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Geological Structural Controls of Slope Instability of the Freetown Layered Igneous Complex (FLIC), Western Sierra Leone

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Introduction

Slope instability in the FLIC remains a major geohazard in tropical West Africa (WA), and its structural controls are not yet fully understood. Although heavy rainfall, deforestation, slope cuts, and uncontrolled hillside urbanization primarily trigger failures, geological discontinuities exert critical control over failure location and mechanisms. This study integrates airborne magnetic lineament mapping, field discontinuity measurements, stereographic projection and kinematic analysis to characterise structural controls on selected landslide slopes

Objectives:

- Characterise the spatial distribution, orientation, mapped trace length, density, and depth variation of geological lineaments and field discontinuities across the FLIC.
- Evaluate structurally controlled slope failure mechanisms at representative landslide sites using stereographic projection and kinematic analysis.

Methodology

1. **Regional Structural Mapping and Lineament Analysis.**
   - Mapped major structural features from airborne magnetic data and DEMs.
   - Analysed lineament orientation, density, mapped trace length, and spatial distribution.
   - Estimated magnetic-source depths using standard Euler Deconvolution (SED).
2. **Field Structural Mapping**
   - Conducted structural mapping within approximately 100 km^2 of the FLIC.
   - Collected 58 discontinuity measurements from 25 structural stations to validate remotely mapped features and characterise joint geometry.
3. **Stereographic and Kinematic Analysis**
   - Analysed discontinuity orientation using stereographic projection.
   - Evaluated potential planar, wedge and toppling failure mechanisms on selected landslide slopes using kinematic analysis.

Results and discussion

- Mapped lineaments are predominantly ENE-WSW-oriented and display heterogeneous spatial distribution, and variable spacing (**Fig. 1**). This indicates a structurally complex rock mass that may be prone to instability.
- Their mapped trace lengths range from 0.08 km to 2.68 km with a mean of 0.46 ± 0.32 km.
- The SED-interpreted magnetic source depths range from ≈53 to 282 m, suggesting subsurface spatial variability.

Results and discussion cont.

- Stereographic analysis of 58 measurements identified five joint sets on the rocks of the FLIC (**Fig. 2** and **Table 1** for Fisher statistics).
- JS1 and JS2 are the dominant joint sets with attitudes 140º/66˚ SW and 312˚/66˚ NE, respectively.
- The joint apertures range (1- 95) mm, and are mostly infilled with iron-oxides and clay minerals (**Fig. 3**)
- The joint sets define pronounced rock-mass anisotropy and locally daylight towards selected slope faces

Results and discussion cont.

- Kinematic analysis indicates wedge-failure at the Regent upper scarp and Lion Mountain, and planar-failure at the Regent midslope, consistent with field observations.(**Fig. 4**).

Figure 3. Landslide scars with observable discontinuities and clay-filled joints

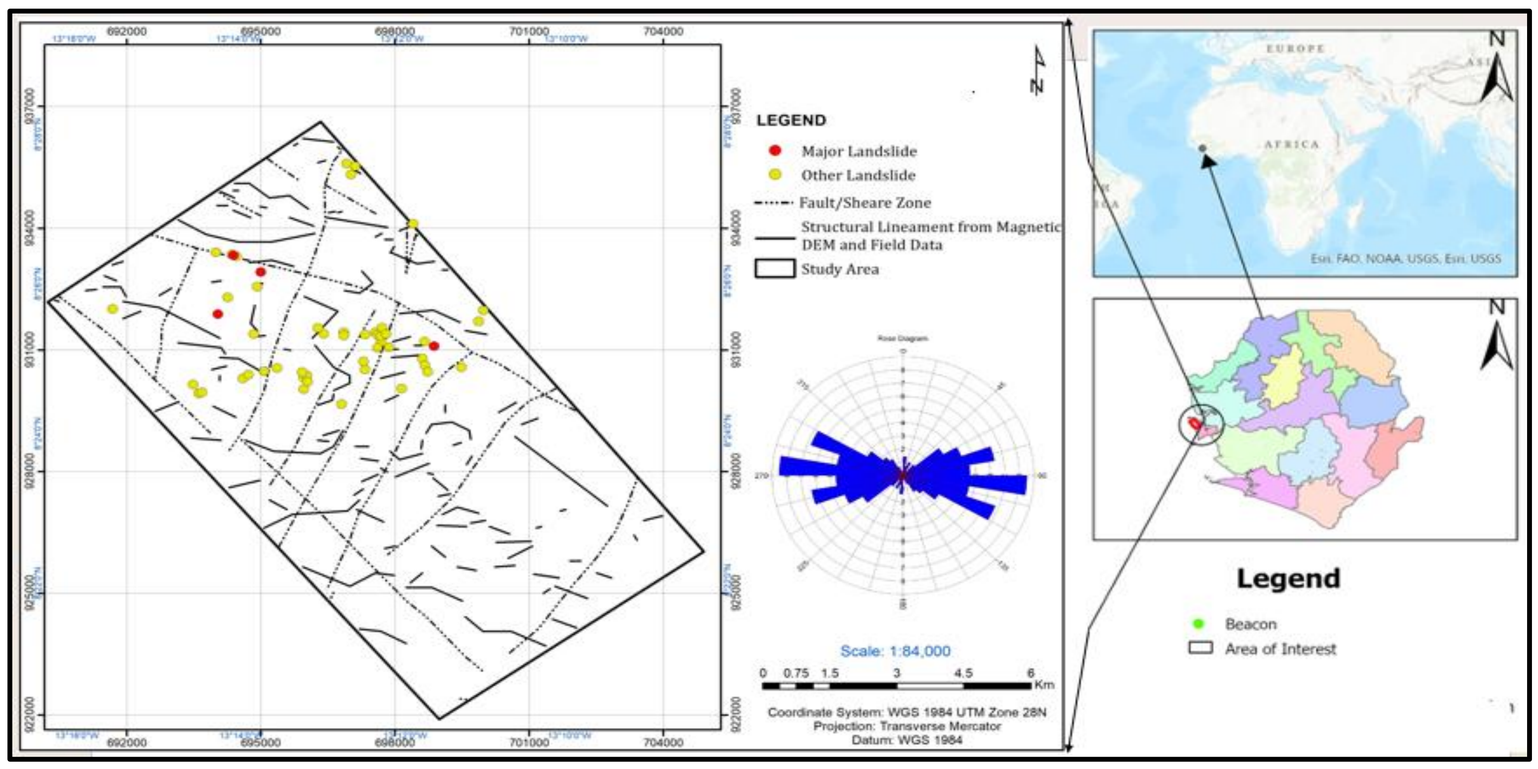

Figure 1. Spatial relationship between mapped Lineaments and Landslide Locations

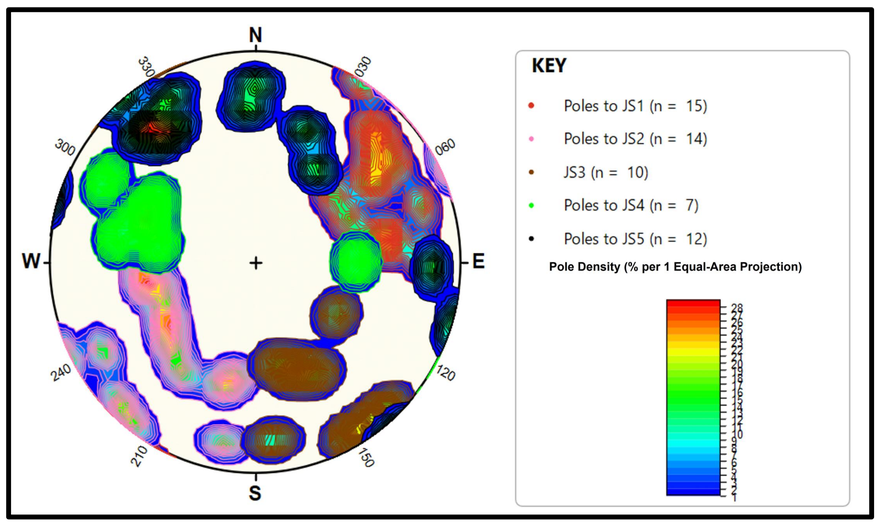

Figure 2. Pole-density Stereonet showing the five dominant joint sets.

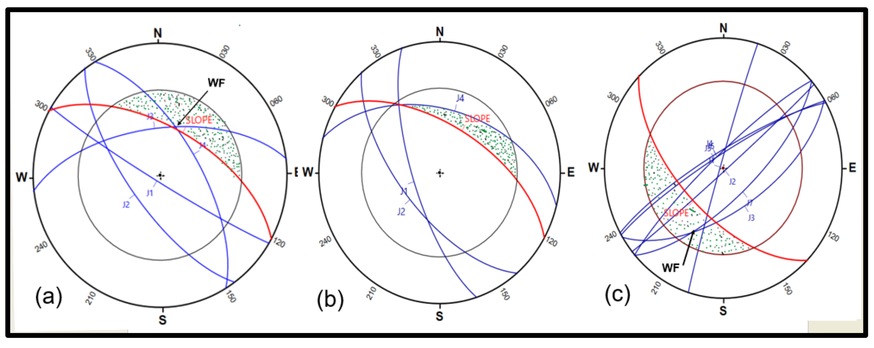

Figure 4. Kinematic Analysis of representative Landslide slopes: (a) Upper scarp Wedge failure at Regent landslide; (b) Mid-slope Planar failure at Regent Landslide ; (c) Wedge failure mode at Lion Mountain landslide.

Table 1. Summary of Orientation and Fisher Statistics for the identified joint sets (DD, D, and a95 are all in degrees)

Joint set	Mean DD	Mean D	Fisher K	a95	Mean vector length
JS1	230	66	15.2	10.1	0.9388
JS2	48	66	13.7	9.3	0.9007
JS3	330	61	14.1	12.7	0.9289
JS4	112	52	27	6	0.8561
JS5	180	67	29.1	3.2	0.713

Conclusions

- This study provides a preliminary structural analysis of the FLIC discontinuities. Slopes characterised by unfavourable joint conditions are susceptible to distinct structurally controlled failure modes.
- The results provide structural inputs for future landslide-susceptibility modelling and site-specific risk assessment.
- Findings may apply to analogous Layered Igneous terrains.

References

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2. Silwal, B. R., Gyawali, B. R., & Yoshida, K. (2024). Geochemical and mineralogical analysis of low-grade metamorphic rocks and their response to shallow landslide occurrence in Central Nepal. Geoenvironmental Disasters, 11(37).