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Geology of slopes in the Crocker Range, Sabah, Malaysia

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ABSTRACT

Slope failures are frequent occurrences along roads in Malaysia. Not until recently, geological inputs were rarely sought when designing and constructing roads on mountainous areas. This paper highlights the result of a geological study on selected slopes along a major road across Sabah's main mountain range, the Crocker Range, which is comprised mostly of folded Eocene sedimentary rocks. A total of 48 slopes facing potential failure problems were studied. The following four main potential sources of failures were recognised: 1) related to intensely sheared mudstones within a localised fault zone; 2) related to unfavourable orientation of discontinuity planes whereby bedding and joint planes of sandstone beds occur parallel or sub-parallel to the slope face; 3) related to the presence of intensely fractured and sheared sandstone and mudstone beds within a regional fold hinge; and 4) related to the presence of old landslide deposits. The recommendations to stabilise problematic slopes include covering the unstable slope face with concrete or vegetation and cutting back the slopes further.

INTRODUCTION

Slope failures associated with steep slopes and heavy rain are quite common along roads that cut through rugged mountainous areas in Malaysia. In the state of Sabah, located in the island of Borneo, several major roads pass through the Crocker Range, the most prominent mountain belt here. The Crocker Range, which is more than 40 km wide and has an average altitude of around 2000 m, stretches about 200 km along the west coast of Sabah (Fig. 1). Mt. Kinabalu (4100 m), the highest peak, rises from the Crocker Range. Not until recently, most of the roads passing through the Crocker Range were designed and constructed without taking into account the local geology of the area. It is therefore not surprising to see that some of these roads were built in geologically unstable areas, such as major fault zones and old landslide zones. As a consequence of this, the recurrence of slope failures at these unstable sites is quite frequent and costly to maintain.

In an attempt to understand better the causes of slope failures in the Crocker Range a geological study on slope failures along a major road linking the coastal town of Kimanis to the interior town of Keningau (Fig. 2) was carried out intermittently from July 2004 to September 2005. The road which stretched for about 40 km through the Crocker Range has undergone upgrading since early 2004, thus providing good rock exposures for geological observations. After carrying out a general geological study of the whole road section, a total of 48 problematic slopes were identified and mapped in detail at a scale of about 1:5,000. The field data gathered included rock types, structural features (stratification, faults, fractures, folds and foliation), surficial deposits and surface hydrological conditions. Based on the data gathered an assessment of existing geological conditions and processes in terms of stability of its geological units were carried out. In this paper, the sources of slope failures associated with the local geology are highlighted.

GEOLOGICAL SETTING

Sabah, situated in the northern part of Borneo, lies at the intersection of the Pacific, Philippines, Eurasian, and Indo-Australian plates, which move relative to one other (Fig. 3). The northern and western parts of Sabah, where the Crocker Range mountain belt occurs, lie adjacent to the rifted continental margin of China, presently occupied by the Reed and Dangerous Grounds carbonate platforms (Hinz et al. 1989), while the northeastern part of Sabah forms the continuation of the Sulu sea basin which is presently subducted to the southeast along the Sulu trench (Rangin 1989). The southeastern part of Sabah lies adjacent to the Celebes sea basin and forms the southwestern continuation of the Sulu volcanic arc. Further southeast the Celebes sea basin is being subducted under the North arm of Sulawesi.

Southeastwards subduction of a Mesozoic oceanic crust in front of a rifted continental margin of China under northwest Borneo which probably started during the late Eocene resulted in the accretion of Palaeogene marine sediments together with the Mesozoic oceanic crust. As the subduction progressed, more rock units were stacked on top of each other causing them to rise above the sea. The

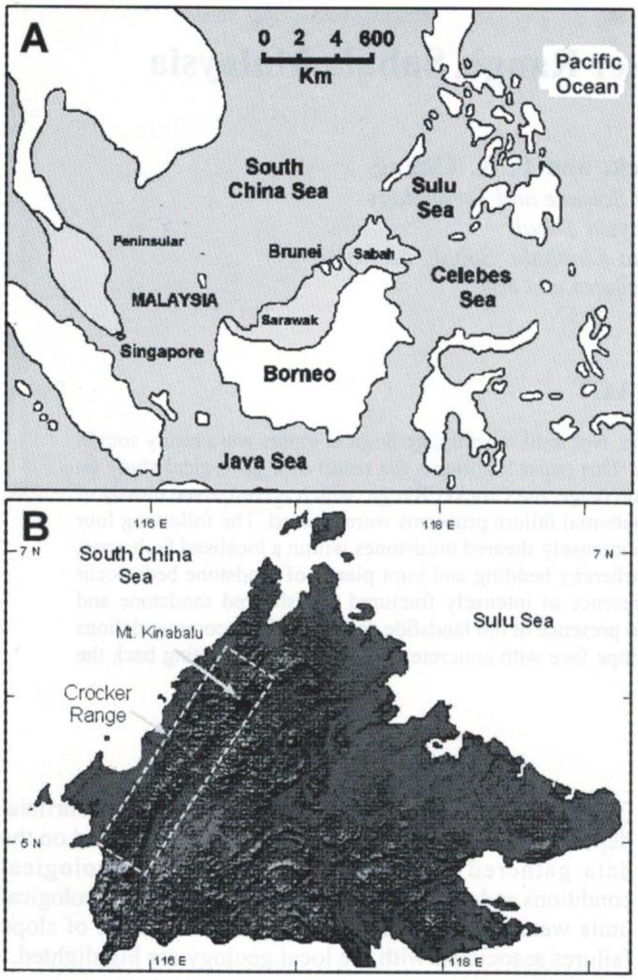

Fig. 1: A. Geographical location of Sabah and B. Satellite image draped on digital elevation model showing the Crocker Range in west Sabah

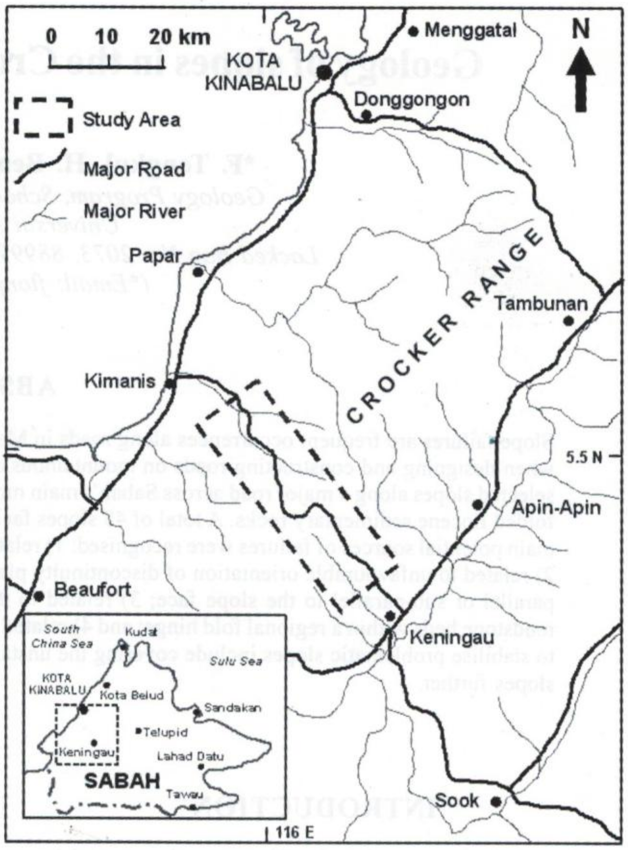

Fig. 2: Location of Keningau–Kimanis Road across the Crocker Range

arrival of the more buoyant rifted continental margin (Dangerous Grounds) under the accreted rock units caused further uplift of the accreted rock units through isostatic rebound (Hutchison et al. 2000), to form what could be an ancient form of the Crocker Range mountain belt. The uplifted rock units were subsequently eroded and became an important source of sediments for the younger Neogene basins offshore. Tremendous heat generated during the subduction process melted rocks, which turned into magma. Weak zones created by major fractures within the accreted rock units became sites for the intrusion of magmas, which later cooled and solidified before reaching to the surface. The cooling of the magma may have occurred 4–9 million years ago. Over the years, stream erosion of the sedimentary cover exposed some of the solidified magmas, such as Mt. Kinabalu batholith and sculptured the sedimentary landscape to form the Crocker range mountain belt as we see today.

GEOLOGY OF THE CROCKER RANGE

The Crocker Range comprises mostly sedimentary rocks with minor occurrences of igneous and metamorphic rocks (Collenette 1958). The oldest rock unit, representing an ancient Mesozoic oceanic crust, occurs around the Ranau area (Fig. 4). This rock unit is made up of serpentinite, basalt, and chert. The Palaeogene sedimentary rocks representing deep marine sediments lie on top of the ancient oceanic crust. The sedimentary rocks constitute the Crocker and Trusmadi Formations. The Crocker Formation, which consists of folded and faulted layers of sandstone and mudstone, occupies most of western Sabah. The Trusmadi Formation, consisting of intensely sheared and deformed metasandstones, slates, and phyllites, is located near the Ranau area. The folding and faulting of rocks has resulted in the stacking and duplication of sedimentary layers (Tongkul 1990), giving a false impression of a great thickness of the sedimentary formations.

The oceanic crust and sedimentary units are intruded by the igneous rocks of Late Miocene age. They are made up mostly of granitic rocks (granodiorite and syenite) and form most of Mt. Kinabalu. The intrusions are thought to have occurred 9–14 million years ago (Jacobson 1970 and Rangin et al. 1990).

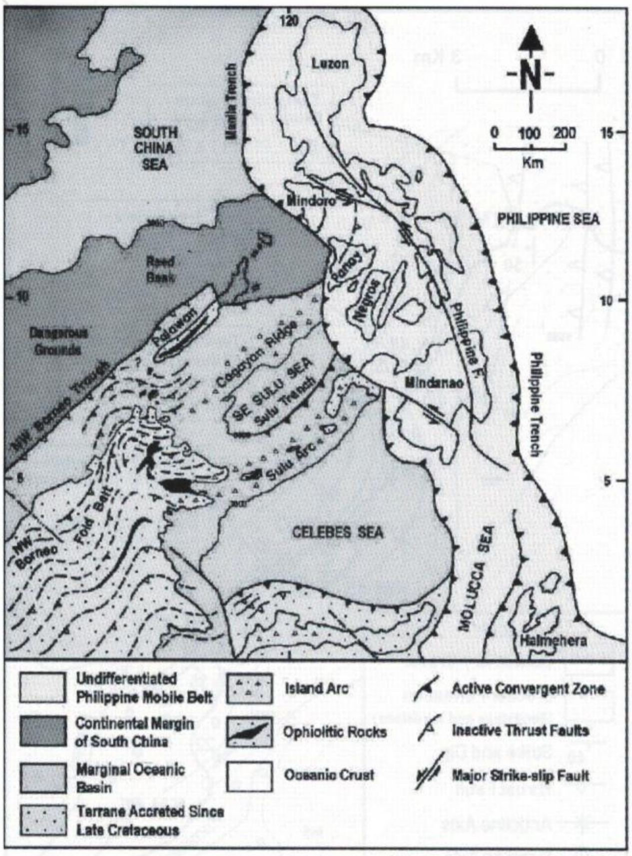

Fig. 3: Tectonic setting of Sabah showing the NW Borneo fold-thrust belt

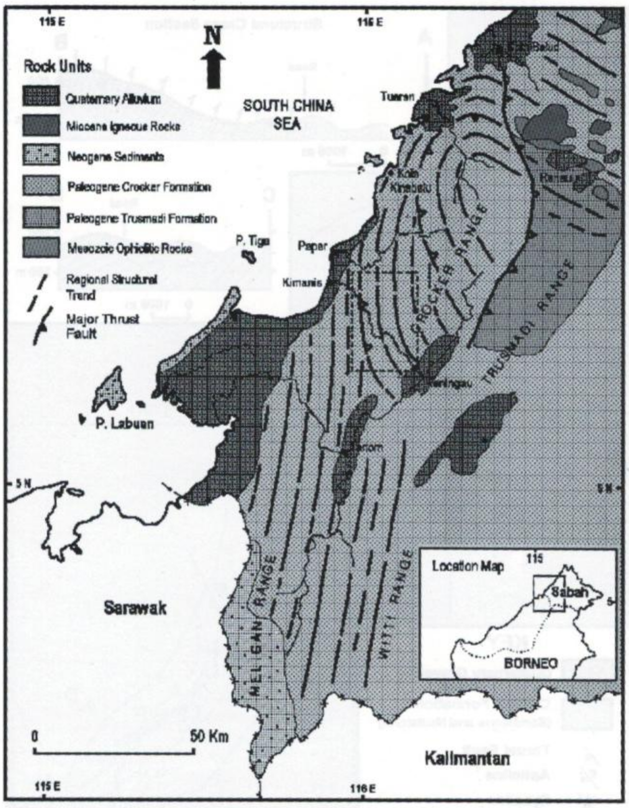

Fig. 4: Geological map of West Sabah showing the Crocker Range fold-thrust belt

Quaternary fluvial and coastal sediments fill river valleys and coastal plains. Quaternary glacial deposits, known as the Pinousuk Gravel (Koopmans and Stauffer 1967; Jacobson 1970) occur at the foot of Mt. Kinabalu and lie on top of the older rock units here. Recent alluvium fills river valleys.

GEOLOGY AND SLOPE FAILURES ALONG KIMANIS-KENINGAU ROAD

The Kimanis–Keningau road is primarily built on top of the sedimentary rocks of the Crocker Formation. A small part of the road is built on the Quaternary and Recent alluvial deposits (Fig. 5). The Crocker Formation is comprised of grey sandstones interbedded with grey and red mudstones of various thicknesses. The sandstones consist mostly of quartz grains cemented by clay minerals. The sandstones are quite hard in the fresh state but turn quite soft after weathering. Most of the exposed slopes that have been studied consist of both fresh and weathered sandstones and mudstones.

The sandstone and mudstone beds of the Crocker Formation are generally oriented between N33°E and N05°E, and show steep (45–85 degrees) dips eastwards. Large-scale folds (100–300 m wavelength) and inactive thrust faults (several metres wide) are common within the Crocker Formation (Fig. 5). Joints, showing at least four orientations, are also common in sandstone beds.

Based on the geological study, the slopes examined are found to be unstable due to two main reasons, firstly related to the weak nature of the rocks itself and secondly due to the unfavourable orientations of discontinuities and slope face cuttings. The following four main potential sources of failure were recognised: 1) related to the presence of intensely sheared mudstones within a localised fault zone; 2) related to the presence of sandstone beds with their joint planes and bedding parallel or sub-parallel to the slope face; 3) related to the presence of intensely fractured and sheared sandstone and mudstone beds within a regional fold zone; and 4) related to the presence of old landslide deposits. Examples of each source of failure are described below.

Source of slope failure Type I: related to localised fault zones

This is the most common source of failure. The fault zones ranges in width from a few metres to tens of metres. A good example of this type of failure can be seen on the slope at Km 35 (Fig. 6).

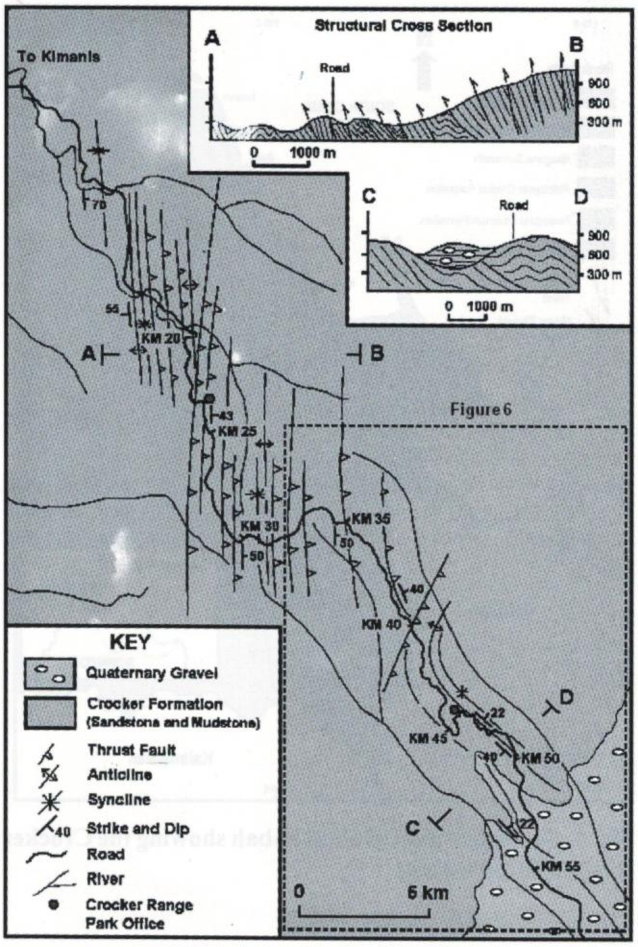

Fig. 5: Geological map along Kimanis–Keningau Road showing highly faulted Crocker Formation

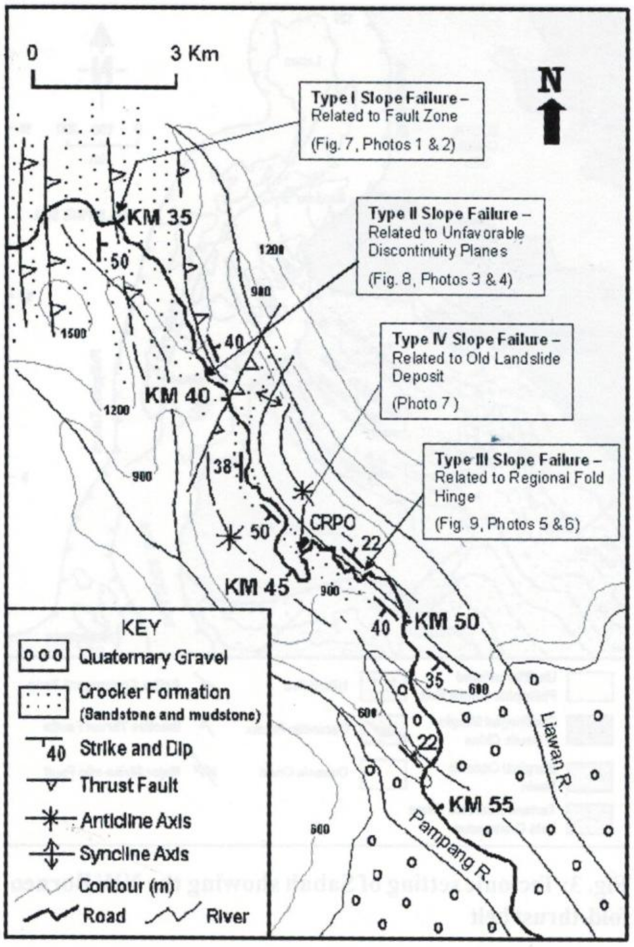

Fig. 6: Location of selected slope failures controlled by lithology

The slope is comprised of interbedded sandstones and grey mudstones. The sandstone beds range in thickness from 5 to 200 cm; they are medium- to fine-grained and highly weathered. The mudstones range in thickness from 1 to 100 cm.

The sandstone and mudstone beds are oriented between N35°E and N20°E with dips from 55 to 65 degrees to the east. The beds are quite dismembered due to the presence of a major fault zone. The fault zone is characterised by the presence of broken sandstone beds and intensely sheared mudstones (Figs. 7 and 8). The sandstone beds are also heavily jointed showing at least four sets (Fig. 9).

Source of slope failure Type II: related to unfavourable orientation of discontinuity planes

This source of failure is also quite common. The unfavourable orientation of discontinuity planes may stretch from a few metres in length to tens of metres. A good example of this type of failure can be seen on the slope at Km 38 (Fig. 6). The slope is comprised of interbedded grey sandstones and mudstones. The sandstone beds range in thickness from 5 to 100 cm. The sandstones are medium- to fine-grained and moderately to highly weathered. The mudstones range in thickness from 1 to 10 cm.

The sandstone and mudstone beds are oriented N34°E with dip angles between 30 and 40 degrees eastwards. The beds are quite persistence throughout the length of the slope. The orientation of bedding is nearly parallel to the slope face and the bedding dips out of the slope face (Figs. 10 and 11). Jointing in the sandstone beds is quite common with its spacing from 5 to 30 cm. At least three sets of joints occur, causing toppling failures (Fig. 12).

Source of slope failure Type III: related to regional fold hinge

This source of failure is restricted to the eastern side of the road towards the Keningau Town. A good example of this type of failure can be seen on the slope at Km 49 (Fig. 6). The slope contains grey and red mudstones with some thin

Fig. 7: Intensely sheared mudstone and deformed sandstone beds in a local fault zone at Km 35

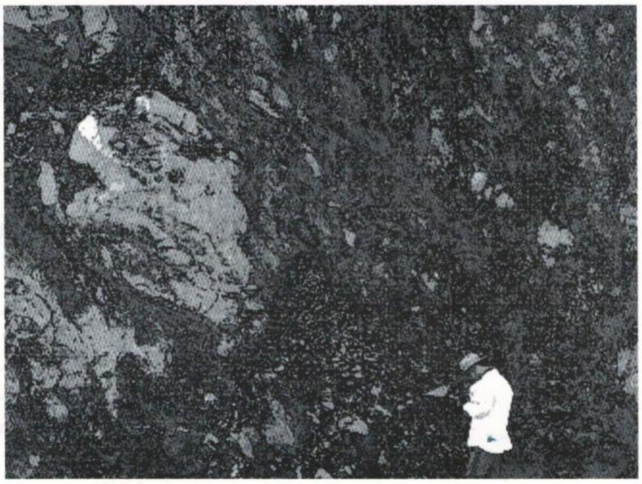

Fig. 8: Close-up view of sheared grey mudstone and highly deformed sandstone beds at Km 35

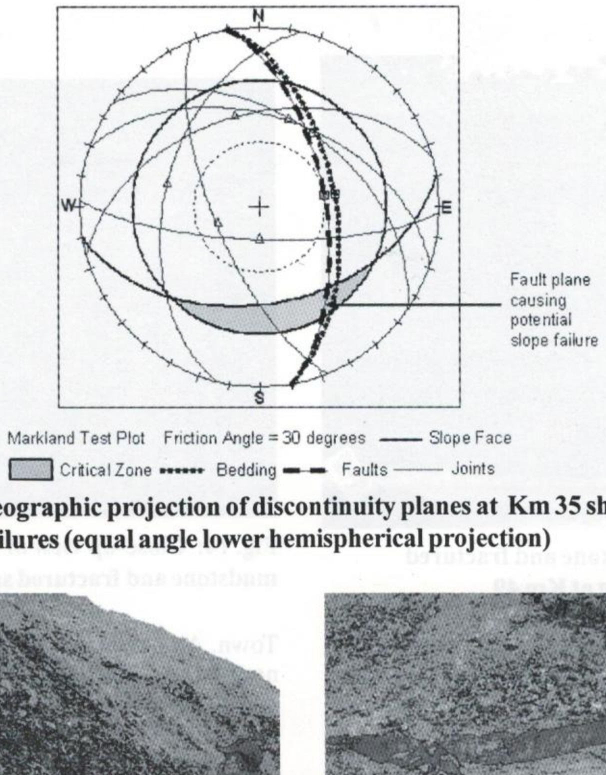

Fig. 9: Stereographic projection of discontinuity planes at Km 35 showing potential failures (equal angle lower hemispherical projection)

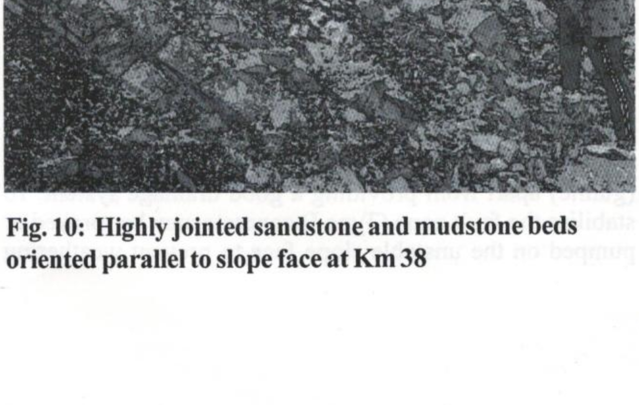

Fig. 10: Highly jointed sandstone and mudstone beds oriented parallel to slope face at Km 38

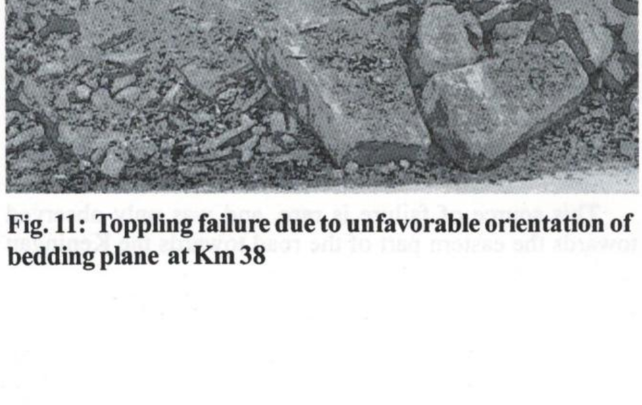

Fig. 11: Toppling failure due to unfavorable orientation of bedding plane at Km 38

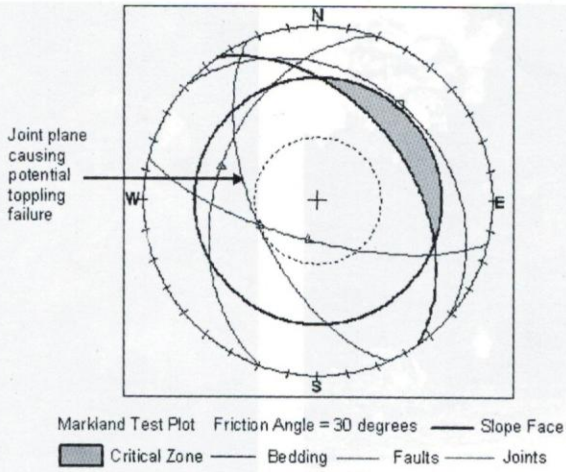

Fig. 12: Stereographic projection of discontinuity planes at Km 38 showing potential failures (equal angle lower hemispherical projection)

Fig. 13: Intensely sheared mudstone and fractured sandstone due to regional folding at Km 49

Fig. 14: Close-up view of wedge failure on sheared mudstone and fractured sandstone at Km 49

sandstone beds. The sandstone beds range in thickness from 5 to 10 cm and occur in a limited area. The grey and reddish brown mudstones make up most of the slope.

The mudstone beds which are intensely sheared and fractured do not show clear bedding (Fig. 13). However, the thin sandstone beds at the bottom of the slope are oriented around N30°E with dip angles between 30 and 40 degrees eastwards. The mudstone and sandstone beds are heavily jointed (Fig. 14) with its spacing from 3 to 20 cm (Fig. 15). The fracturing of mudstone and sandstone is related to the occurrence of a huge fold in this area.

Source of slope failure Type IV: related to old landslide deposit

This source of failure is rare, and was only observed towards the eastern part of the road towards the Keningau Town. A good example can be seen on the slope at Km 46 near the Crocker Range Park Office (Fig. 6). This failure is characterised by the presence of sandstone fragments chaotically mixed with grey and red mudstone (Fig. 16). The sandstone fragments measure 1–10 cm. No bedding was observed. The surrounding area is covered by grass.

RECOMMENDATIONS FOR SLOPE STABILISATION OPTIONS

The four sources of slope failure require appropriate stabilisation techniques. In this study the stabilisation options recommended involved grading of slope, establishment of vegetation, and spraying of concrete (gunite) apart from providing a good drainage system. To stabilise the fault zone (Type I) concrete may be sprayed or pumped on the unstable slope face to prevent weathering

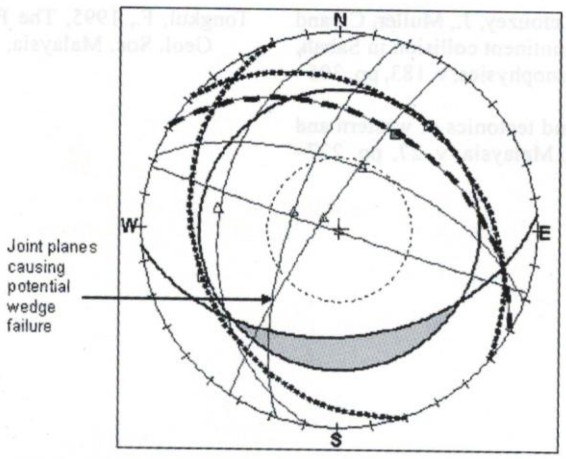

Fig. 15: Stereographic projection of discontinuity planes at Km 49 showing potential failures (equal angle lower hemispherical projection)

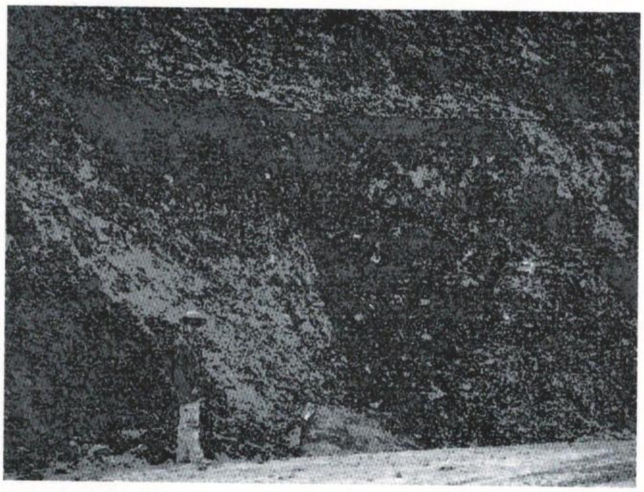

Fig. 16: Chaotic mixing of grey and red mudstone with blocks of sandstone in an old landslide deposit at Km 46

and spalling of the rock surface as well as to knit together the surface of the slope. To reduce failure of the sandstone beds along the bedding plane (Type II) grading of the slope cut to match the dip of bedding may be necessary followed by the establishment of appropriate vegetation. The slope failure related to regional folding (Type III) may require lowering the slope face angle considerably and spraying concrete onto the surface of the slope to hold together the intensely fractured mudstone and sandstone. The Type IV slope failure related to old slump deposits may require cutting the slope further and establishment of vegetation.

CONCLUSIONS

This study has demonstrated that geological input plays an important role in understanding the causes of slope failures. With this understanding appropriate stabilisation works can be carried out immediately and effectively before the unstable slope face deteriorates further due to weathering and erosion. It is quite common that a particular slope stabilisation technique (e.g. gunite) is applied indiscriminately over any failed slope. A good knowledge of the local geology can help avoid such an unnecessary expensive slope stabilisation option.

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