INTRODUCTION

Slope failures associated with steep slopes and heavy rain are quite common along major roads cutting through rugged mountainous areas in Malaysia. In the state of Sabah, located in the island of Borneo several major roads (Tamparuli-Ranau, Ranau-Tambunan, Penampang-Tambunan and Kimanis-Keningau Roads) pass through the Crocker Range, the most prominent mountain range of West Sabah. The Crocker Range, which is more than 40 km wide and has an average height of around 2000 metres, stretches about 200 km along the west coast of Sabah (Fig. 1). 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 that some of these roads were built on geologically unstable areas, such as major fault zones and old landslide deposits. As a consequence of this, the recurrence of slope failures at these unstable sites is quite frequent and very costly to maintain.

In early 2006 a road upgrading project linking the town of Ranau to the interior town of Tambunan was awarded. This upgrading involved redesigning the slope as the road has deteriorated since it was built more than 13 years ago. In an attempt to assist the civil engineers to design the road a detailed geological and geomorphological mapping along a 10 km stretch of the road from Km 13.5 to Km 23.5 towards Tambunan was carried out from August to September 2006. Aerial photo interpretation was carried out to determine the occurrence of landslide features (stratification, faults, fractures, folds and foliation), surficial deposits and surface hydrologic 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. This paper describes two landslide sites along the Ranau-Tambunan road.
2 GEOLOGY OF WEST SABAH

The western part of Sabah comprised mostly of sedimentary rocks with minor occurrence of igneous and metamorphic rocks (Figure 2). The oldest rock unit, representing an ancient Mesozoic oceanic crust occurs around Ranau area. This rock unit is made up of serpentinite (igneous), basalt (igneous) and chert (sedimentary). A Paleogene sedimentary rock representing deep-water marine sediments lie on top of the ancient oceanic crust. The sedimentary rock comprised of the Crocker and Trusmadi Formations (Collenete, 1958; Stauffer, 1967; Wilford, 1967). The Crocker Formation, which consists of folded and faulted layers of sandstone and mudstone occupies most of western Sabah (Tongkul, 1990). The Trusmadi Formation, which consists of intensely sheared and deformed meta-arenites, slates and phyllites are located near Ranau area. The oceanic crust and sedimentary units are intruded by an igneous rock of Late Miocene in age (Jacobson, 1970). The intrusive igneous rock, which comprises mostly of granitic rocks (granodiorite and syenite) form most of Mt. Kinabalu located in Ranau. Quaternary fluvial and coastal sediments fill river valleys and coastal plains. Quaternary glacial deposits, known as the Pinousuk Gravel (Jacobson, 1970) occur at the foot of Mt. Kinabalu.

Figure 2. Geological map of West Sabah showing major rock units and structures.

3 GEOLOGY ALONG RANAU-TAMBUNAN ROAD

The Ranau-Tambunan road is built on top of two major sedimentary rock formations, the Trusmadi Formation and Crocker Formation. The Crocker Formation sits unconformably on top of the Trusmadi Formation.

The Trusmadi Formation consists mostly of dark grey shales with thin-medium bedded sandstones, typical of a turbidite deposit. In certain areas, the unit has been subjected to mild metamorphism, producing slates, sub-phyllices and meta-sandstones, and intense tectonic deformation producing disrupted or brecciated beds. Quartz veins are quite widespread within the deformed sandstone beds. The shale is dark grey when fresh but changes to light grey when weathered. The sandstone interbeds are generally 1-100 cm thick. The sandstones consist predominantly of quartz grains with sutured grain boundaries. The Trusmadi Formation generally shows two major structural orientations, NW-SE and NE-SW.

The Crocker Formation consists mostly of interbedded grey sandstones and grey mudstones or shales. Sometimes red shales do occur. They are typically deep water sediments, deposited as submarine fans. The sandstone beds range in thickness from a few cm to several meters thick. The sandstones are texturally immature where angular to subrounded quartz grains are cemented by clay minerals and occasionally by calcite. The Crocker Formation has also undergone intense deformation – tight folds and thrust faults are common. The sandstones are also heavily jointed. The structural orientation of the Crocker sediments is mostly NW-SE.

4 LANDSLIDE ALONG RANAU-TAMBUNAN ROAD

Landslides of various sizes are observed on aerial photographs along the Ranau-Tambunan Road from Km 12 to Km 24 (Fig. 3). The landslides are marked by scars and hummocky surface. Abrupt change in the type of vegetation was also observed in the failed slope. The Trusmadi and Crocker Formation rock units are both equally susceptible to the development of landslides. Some of the landslide appears to have stabilized whereas others have moved recently causing damage to the roads in the form of cracks, subsidence and bulging.
4.1 Case Study 1 - Landslide at Km 13.7

The site is characterized by steep slopes above and below the road. A small stream flows towards the Southwest. Landslide scarp occurs above and below the road (Figure 4). The landslide area above the road has a gentler slope showing hummocky surface. The road below the landslide deposit shows sign of bulging. The landslide scarp seen above the road shows vertical displacement up to 2m in height (Figure 5). The head of the landslides below the road occur right at the edge of the road, causing damage to existing drains.

The site is underlain by deformed and sheared dark grey slates with thin meta-sandstone of the Trusmadi Formation oriented N290E with dip angles between 35-45 degrees northward. Several sets of joints are present in the slates and meta-sandstones. The landslide materials comprised of blocks of meta-sandstone and slates mixed with soil. A clear contact between the failed material and Trusmadi slates was observed near the road (Figure 6). The borehole data above and below the road indicated that the thickness of the landslide material is between 6-12m. The geological cross-section suggests that the existing road floats on top of the landslide material.
4.2 Case Study 2 - Landslides at KM 18.7

The site has steep slopes above and below the road. A small stream flows towards the southwest. Landslide scarps occur above and below the road (Figure 7). The landslide has caused a depression and tension cracks on the road (Figure 8). Groundwater seepage was detected near the depressed road. Below the depressed road bent trees occur.

Above the road several landslide scarps occur, some showing vertical displacement up to 2 m in height (Figure 9).

The site is underlain by sandstone and mudstones of the Crocker Formation. The sandstones and mudstones are highly weathered. The sandstone and mudstone beds are oriented N130E with dip angles between 25-30 degrees. The sandstones are highly
jointed. The landslide above the road appears to be localized and shallow and do not affect the road. However, the landslide below the road due to embankment failure affected the road.

5 DISCUSSION

Conventionally local engineers rely on general field observations to determine potential problematic slopes along a particular road. Using this information, a more detailed geotechnical studies is carried out to determine the subsoil condition based on boreholes. As these boreholes are quite expensive, only a few will normally be made. Based on this limited information the slope is then designed.

In Case Studies 1 and 2, before the geological mapping exercise was carried out, the extent of the slope problem determined was confined primarily to those located immediately near the road. Borehole locations were also determined based on the apparent presence of slope instabilities. So when the earlier design was made, it was solely to address the problem of localized landslides and embankment failures, completely ignoring those that are not seen from the road. After the geological mapping exercise was completed, a totally different design was proposed to address the presence of large active landslides above and below the road.

In the first case study at Km13.7, the thick loose materials from the landslide above the road was proposed to be trimmed. Due to the weak nature of the landslide material, the slope angle will be cut as low as possible and immediately covered with vegetation. To ensure that the groundwater level is kept at a minimum, a comprehensive drainage system will be put in place. The slope below the road will be reconstructed by using bored pile retaining wall to stabilize the failed embankment and landslide above the road. To have an effective monitoring program of the slope above the road additional boreholes will be made.

In the second case study at Km 18.7, the slope below the road was proposed to be reconstructed using bored pile retaining wall to stabilize the failed embankment. Since the slope failure above the road is shallow and does not affect the road, it will be subjected to only minor disturbance. A proper drainage system will also be put in place. The movement of the landslide above the road will also be monitored by adding more boreholes.

6 CONCLUDING REMARKS

Both the case studies have demonstrated that with proper geological input based on detailed field mapping data and subsoil conditions from boreholes a better understanding of the slope characteristics, conditions and extent can be effectively established which could then lead to a more appropriate slope design. Long term slope monitoring plans could also be determined at an early stage of the project. It is therefore essential that geological studies be included as early as possible when designing and constructing roads in mountainous areas.

ACKNOWLEDGEMENTS

This paper is an extract of a technical report on the geology of slopes along the Ranau-Tambunan road submitted to Perunding Menara HAC Sdn. Bhd. Universiti Malaysia Sabah provided the facilities to carry out the research. Harry Benedick and Chang Fui Khiong assisted with the mapping.

REFERENCES