica, and oxides of iron, manganese and aluminium. Crystalline clay cements such as halloysite are less common.

In considering the applicability of this concretionary hypothesis to the formation of both simple and compound clay lobes, the question arises as to the source of halloysitic clay in a bed where the clays are predominantly allophane and gibbsite (Table 1). Mr I. J. Pohlen (pers. comm.) has made the suggestion that these clay lobes may have formed by the accretion of halloysitic clay, derived from overlying clay beds, in drainage channels passing through the allophanic bed. This involves the colloidal suspension of halloysite and its reflocculation at the base of the allophanic bed. In some exposures, fractures which may have acted as drainage channels through the allophanic bed, often coincide with the upward projection of simple clay lobes, but this is not always the case. Where fractures do occur, they pass through both the allophanic bed and the clay lobe features as if they were secondary to the formation of the clay lobes themselves. Objections to this clay accretionary mechanism are (a) the apparent lack of residual allophanic bed fabric within the clay lobes, (b) the purity of the halloysite which forms the lobes and, (c) the large volume of halloysite that is required to be translocated from an original source. An alternative mechanism is that the halloysite was formed in place by the movement of silica solutions into a system containing an abundance of allophane and gibbsite. This mechanism could account for the purity of the halloysite forming the clay lobes (Table 1). However it is similar to the differential weathering hypothesis already discussed, and has the same limitations in explaining the form and association of the clay lobes with the underlying clay bed.

(c) Deformation

Structures with a marked resemblance to both the simple and compound forms of clay lobes have been described in unconsolidated non-marine sediments by Sharp (1942). He concluded that the structures, which he termed involutions, were the result of intense differential freezing and thawing during the development and melting of masses of ground ice in a periglacial environment. At present no comparable periglacial features that might support this hypothesis have been recognised in association with the lobe structures under discussion.

Intra-stratal sedimentary structures with many similarities to the clay lobes of this paper have been described in both marine and non-marine sequences (Kelling and Walton, 1957; Williams, 1960; Dott and Howard, 1960; and more recently Van der Lingen, 1969). Dott and Howard (1960) suggested the term "contorted stratification", used in the title of this paper, to describe all disturbed stratification regardless of the inducing agent or agents. Van der Lingen (1969) in a review on turbidites, illustrates numerous examples of sedimentary structures, termed convolute laminations, which have many similarities both in form and internal fabric to both the simple and compound clay lobes. Just as with the simple clay lobes, some of Van der Lingen's examples show no preferred orientations. He postulates that the principal mechanism involved in the formation of these structures was the liquefication of laminated fine sediments. Terzaghi and Peck (1967) describe the mechanism by which a saturated fine sediment under conditions of minimal drainage loses strength to the point where the material liquefies when subjected to cyclic reversals of stress and strain. The build-up of pore water pressures in the material to the point where shearing resistance becomes so low that the material liquefies, can be caused by such means as shock waves produced by earthquakes, differential load, or differences in ground water level (Graff-Peterson, 1967).

The hypothetical deformation of the clay and allophanic beds, involving the upwelling of plastic halloysitic clay into a fluid or sensitive, water-saturated allophanic material, is a possible explanation of:

(a) The morphological similarity of both simple and compound lobe forms to examples of deformation structures in sediments.

(b) The similarity in composition of the lobe forms and the clay bed.

(c) The continuity of layering from lobe forms into residuals of the underlying clay bed.

(d) The apparent disruption to the allophanic bed around the margins of the simple lobe forms.

(e) The occurrence of "eyes" of the allophanic bed within the compound lobe forms.

(f) The irregularities of the upper and lower boundaries of the allophanic bed as occurs in some sections (Fig. 3a).

CONCLUSION

From the foregoing discussion it is concluded that both the simple and compound lobe forms were developed as a result of the plastic deformation of the halloysitic clay bed upwelling into a sensitive allophanic bed. The loss of strength of these beds was probably triggered by earthquake shock waves since throughout the Quaternary there have been numerous catastrophic volcanic eruptions in the North Island (Healy, 1964; Vucetich and Pullar, 1964 and 1969), which presumably were accompanied by earthquakes of sufficient magnitude to produce the required surface vibrations.

Subsequent to their emplacement many of the smaller simple lobe forms became hard and brittle, wheras many of the larger compound lobes have retained some plasticity. Where fissures penetrated the clay lobes, their interiors became impregnated with black manganese oxides and to a lesser extent iron oxides (Fig. 3b).

If this interpretation of the origin of these clay lobes is correct, it follows that the allophanic bed (Te Uku Variant of Ward, 1967) and the clay bed (Huntly Variant of Ward) are not two weathering forms of one parent ash bed, but are two separate ash beds. The sandy bed (which Ward considered the basal sand of his parent ash bed) may also be a separate ash bed.

ACKNOWLEDGMENTS

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