

# The role of halloysite morphology on undrained shear strength and sensitivity of volcanic ashes in New Zealand

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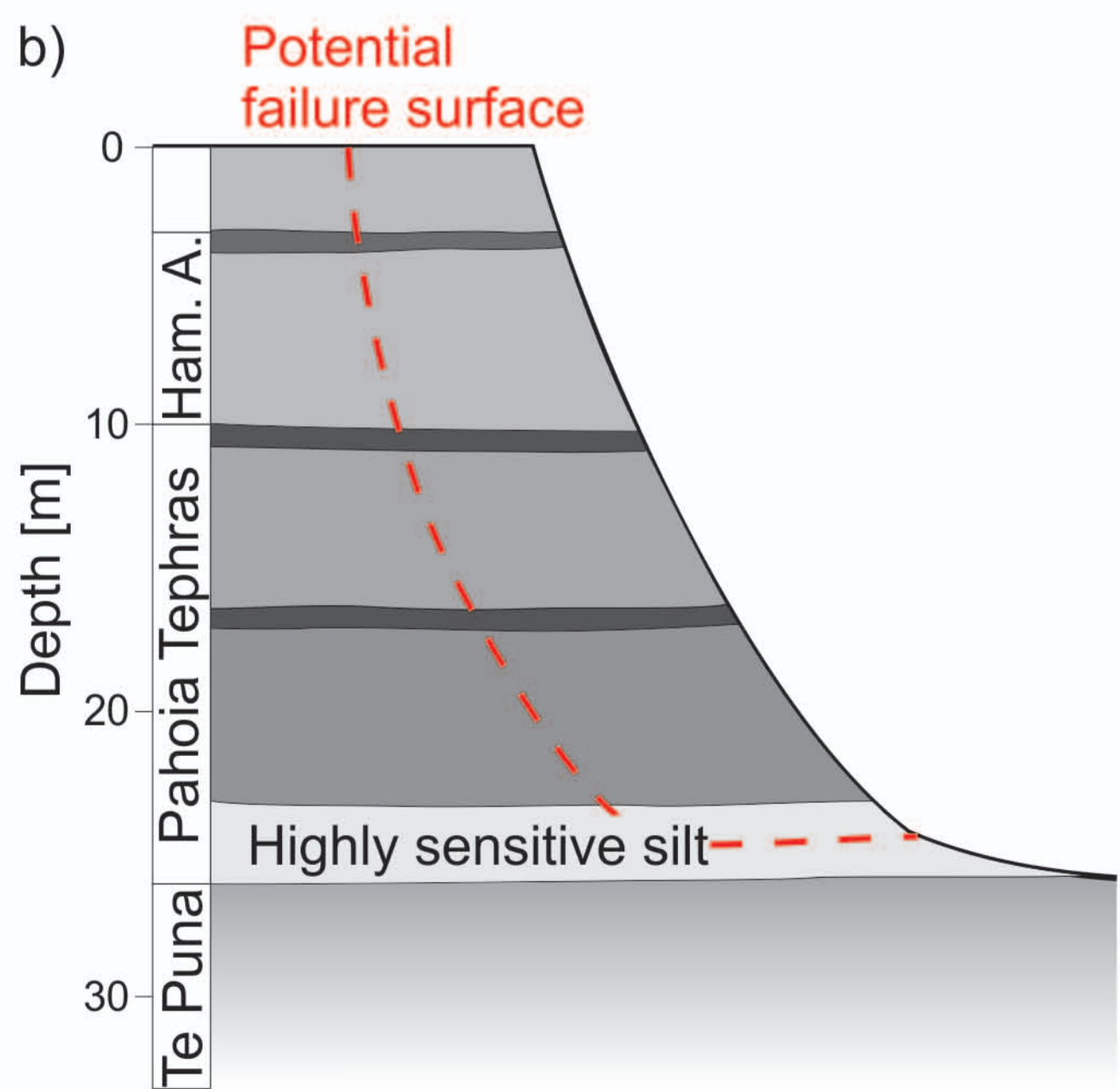
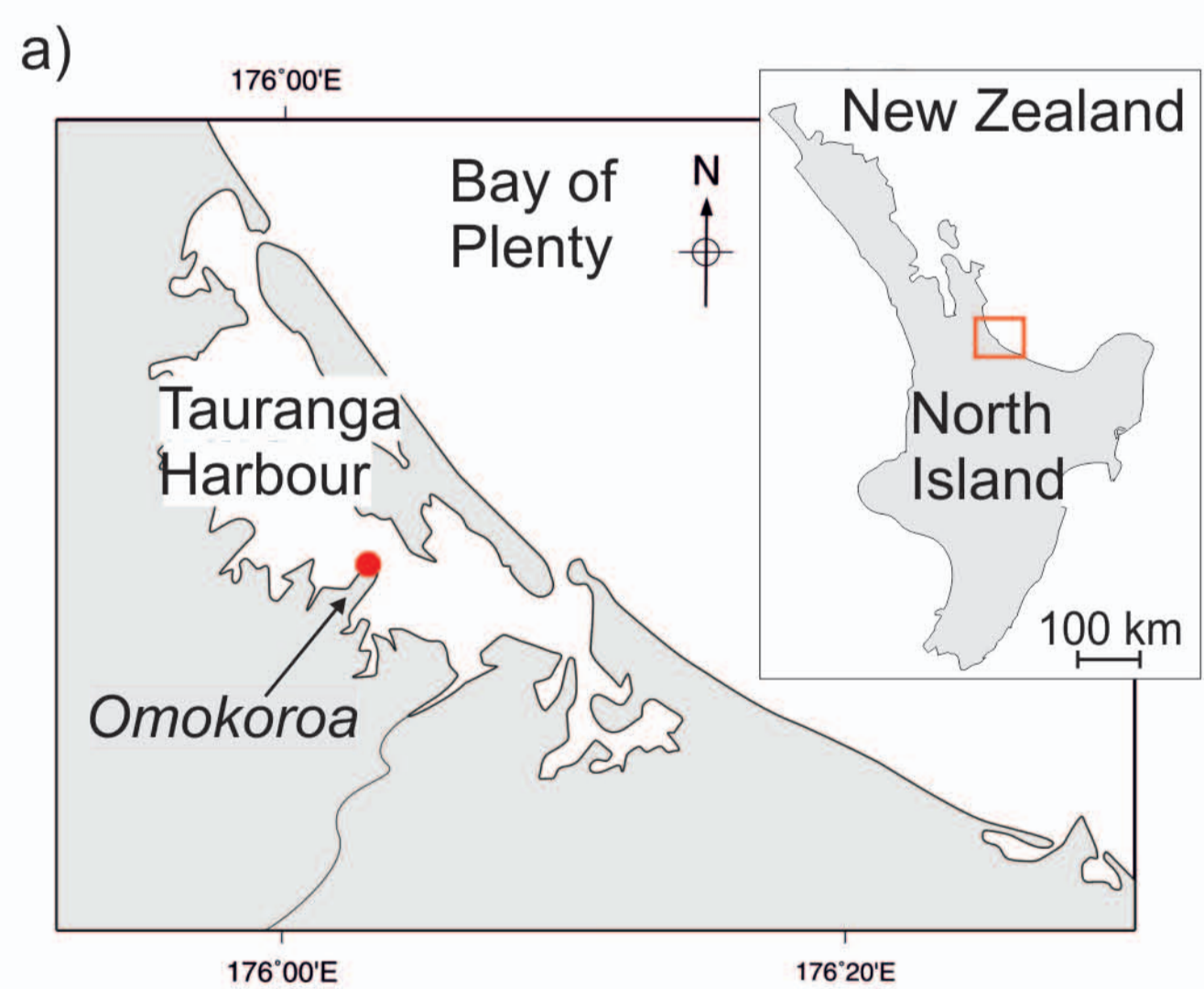
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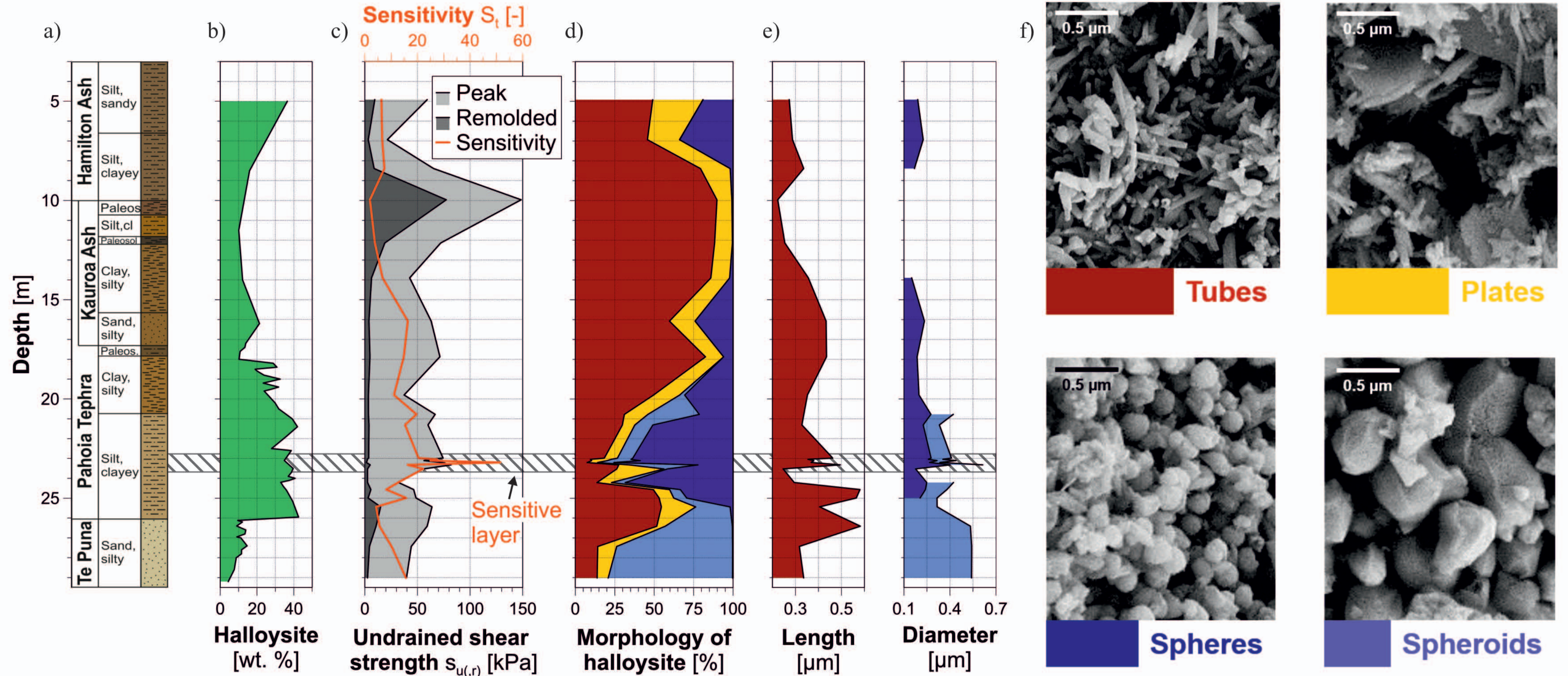
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## Introduction

Large areas of the North Island of New Zealand are covered by thick Pleistocene pyroclastic deposits that are often prone to coastal landslides. In the Tauranga region (Fig. 1a) some landslides are associated with the Pahoia Tephra, a sequence of highly weathered sensitive rhyolitic ashes containing high amounts of the clay mineral halloysite (Moon et al., 2013, 2015). Halloysite is a phyllosilicate that forms under Si-rich conditions and exhibits different morphologies, with tubes, plates, spheres and spheroids being the most prominent (Joussein et al., 2005). In 1979, a major landslide occurred at Bramley Drive, Omokoroa. It has since reactivated in 2011 and 2012 (Fig. 1b). The slide plane most likely involves a weathered highly sensitive silt layer at around 23 m depth with a high concentration of halloysite (Steinborn, 2015), that is composed almost entirely of spheres (Smalley et al., 1980). Previously, the effect of halloysite morphologies on sensitivity have only been studied on single outcrop samples (Jacquet, 1990, Cunningham, 2012). No systematic correlation of halloysite morphologies with soil sensitivity has yet been conducted along depth profiles. Therefore, in this study an entire sediment core from the Bramley Drive landslide is analyzed to quantify the effect of halloysite morphology and particle size on sensitivity, respectively.



**Fig. 1** a) Map of the study area showing the location of the Omokoroa peninsula. b) Potential failure surface of the landslide at Bramley Drive, Omokoroa.



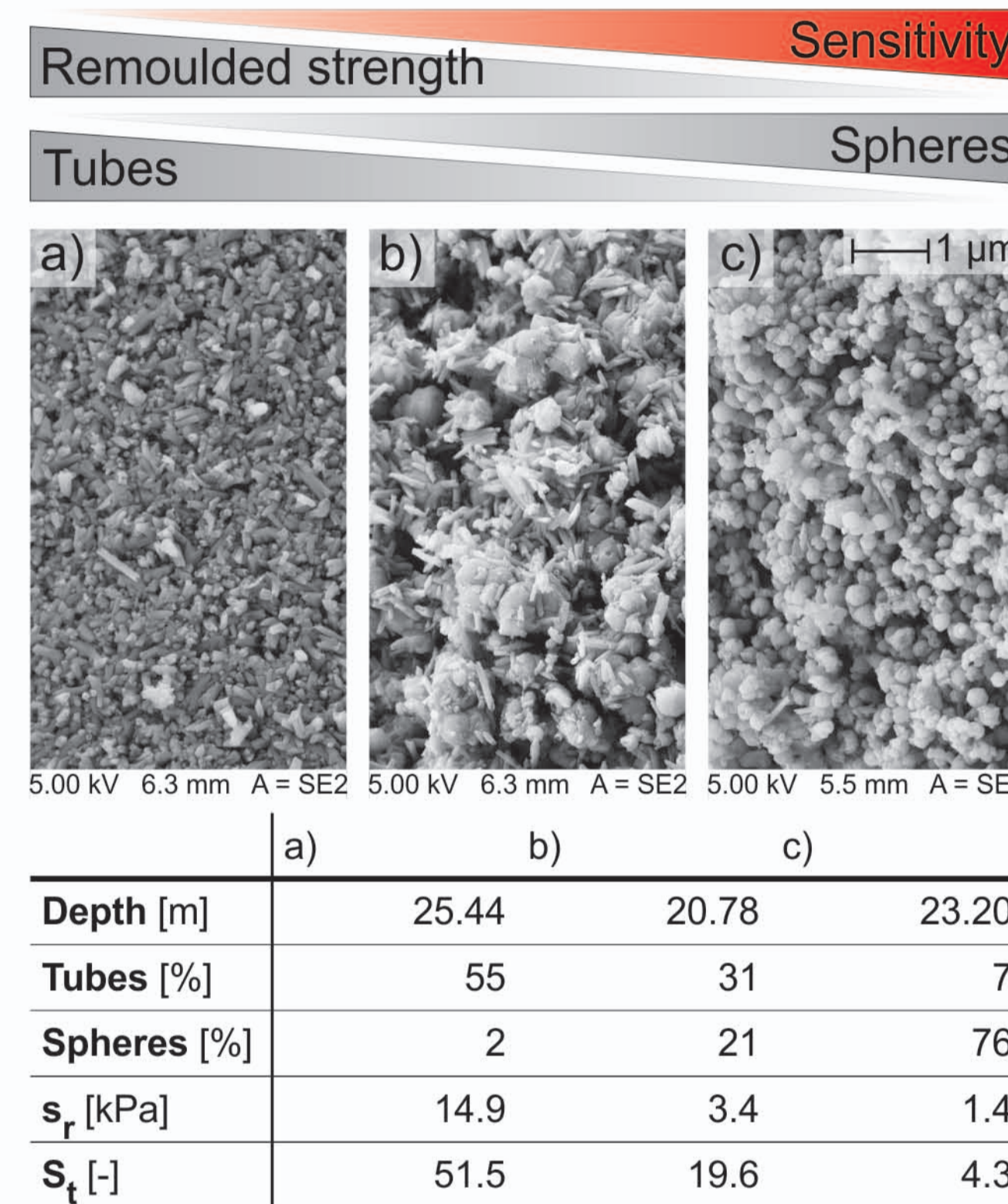
**Fig. 2** a) Stratigraphy and sediment description of core Omokoroa b) Halloysite concentration (Steinborn, 2015) c) Laboratory vane shear results d) Volume concentration of halloysite morphology e) Particle size of main halloysite morphology types f) Typical SEM-photographs of halloysite matrix. Shaded area marks highly sensitive silt.

## Methods

The sensitivity  $S_t = s_u/s_r$  was measured in 24 depths of core Omokoroa (Fig. 1a) by laboratory vane shear (Genske, 2006) in undisturbed ( $s_u$ ) and remolded ( $s_r$ ) material. Remolding was achieved by putting the sample in a plastic bag and shearing it for 10 minutes (Jacquet, 1990). From same depths samples were collected for X-ray diffraction (XRD) and Scanning Electron Microscopic (SEM) analyses. XRD tests were performed by Bastian Steinborn at Waikato University, New Zealand. XRD-quantifications were undertaken afterwards by Dr. Christoph Vogt at the University of Bremen, Germany, using QUAX (Vogt et al., 2002). SEM-samples were shock-frozen in liquid nitrogen and freeze-dried to preserve the nanostructure of halloysite matrix (Reed, 2005). From SEM-photographs the fraction of the different halloysite morphologies were quantified using point counting (Weibel, 1969).

## Results

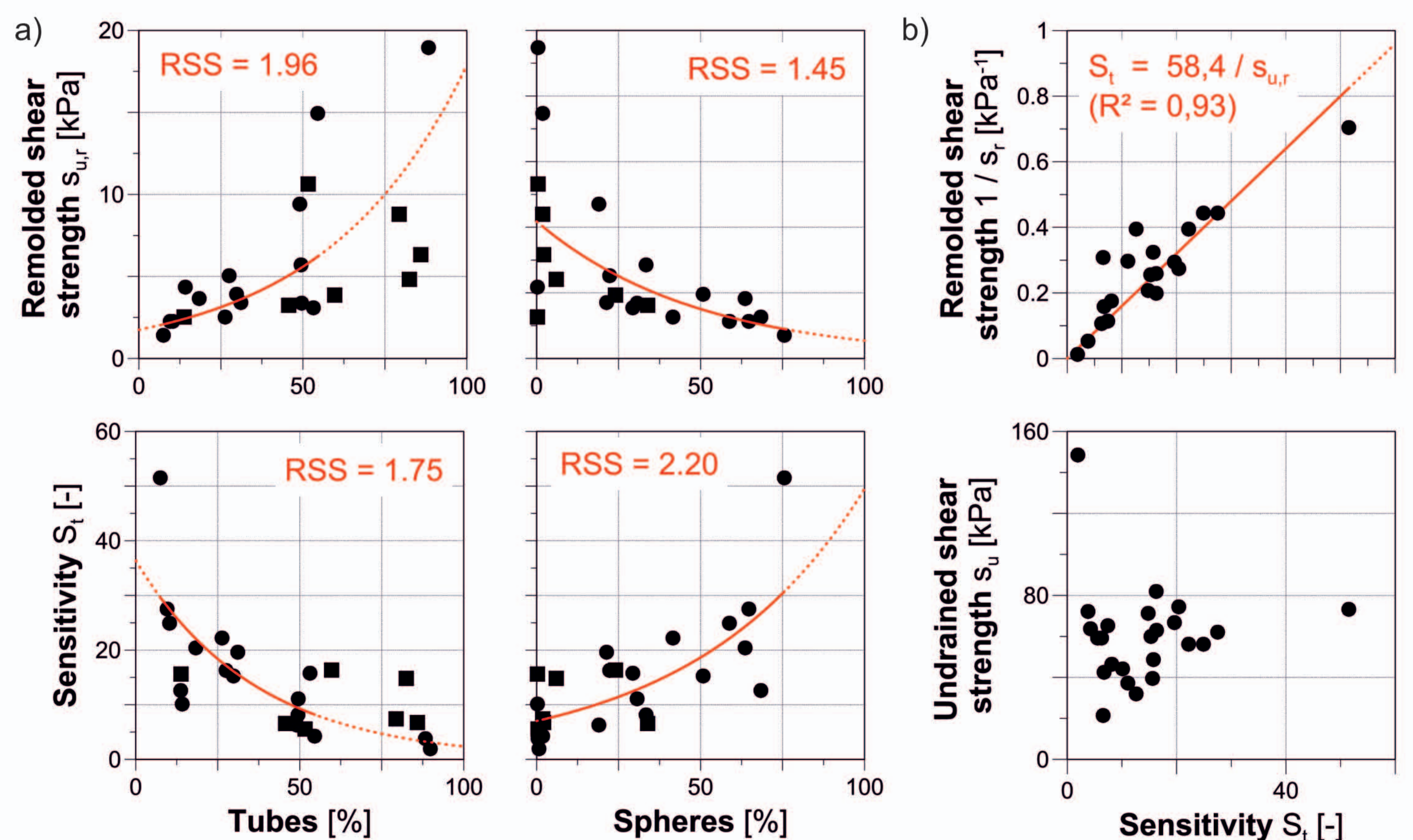
The Pahoia Tephra is characterized by high halloysite concentration of up to 40 wt.% (Fig. 2b). The relative amount of halloysite tubes decreases with depth, while halloysite spheres increase in abundance until a highly sensitive silt at 23 m where they predominate (Fig. 2c,d). In this interval the particle size of spheres reaches its maximum (Fig. 2e). Cross plots point out that sensitivity arises from low concentration of tubes and high amount of spheres, respectively (Fig. 4a). The sensitivity highly depends on the remolded shear strength whereas it shows no correlation with undisturbed shear strength (Fig. 4b).



**Fig. 3** Sensitivity model of the Bramley Drive landslide.

## Conclusion

- The Pahoia Tephra has a consistently high halloysite concentration.
- The morphological composition of halloysite has strong influence on soil sensitivity (Fig. 3).
- The high sensitivity correlates with a combination of low tube and high sphere concentration.
- The sensitivity arises from low remolded shear strength rather than high undisturbed strength.
- The diameter of halloysite spheres increases with sensitivity. An influence of tube length, however, was not observed.



**Fig. 4** Cross plots of a) Halloysite morphology concentrations with remolded shear strength and sensitivity. b) Sensitivity of undrained and remolded shear strength.