EPS 215 Independent Project Proposal

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Scientific Question

Can we use electromagnetic induction (EM) to provide reliable, spatially continuous estimates of colluvium depth in hillslope hollow, thus improving our ability to model slope stability and landslide risk?

Motivation

Landslide activity in hillslope environments is strongly influenced by both soil moisture conditions and the volume of colluvium stored in the landscape. Accurately characterizing this material is essential for evaluating landslide susceptibility and understanding sediment fluxes emerging from drainage basins (Syvitski & Milliman, 2007). In concave hollows, colluvium progressively accumulates as soils weather and creep downslope (Dietrich et al., 1982; Lehre, 1981). As soil thickness increases and rainfall events elevate pore-water pressures, these hollows may eventually destabilise and fail catastrophically as debris flows.

We know that soils are thinner on ridges, and that gradually steepening slopes enable thicker soils to accumulate in convergent areas (Dietrich et al., 1995; McKean et al., 1993). However, the actual thickness of the colluvium itself is difficult to measure. This presents a major limitation: without reliable estimates of subsurface soil depth, our ability to assess landslide hazards and anticipate slope failures remains constrained.

Literature Review

Within the context of geomorphology, hillslopes have been mapped using non-EM geophysical methods for various purposes, such as:

- Seismic refraction to quantify fill deposits in the Bavarian Alps (Schrott et al., 2003).
- Seismic refraction to identify the basal surface of a deep-seated landslide in the Austrian alps (Brückl et al., 2006).
- Electrical resistivity tomography to identify changes to near-surface hydrologic conditions at an active landslide in northeastern England (Boyd et al., 2021).

However, while methods like seismic refraction and Electrical Resistivity Tomography (ERT) offer good depth resolution, they are often labor-intensive and time-consuming to deploy. EM addresses these limitations. This geophysical technique is advantageous since it is non-invasive, rapidly deployable, and highly scalable over kilometres of terrain. EM has been used under the auspices of geomorphology to successfully detect hetereogeneities in soils. Examples in the literature demonstrate EM's application in measuring:

- Salt distribution across Western Australian basins (Salama et al., 1994).
- Clay extents overlain by Pleistocene loess and Holocene colluvial deposits in Bavaria, Germany (Weller et al., 2007).
- The pre-glacial landscape obscured by present day loess cover in Belgium (Saey et al., 2008).
- The detection and reconstruction of a palaeoriver by detecting palaeomire sediments overlain by Quaternary sands in Belgium (De Smedt et al., 2011), and to reconstruct a palaeochannel in New South Wales, Australia (Vervoort & Annen, 2006).
- The formation of barrier islands in response to sea-level rise and sediment transport (Weymer et al., 2015).

On one hand we have the scalable and efficient EM method, and on the other hand we have the the critical need to map colluvium and soil moisture in hillslopes for slope stability assessment. The intersection of the method and the geomorphic problem presents a gap in the literature for non-invasively and efficiently mapping colluvial deposits. Altdorff & Dietrich (2014) came closest to addressing this gap by measuring soil properties in the Austrian Alps over a nine-month period. They successfully identified distinct soil layers, which they then used to delineate landslide-susceptible hillslopes. However, their methodology was limited to using only apparent resistivity values. In other words, they used raw data to infer subsurface properties, and they missed the opportunity to create a continuous 3D model of the hillslope by performing a data inversion on the raw values.

Outcome

To address this gap, this study will employ EM induction coupled with a full data inversion scheme to produce continuous, three-dimensional models of subsurface resistivity, thereby enabling reliable, non-invasive estimates of colluvium depth in hillslope hollows.

Site

- The study area is a 180 m^2 hillslope hollow east of the UC Berkeley campus, located directly upslope of the Foothill Parking Lot and approximately 100 m downslope of the “Big C” (see Figure 1).
- The hollow is a distinct topographic feature and is easily accessible (Figure 2). Although trees appear in Figure 1, the trees along the spur ridges have since been cleared.
- The site presents several challenges: the ~48% slope complicates field surveys; the survey path is biased toward less difficult terrain; and the ground surface is littered with natural (logs, branches, boulders) and anthropogenic (beer cans, broken pipes) debris.

- The site lies on UC Berkeley property with public access, and no barriers or restrictions were identified that prohibit entry.

Figure 1: The location of the study site (highlighted in red) shown within the context of eastern UC Berkeley campus. Note the yellow “Big C” uphill of the site, adjacent to the Lawrence Berkeley National Lab structures.

Method

The EM survey was conducted using a “ski” system manufactured by Geophex Ltd. This mobile, non-invasive device functions by generating a primary magnetic field through an alternating current. When this primary field interacts with conductive materials in the subsurface (e.g., water-saturated colluvium), eddy currents are induced which in turn generate a secondary magnetic field that is measured by the receiver coils on the device. The depth of investigation is controlled by setting the frequency of the alternating current: higher frequencies correspond to shallower depths (due to smaller wavelengths), while lower frequencies penetrate to greater depths (Figure 3). The raw output from the instrument is an estimate of apparent electrical resistivity.

A key step in data processing involves converting this raw output into a more informative measure

Figure 2: The study area viewed from the bottom of the hollow looking uphill, taken November 23, 2025.

of subsurface variability. By applying inversion algorithms, the apparent resistivity is transformed into a continuous profile of either conductivity (measured in millisiemens per metre, mS/m), or its reciprocal, resistivity (measured in ohm-metres, $\Omega \cdot \mathrm{m}$). This conversion moves beyond simple point measurements to provide a continuous profile of subsurface variability with depth (see Figure 4 as an example). The major advantages of this EM method over other geophysical surveying techniques are its high efficiency and scalability, given that the EM system is highly mobile, rapidly deployable, non-invasive, and scalable for surveys ranging from a few meters up to kilometers of terrain.

The EM survey was designed to transect the hollow multiple times perpendicular to its long axis. The idea is to construct the colluvium volume by connecting these resistivity cross-sections using a spatial interpolation method such as kriging.

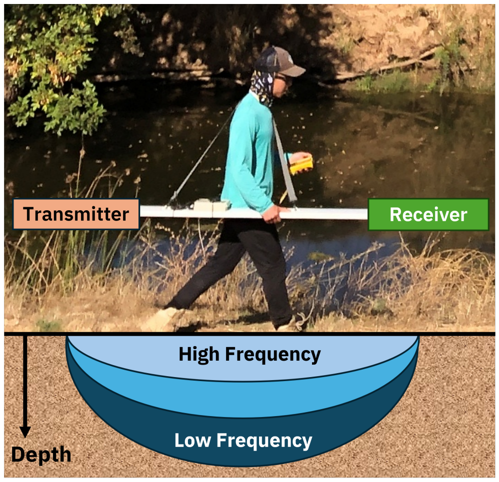

Figure 3: An example of a multi-frequency EM "ski" in operation, highlighting the positions of both the transmitter and receiver coils. Multiple frequencies can be set to model the conductivity of the subsurface, with higher frequencies corresponding to shallower depths of investigation, and vice versa.

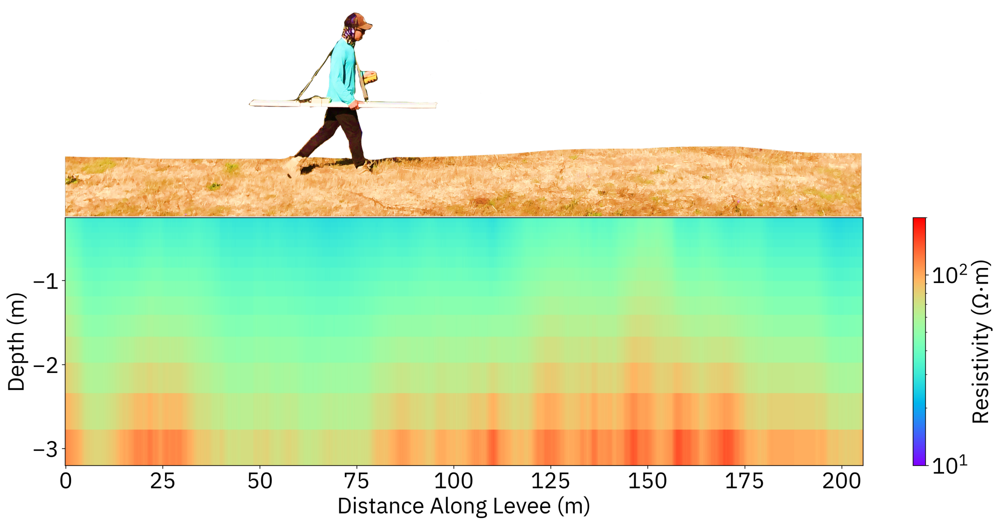

Figure 4: An example output from an EM inversion. The raw EM data in parts per million is inverted to generate a resistivity-depth profile of the subsurface. Note that the EM ski is fully decoupled from the ground.

Data

- EM data were collected in the field on November 23, 2025.
- Data collection followed recent rainfall events (Figure 5). The saturated soil was expected to enhance the EM response, since the instrument is more sensitive to conductive materials like wet colluvium (as opposed to drier soils with air-filled and more resistive pores).
- A 0.5 m resolution Digital Elevation Model (DEM) from the NSF-funded EarthScope Northern California LiDAR project (OpenTopography, 2008) was used to correct the EM data for topographic elevation.

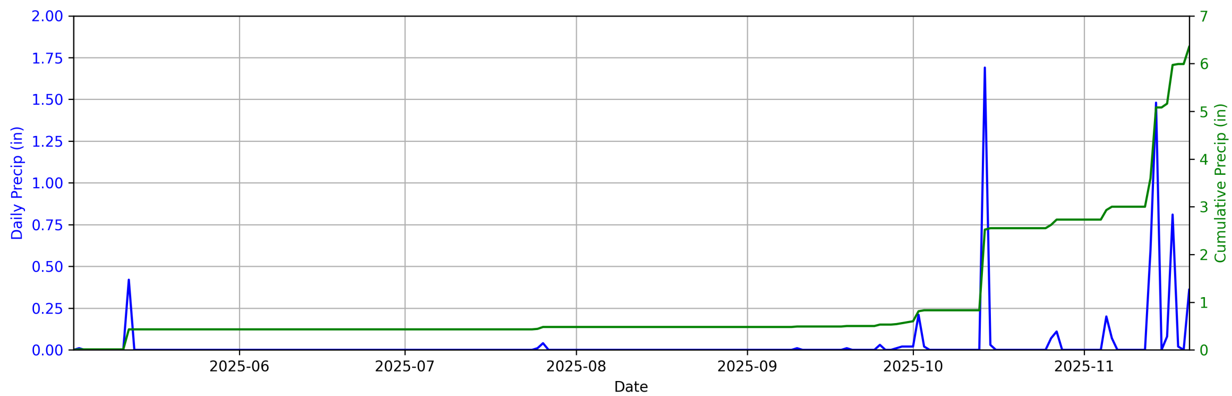

Figure 5: Daily and cumulative rainfall data in the 6 months preceding data collection (NOAA). The rainfall event in the week prior to data collection would raise soil moisture levels, which would theoretically produce a stronger EM signal-to-noise ratio. The weather station is approximately 2 km from the site.

References

Altdorff, D., & Dietrich, P. (2014). Delineation of areas with different temporal behavior of soil properties at a landslide affected Alpine hillside using time-lapse electromagnetic data. *Environmental Earth Sciences*, *72*(5), 1357–1366. https://doi.org/10.1007/s12665-014-3240-7

Boyd, J., Chambers, J., Wilkinson, P., Peppa, M., Watlet, A., Kirkham, M., Jones, L., Swift, R., Meldrum, P., Uhlemann, S., & Binley, A. (2021). A linked geomorphological and geophysical modelling methodology applied to an active landslide. *Landslides*, *18*(8), 2689–2704. https://doi.org/10.1007/s10346-021-01666-w

Brückl, E., Brunner, F. K., & Kraus, K. (2006). Kinematics of a deep-seated landslide derived from photogrammetric, GPS and geophysical data. *Engineering Geology*, *88*(3-4), 149–159. https://doi.org/10.1016/j.enggeo.2006.09.004

De Smedt, P., Van Meirvenne, M., Meerschman, E., Saey, T., Bats, M., Court-Picon, M., De Reu, J., Zwertvaegher, A., Antrop, M., Bourgeois, J., De Maeyer, P., Finke, P. A., Verniers, J., & Crombé, P. (2011). Reconstructing palaeochannel morphology with a mobile multicoil electromagnetic induction sensor. *Geomorphology*, *130*(3-4), 136–141. https://doi.org/10.1016/j.geomorph.2011.03.009

Dietrich, W. E., Dunne, T., Humphrey, N. G., & Reid, L. M. (1982). Construction of sediment budgets for drainage basins. In *Sediment Budgets and Routing in Forested Drainage Basins* (pp. 5–23).

Dietrich, W. E., Reiss, R., Hsu, M., & Montgomery, D. R. (1995). A process-based model for colluvial soil depth and shallow landsliding using digital elevation data. *Hydrological Processes*, *9*(3-4), 383–400. https://doi.org/10.1002/hyp.3360090311

Lehre, A. K. (1981). Sediment budget of a small California Coast Range drainage basin near San Francisco. *Erosion and Sediment Transport in Pacific Rim Steeplands*, *132*, 123–139. https://pascal-francis.inist.fr/vibad/index.php?action=getRecordDetail&idt=PASCALGEODEBRGM8320072557

McKean, J. A., Dietrich, W. E., Finkel, R. C., Southon, J. R., & Caffee, M. W. (1993). Quantification of soil production and downslope creep rates from cosmogenic 10Be accumulations on a hillslope profile. *Geology*, *21*(4), 343. https://doi.org/10.1130/0091-7613(1993)021%3C0343:QOSPAD%3E2.3.CO;2

OpenTopography. (2008). *EarthScope Northern California LiDAR Project*. National Center for Airborne Laser Mapping. https://doi.org/10.5069/G9057CV2

Saey, T., Simpson, D., Vitharana, U. W. A., Vermeersch, H., Vermang, J., & Van Meirvenne, M. (2008). Reconstructing the paleotopography beneath the loess cover with the aid of an electromagnetic induction sensor. *CATENA*, *74*(1), 58–64. https://doi.org/10.1016/j.catena.2008.03.007

Salama, R. B., Bartle, G., Farrington, P., & Wilson, V. (1994). Basin geomorphological controls on the mechanism of recharge and discharge and its effect on salt storage and mobilization — comparative study using geophysical surveys. *Journal of Hydrology*, *155*(1-2), 1–26. https://doi.org/10.1016/0022-1694(94)90155-4

Schrott, L., Hufschmidt, G., Hankammer, M., Hoffmann, T., & Dikau, R. (2003). Spatial distribution of sediment storage types and quantification of valley fill deposits in an alpine basin, Reintal, Bavarian Alps, Germany. *Geomorphology*, *55*(1-4), 45–63. https://doi.org/10.1016/S0169-555X(03)00131-4

Syvitski, J. P. M., & Milliman, J. D. (2007). Geology, Geography, and Humans Battle for Dominance over the Delivery of Fluvial Sediment to the Coastal Ocean. *The Journal of Geology*, *115*(1), 1–19. https://doi.org/10.1086/509246

Vervoort, R. W., & Annen, Y. L. (2006). Palæochannels in Northern New South Wales: Inversion of electromagnetic induction data to infer hydrologically relevant stratigraphy. *Soil Research*, *44*(1), 35–45. https://doi.org/10.1071/SR05037

Weller, U., Zipprich, M., Sommer, M., Castell, W. Z., & Wehrhan, M. (2007). Mapping clay content across boundaries at the landscape scale with electromagnetic induction. *Soil Science Society of America Journal*, *71*(6), 1740–1747. https://doi.org/10.2136/sssaj2006.0177

Weymer, B. A., Everett, M. E., De Smet, T. S., & Houser, C. (2015). Review of electromagnetic induction for mapping barrier island framework geology. *Sedimentary Geology*, *321*, 11–24. https://doi.org/10.1016/j.sedgeo.2015.03.005