TECTONIC UPLIFTS BASED ON MORPHOMETRIC INDICES IN NORTH WEST SABAH, MALAYSIA

CHUNG WEI KIAT

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CHUNG WEI KIAT
DS1721010T

(Tandatangan Pustakawan)

Tarikh : 31 October 2020

(Prof. Dr. Felix Tongkul)
Penyelia

DECLARATION

I hereby declare that all results and discussion in this thesis is my own original work, while acknowledging previous works in existing literature.

4 August 2020

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CHUNG WEI KIAT

DS1721010T

CERTIFICATION

NAME : **CHUNG WEI KIAT**

MATRIC NO : **DS1721010T**

TITLE : **TECTONIC UPLIFTS BASED ON MORPHOMETRIC INDICES IN NORTH WEST SABAH, MALAYSIA**

DEGREE : **DOCTOR OF PHILOSOPHY**

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VIVA DATE : **4 AUGUST 2020**

CERTIFIED BY;

Signature

SUPERVISOR

Professor Dr. Felix Tongkul ________________________

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ABSTRACT

The study constitutes the identification of uplift sites based on gradient and erosion anomalies over four major catchments in northwest Sabah, namely Kota Belud, Tuaran, Kinabalu Northeast, and Kinabalu Southeast catchments. The objectives of the study are to identify and screen regional sites of tectonic uplifts; identify and characterize sites of local uplift; validate the tectonic uplift in the field; and infer the active tectonics of northwest Sabah. The sites of tectonic uplifts at a regional and local scale were identified using gradient and erosion metrics over the 30 m resolution SRTM digital elevation models (DEM) and 5 m resolution IFSAR digital elevation models (DTM & DSM), respectively. The gradient metrics includes stream-length gradient index, surface-shape length gradient index, and knickpoint identifications whereas the erosion metrics includes normalized channel steepness index, chi-factor analysis and minimum bulk erosion. Based on the morphometric indices, several sites located both in the western and eastern flank catchments showed significant anomalies interpreted to be uplifted sites due to faults or lithological differences. Some of the anomalies are aligned N40E and may indicate alignment of regional faults. A closer analysis of some of the most significant anomalies in 18 sites clearly showed the presence of uplifted landforms. Out of 18 uplifted sites validated and characterized in the field, 11 sites from the western flank catchments indicates a NW-SE extensional regime, where the landform appears to be stretched forming a series of rapids and small waterfalls, whereas 7 sites from the eastern flank catchments indicates a NW-SE compressional regime, where the landform appears to have buckled causing stream ponding and incised valleys. The presence of both compressional and extensional tectonic regimes in northwest Sabah may be associated with NW-SE intraplate compression and gravity sliding towards the South China Sea.

ABSTRAK

PENGANGKATAN TEKTONIK BERDASARKAN INDEKS MORPHOMETRI DI KAWASAN BARATLAUT SABAH, MALAYSIA

Kajian ini bertujuan mengenalpasti tapak terangkat berdasarkan anomali kecerunan dan hakisan di empat tadahan utama di Baratlaut Sabah, iaitu tadahan air Kota Belud, Tuaran, Timurlaut Kinabalu dan Tenggara Kinabalu. Objektif kajian adalah untuk mengenalpasti dan menyaring tapak terangkat rantau; mengenalpasti dan mencirikan tapak terangkat tempatan; mengesahkan pengangkatan tektonik di lapangan; dan mentafsir tektonik aktif di Baratlaut Sabah. Tapak terangkat pada skala rantau dan skala tempatan dikenalpasti menggunakan morfometri kecerunanan dan hakisan keatas model ketinggian digital (DEM) SRTM dengan resolusi 30 m dan model ketinggian digital (DTM & DSM) IFSAR dengan resolusi 5 m. Morfometri kecerunan merangkumi indeks kecerunan panjang sungai, indeks kecerunan panjang dan bentuk permukaan, dan pengenalpastian titik perubahan kecerunan mendadak, sementara morfometri hakisan merangkumi indeks kecuraman tebing sungai, analisis faktor-chi dan hakisan pukal minimum. Berdasarkan kepada indeks morfometri, beberapa tapak yang terdapat di tadahan air di bahagian barat dan bahagian timur menunjukkan anomali yang signifikan, yang ditafsirkan sebagai tapak terangkat disebabkan oleh sesar atau perbezaan litologi. Terdapat anomali yang tersusun pada arah N40E yang mungkin mewakili orientasi sesar rantau. Analisis lebih dekat terhadap beberapa anomali yang paling signifikan di 18 tapak jelas menunjukkan kehadiran mukabumi terangkat. Dari pada 18 tapak terangkat yang disahkan dan dicirikan di lapangan, 11 tapak dari tadahan sungai bahagian barat menunjukkan regim regangan Baratlaut-Tenggara, dimana mukabumi kelihatan tertarik membentuk beberapa siri jeram dan air terjun kecil, sementara 7 tapak dari tadahan sungai di bahagian timur menunjukkan regim mampatan Baratlaut-Tenggara, dimana mukabumi kelihatan terangkat menyebabkan pembentukan kolam pada sungai dan lembah terhakis dalam. Kehadiran kedua-dua regim tektonik mampatan dan regangan di Baratlaut Sabah mungkin dikaitkan dengan mampatan Baratlaut-Tenggara plet intra dan gelinciran graviti kearah Laut China Selatan.

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INTRODUCTION

1.1 Research Background

During the past five years, two significant earthquakes of greater than magnitude 5 have occurred in Sabah, both located around the Mount Kinabalu area. The two significant quakes occurred on June 2015 (Tongkul, 2016), while the other as recent as March 2018. The tele-seismic signatures highlighted displacement over the Marakau fault that had generated a 6.0 Ma shallow earthquake in 2015 (Wang *et al.*, 2017). Thus, there is an increased interest over the heavily faulted region of Kinabalu granitoid as the vicinity has been a source of rupture-slippage in the recent shallow quakes (Tongkul, 2017). The deformations in intraplate regions are a consequence of active fault plane displacement that exists due to the accumulated intrinsic stress due to its structural configuration (Bull & Scrutton, 1992). These may occur independently or in absence of a subducting zone (Bracène & de Lamotte, 2002). Hence, to identify potential sites of uplift that has not been known within the intraplate of NW Sabah, the landform will be evaluated using morphometric computation through tectonic and erosional indices (Keller & Rockwell, 1984; Keller & Pinter, 1996).

The uplift can be defined as an elevated landform body where there is an observable disparity in elevation between two adjoined surfaces. These surfaces are usually linked by a steep surface where the faults are located either outcropped or buried. The faults are the plane of displacement that forms to accommodate the plate motions. In this study, we applied several gradient based and erosional morphometric parameters to identify uplift. The gradient has been a crude indicator of uplift for a regionally uplifted body (Davis, 1899) and this may be reflected within the incised stream channels. The gradient can be normalized with a factor to reflect certain attributes namely stream power or as an uplift indicator as applied in many literatures (Chen *et al.*, 2003; Troiani & Della Seta, 2008; Hürtgen *et al.*, 2014; Kothyari, 2015; Pirasteh & Li, 2017; Siddiqui *et al.*, 2017). In many studies, Stream-Length gradient (SL) indices were known to reflect the location of faults in literatures (Jaberi *et al.*, 2018). The SL-indices, however, does not differentiate between a high or low gradient uplift. Thus, a novel formulation, the surface-shape length technique will be applied to supplement the SL-indices in this study.

The NW Sabah is known to have undergone intense uplift and weathering since the Cenozoic (Hall & Nichols, 2002; van Hattum *et al.*, 2006; Morley & Back, 2008; van Hattum *et al.*, 2013). Though climate is known to fluctuate in the Cenozoic, on average, is presumed to be contiguous up to be present day. This is assumed for simplicity as the region is geographically located at the equator since the first rapid uplift during the Cenozoic evolution. However, the climatic forcing imprints are not as conspicuous as imprints by tectonic forcing where the erosional metrics are not directly quantifiable with preserved structures (Whittaker, 2012). Fundamentally, the modern-day landform is a function of tectonic uplift, capacity bedrock erosion and intensity of regional climatic forcing (Ahnert, 1970; Bull, 1991; Whipple & Tucker, 1999; Bull, 2008; Whipple, 2009; Whipple *et al.*, 2013). The drainage stream networks, as a function of climate would modify discharge volume of sediment, hence, reconfiguring patterns of fluvial incision (Sklar & Dietrich, 1998; Wobus *et al.*, 2010; Whitfield & Harvey, 2012). In the earliest works, the slope gradient is directly correlated to the erosion intensity along a slope (Davis, 1899; Strahler, 1950). Thus, the channel gradient is then integrated as a function of erosion; represented in a normalized channel steepness index where it became an indicator for anomalous erosion streams. On the state of basin-wide scale, the computation of chi-factor elucidates regions susceptible to modification relative to adjacent basins. Therefore, highlighting the phases of basin stage as it shifts towards steady-state from disequilibrium (Montgomery & Foufoula-Georgiou, 1993). The erodible landforms would be highlighted by hypsometry integral (Lifton & Chase, 1992; Ohmori, 1993; Brocklehurst & Whipple, 2004; Whipple, 2004; Pérez-Peña *et al.*, 2009). The future shifts in drainage basins is elucidated with chi-factor to shed light on the present state of erosion within the catchment in NW Sabah. Therefore, the overall interest pertaining to erosion metrics would primarily cover the past, present, and future erosional metrics. However, in terms of uplift, only the past changes through an estimated depth of bulk column will be applied in his study.

In the earliest of days, before the advances of morphometric techniques, the structural characteristics of landform uplift were identified to be associated with some form of ponding or ponded feature (Campbell, 1896). The ponding feature has been a consistent and evident feature for an uplift in many literatures (Hutton *et al.*, 1994; Michetti *et al.*, 2012). For a significant uplift, the knickpoints generally coincide with a waterfall feature (Mathew *et al.*, 2016) or a significant fault scarp (Menier *et al.*, 2017). However, there are several challenges in the identification of structural landforms in NW Borneo. For an intraplate region, the lithosphere motion at a steady state is about 2 mm annually (Gordon, 1995, 1998). Thus, the uplift within NW Sabah is quite miniscule. Previous works on regions with miniscule uplift, suggested an extensive difficulty in identification of any forms of minor uplift (Figueiredo *et al.*, 2018) as it may be potentially obscured (Giamboni *et al.*, 2005). The knickpoints will be validated in the field and it remained an interest to observe the structural landform namely ponding and gorge formation that is pinpointed by morphometrics. Thus, the interest to observe the landform structures as a consequence of uplift in the field of NW Sabah.

1.2 Study Location

The study area within NW Sabah is focused on four drainage streams that surround the Kinabalu granite. Three of the basins with stream source point originating from the highest elevated apex (4095 m), while Tuaran catchment is an independent basin (Fig. 1.1). All the major catchment basins of interest have distinct and unique characteristics. On the western flank, two basins of interest are denoted as the Tuaran basin (TB) and Kota Belud (KB) basin; named respective of their bounded geographical location. The surface of the Tuaran Basin is about 981.92 km^2, while the Kota Belud basin is at about 859.29 km^2. On the eastern flank, two catchment basins that drains from the Kinabalu granite is named based on its relative geographical position to the apex, Kinabalu North East (KNE) flank and Kinabalu South East (KSE) flank basin. The KNE catchment basin measures to be about 3113.1 km^2 of total surface area, while the KSE catchment basin is measured to be about 3529.6 km^2 of drainage area. Each catchment basin has an active river stream. Tuaran Basin hosts the Tuaran river, while Kota Belud basin hosts the Kedamaian and Wariu river. The length of both streams is approximately 30 km. Sugut river is located in the Kinabalu North-east basin. The Kinabalu South-east (KSE) basin hosts the Labuk river, that were fed by the Liwagu river and Kagibangan river.

1.2.1 Regional Climate

The NW Sabah is classified as an equatorial climate with near maximum humidity, under the Köppen-climate classification (Kottek *et al.*, 2006). The present-day climate of NW Sabah ranged between a low of 24 degrees Celsius to a high of 32 degrees Celsius. However, temperature were significantly lower over highland areas, registering an annual average of 20 degree Celsius. Sabah experiences monsoonal rainfall pattern changes, where the November to December period recorded the wettest season (Chen *et al.*, 2013).

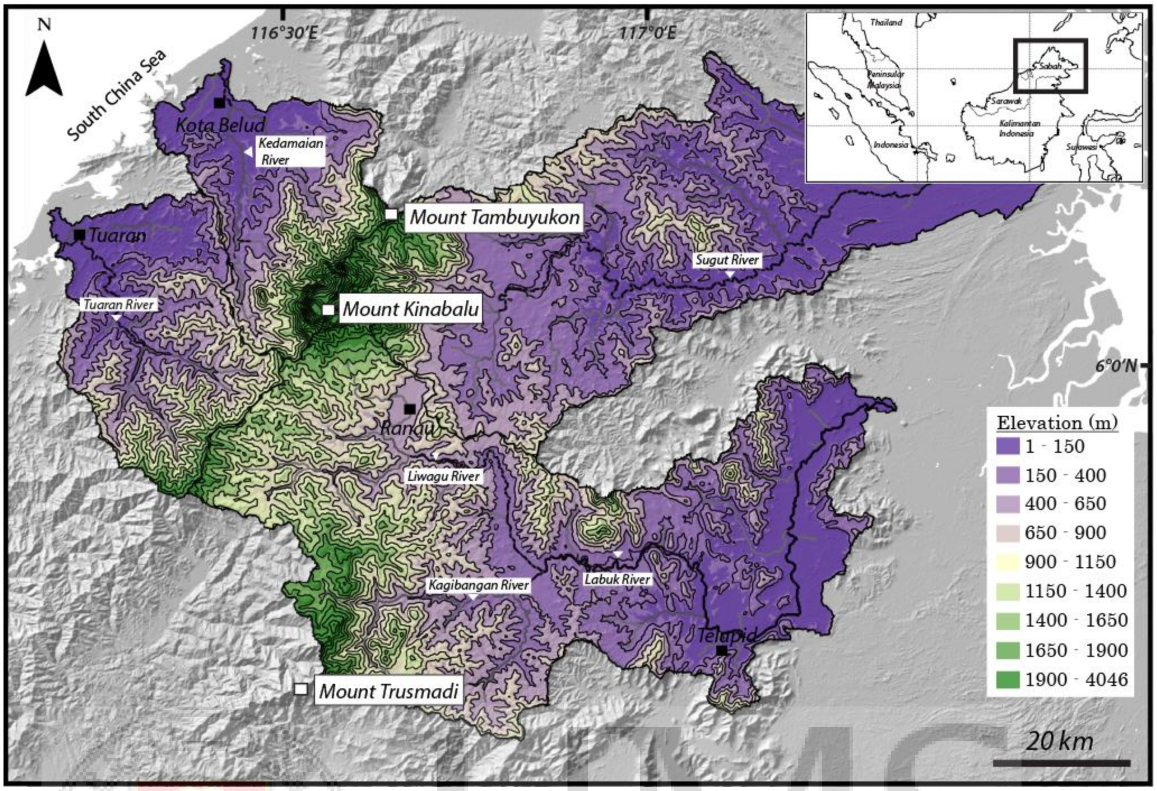

Figure 1.1: The topographical map of the major drainage basins that are located on the Kinabalu granite flanks. The active flowing river streams are generated on the respective basin catchment. The darker river lines indicate broader river width and higher volume of stream discharge, while lighter lines reflect tighter and lower stream discharge volume.

1.2.2 General Geology and Tectonic Setting

The study area is predominantly underlain by a deformed sandstone and shale sequence. The exception is noted for an exhumed granite body with sparsely distributed ophiolitic ultrabasic rocks (Fig. 1.2). This is supported by great number of mapped lithological boundaries in previous literatures (Tongkul, 1993, 1994; Balaguru *et al.*, 2003; Tongkul & Chang, 2003; Balaguru & Nichols, 2004; Hall, 2013; Burton-Johnson *et al.*, 2017). The oldest known formation of Cretaceous-Jurassic origin are the ophiolite outcrops and is regarded as the basement rock in the study area (Tongkul, 1991). A great extent of ophiolitic rocks within the study area were observed