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# Late Quaternary denudational chronology of the Kampung Air Jernih area, Terengganu, Malaysia

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**Abstract:** Four geomorphological units with distinctive subsurface earth materials were identified in the Kampung Air Jernih area, i.e., flood-plains and swamps over Holocene Beruas Formation sediments (3-8 m thick), river terraces over Pleistocene Simpang Formation sediments (3-6 m thick), and denudational terrain over Carboniferous meta-sediments (Sungai Perlis Beds), and over Triassic granite. The flood-plains and swamps are 5 to 8 m above mean sea-level, the terraces between 9 and 15 m, and the denudational terrain above the 15 m topographic contour. Three main rivers are present; the south flowing Sungai Air Jernih, and Sungai Payuh, in the western, and central, sectors, respectively, and the east flowing Sungai Tumpat in the northern sector. Correlation with Quaternary global sea-levels indicates that denudational processes under a tropical savanna climate were operative from circa 500 ka to circa 140 ka BP; the global sea-level rise (Termination II) from -120 m (circa 140 ka) to +6 m (circa 120 ka) giving rise to a tropical rainforest climate and deposition of Simpang Formation sediments by south flowing rivers. The global sea-level fall from +6 m (circa 120 ka) to -120 m (circa 20 ka) led to denudational processes under a tropical savanna climate and formation of river terraces, as well as capture of Sungai Tumpat by the east flowing Sungai Kemasik. Global sea-level rise (Termination I) from -120 m (circa 20 ka) to +5 m (circa 5 ka) led to a tropical rainforest climate and deposition of Beruas Formation sediments followed by down-cutting of rivers from circa 5 ka to the present day. It is concluded that correlating the development of landforms and river capture with Quaternary global sea-levels that allowed for derivation of the denudational chronology.

**Keywords:** Denudational chronology, Late Quaternary global sea-levels, river capture, Kampung Air Jernih

## INTRODUCTION

Differing views have been expressed on the Quaternary geological history of Peninsular Malaysia; Douglas (1969) considering the Peninsula to belong to the inner core of the humid tropics, i.e., areas with landforms resulting from processes of a similar nature and intensity as those of the present-day. Swan (1972) similarly considered Johore state to be a region "where evergreen forest has been the climax vegetation since late Mesozoic times". Morgan (1973) furthermore, stated that slope and soil features of Selangor and Negeri Sembilan states reflected the present processes operative in the landscape and that the landforms were uncomplicated by the presence of dissected surface remnants.

Koopmans & Stauffer (1967), however, have shown that the summit and upper flanks of Mount Kinabalu in Sabah were capped by ice fields during the Pleistocene with two valley glaciers. As the present-day snowline exceeds the summit height (4,095 m) of Mount Kinabalu, it is clear that climates there must have been colder in the past. Two phases of colder climates may in fact have existed for Koopmans & Stauffer (1967) proposed that ice caps were present on the summit at the time of both the Riss and Wurm glaciations in Europe. Fenley & Morley (1978) have shown that one of the glaciations occurred during the Holocene with a minimum age of 9,186$\pm$120 years Before Present (BP) provided by a $^{14}C$ date.

Batchelor (1979) proposed that discontinuously rising eustatic sea-levels and accompanying climate changes were the major controls on sedimentation in Sundaland (i.e. modern insular Indonesia and Malaysia and the then sub-aerially exposed Sunda Shelf) during the late Cenozoic. Batchelor (1979) derived a tentative time framework for the depositional history, starting with development of the Sundaland Regolith under a semi-arid climate in the late Miocene to early Pliocene, followed by the unconformably overlying, early Pliocene to early Pleistocene, Older Sedimentary Cover. Increased precipitation towards the end of the early Pleistocene led to stream entrenchment, and following a lateritisation phase, a second braided stream entrenchment resulted in redeposition downstream within a Transitional Unit. Superficial reworking then followed during two major transgressions across the Sunda Shelf, responsible for an older marine unit and the Holocene Younger Sedimentary Cover (Batchelor, 1979).

De Dapper & Debaveye (1986) proposed that Quaternary climate and vegetation changes in north Kedah led to stable and unstable morphogenic phases; the unstable

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phases coinciding with shifts in climate from a very wet to a drier one, and shifts in vegetation cover from a dense to a more open one. De Dapper (1989) considered that erosion and deposition were prominent during the unstable phases, whilst weathering and soil formation were prominent during the stable phases. De Dapper (1989) proposed a tentative denudational chronology for landforms in the area; river terraces only developed in late Pleistocene and Holocene times, whilst pedimentation and planation took place in early to middle Pleistocene.

Wust & Bustin (2004) investigated the lowland fluvial/lacustrine mire system of Tasek Bera in Pahang State and concluded that widespread peat deposition only started after 5,300 years BP when climate changes led to evolution of a wetland system. Wust & Bustin (2004) assumed a correlation between water table level, detrital influx and organic matter preservation, and proposed a model where ash yield variations of peat samples reflected changes in precipitation. The model shows relatively moderate to high precipitation from some 4,500 years BP to the present-day, though from 4,500 to 5,500 BP there was very high precipitation with restricted drainage and the onset of peat accumulation (Wust & Bustin, 2004).

Alqahtani *et al*. (2015) reconstructed and quantified Late Pleistocene fluvial systems in the Malay Basin from a large, subregional merged three-dimensional seismic dataset, augmented by high-resolution site survey seismic and borehole data. Two types of fluvial channel incisions were identified; one involving deeply incised valley systems (up to 80 m deep) interpreted to form during periods of major sea-level fall (100 to 120 m), and the other involving weakly incised channel systems (20 to 30 m deep) interpreted as low-stand alluvial bypass channel systems. The largest and most prominent incised valley was said to have formed during the Last Glacial Maximum (LGM) low-stand, when sea-level had fallen to, or just below, the shelf edge and when most of the extensive and low-gradient Sunda Shelf was exposed. This large valley was considered part of the palaeo-Chao Phraya-Johore River, which originated in the highlands of northern Thailand, drained southwards through the Gulf of Thailand and the Malay Basin, and discharged into the South China Sea (Alqahtani *et al*., 2015).

During field mapping of the geology along the Kuantan-Kertih railway line in the Kampung (Kg.) Air Jernih area were encountered several stretches of flat to gently sloping ground covered with coconut trees and overlying loose to medium dense, sands and gravels. This landscape is reminiscent of the coastal areas of the East Coast of the Peninsula where coconut trees over loose sands mark the distribution of Holocene beach ridges (‘permatang’). In view of the similarity in landscapes but differing environmental settings, a study was carried out to determine the denudation chronology of the Kg. Air (or Ayer) Jernih area. Denudation chronology is the branch of landform studies that deals with the historical development of landscapes by denudation; evidence for developmental stages provided by studies of erosion surfaces and their mantling deposits, drainage patterns, stream long-profiles, and geologic structures (Jones, 2004; Allaby, 2008).

## STUDY AREA - LOCATION AND CLIMATE

The study area is located in the south of Terengganu state (Figure 1); the main settlement being Kg. Air Jernih which is some 12 km by road to the west of Kemasik town in the East Coast of Peninsular Malaysia (Figure 2). The study area has presently a humid tropical climate that is primarily influenced by the NE Monsoon, blowing from mid-November to mid-March, and to a lesser extent by the SW Monsoon blowing from late May to September (MetMy, 2023). During the NE Monsoon, steady easterly or northeasterly winds of 10 to 30 knots prevail and bring heavy rainfall, whilst during the SW Monsoon, generally south-westerly and light (<15 knots) winds are present with less rainfall. The inter-monsoon periods are characterized by light surface winds with variable rainfalls (MetMy, 2023).

Rainfall is distinctly variable with time of year; October, November, December and January being the wettest months with monthly rainfalls of 234 to 591 mm, whilst June, July, August and September are the driest months with monthly rainfalls of 105 to 128 mm. The months of February, March, April and May have intermediate monthly rainfalls of 139 to 178 mm (MetMy, 2023). Temperatures are generally high throughout the year with November, December, January and February being the coolest months with average monthly


**Figure 1:** Location of the Kampung Air Jernih area.

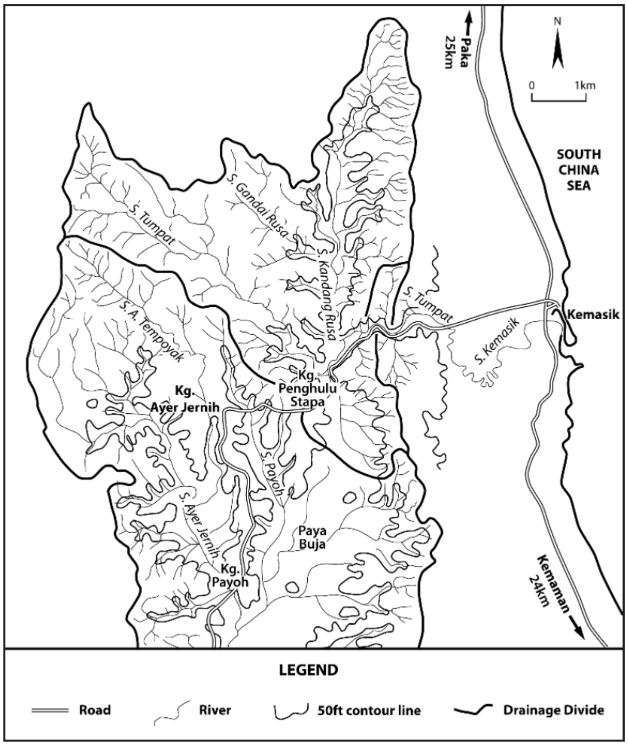


**Figure 2:** Main rivers and drainage divides in the Kampung Air Jernih area.

temperatures of 25.1 to 25.7°C, and April, May and June being the warmest months with average monthly temperatures of 26.2 to 27.1°C. August, September and October have intermediate monthly average temperatures of 26.1 to 26.5°C (MetMy, 2023). Diurnal temperature ranges are up to 5°C with a typical day in March ranging from a high of 29°C to a low of 25°C, whilst in May, some days have highs of 30°C and lows of 27°C. In February, daily temperatures range from highs of 28°C to lows of 24°C (MetMy, 2023).

## STUDY AREA – DRAINAGE PATERN

Three main rivers drain the study area (Figure 2), i.e.

(a) the east flowing S. (or Sungai) Tumpat and its tributaries in the northern sector,
(b) the south flowing S. Air Jernih and its tributaries in the western sector, and
(c) the south flowing S. Payuh and its tributaries in the central and eastern sectors.

The eastern, and western, drainage divides of S. Payuh, and S. Air Jernih, respectively, are aligned in a N-S direction which coincides with their N-S flow. Their northern drainage divides, however, trend in a NW-SE direction and cross low-lying terrain (<50 feet contour) to the SE of Kg. Penghulu Stapa (Figure 2).

In the north, S. Tumpat first flows SE, but abruptly turns and heads NE (close to Kg. Penghulu Stapa) before joining S. Kandang Rusa and then flowing E into S. Kemasik (Figure 2). In the northeast, S. Kandang Rusa first flows S, but abruptly turns and flows E into S. Kemasik after meeting S. Tumpat. The contrary flow directions of S. Tumpat and S. Kandang Rusa suggest that they have been captured by the E flowing S. Kemasik. The topographically low (<50 feet contour) drainage divide between the S flowing S. Payuh, and the N flowing S. Tumpat to the SE of Kg. Penghulu Stapa also suggests that S. Tumpat and S. Kandang Rusa once flowed S (Figure 2).

## STUDY AREA – GEOMORPHOLOGY AND GEOLOGY

The study area consists for the most part of a central, flat to undulating plain that broadens out towards the south where it continues into the floodplain of S. Kemaman. To the west, north and east, however, is found hilly terrain that rises to some 200 m above mean sea-level in the west but to about 150 m in the north. To the east, the hilly terrain forms a broad, N-S trending ridge that rises to 192 m at Bt. (Bukit) Harimau Menangis (Figure 3) and is cut by S. Tumpat which flows into S. Kemasik and then into the South China Sea (Figure 2). Between the N-S trending ridge and the South China Sea is a broad coastal plain of some 3 to 5 km wide with two main sets of beach ridges, mapped as the Matang Gelugor Member of the Holocene Gula Formation by Jabatan Mineral dan Geosains Malaysia (JMG) (Suntharalingam, 1987; Bosch, 1988).

Field mapping and interpretation of aerial photographs and topographic maps show that landforms in the study area can be differentiated into four main geomorphological units (Figure 3), i.e.,

1. floodplains and swamps,
2. river terraces,
3. denudational terrain over meta-sediments, and
4. denudational terrain over granite.

### Floodplains and swamps

These depositional landforms, located some 5 to 8 m above mean sea-level, are characterized by narrow to broad (>10 m wide) stretches of flat and swampy ground that flank the larger river channels (Figure 3). Water levels in the rivers during normal flow are some 1 to 3 m below the floodplains and indicate their continued down-cutting.

Boreholes show the floodplains and swamps to overlie soft, grey clays and silts with loose sand and abundant organic matter including decayed wood. The sediments are some 3.0 to 8.5 m thick and continue south into the floodplain of S. Kemaman where they have been mapped as the Holocene Beruas Formation by JMG (Bosch, 1988). The Beruas Formation refers to the clay, silt, sand, gravel and peat deposited in a terrestrial environment after the most recent major low sea-level, some 15 to 18 ka (thousands of years) BP (Suntharalingam, 1987; Bosch, 1988).

The Beruas Formation in the study area (Figure 4) overlies a variety of lithology, including meta-sedimentary and granitic bedrock, as well as older (Pleistocene) alluvial sediments. Borehole A (Relative Level = RL=5.75 m) in the lower floodplain of S. Semayur (Figure 4) for instance,

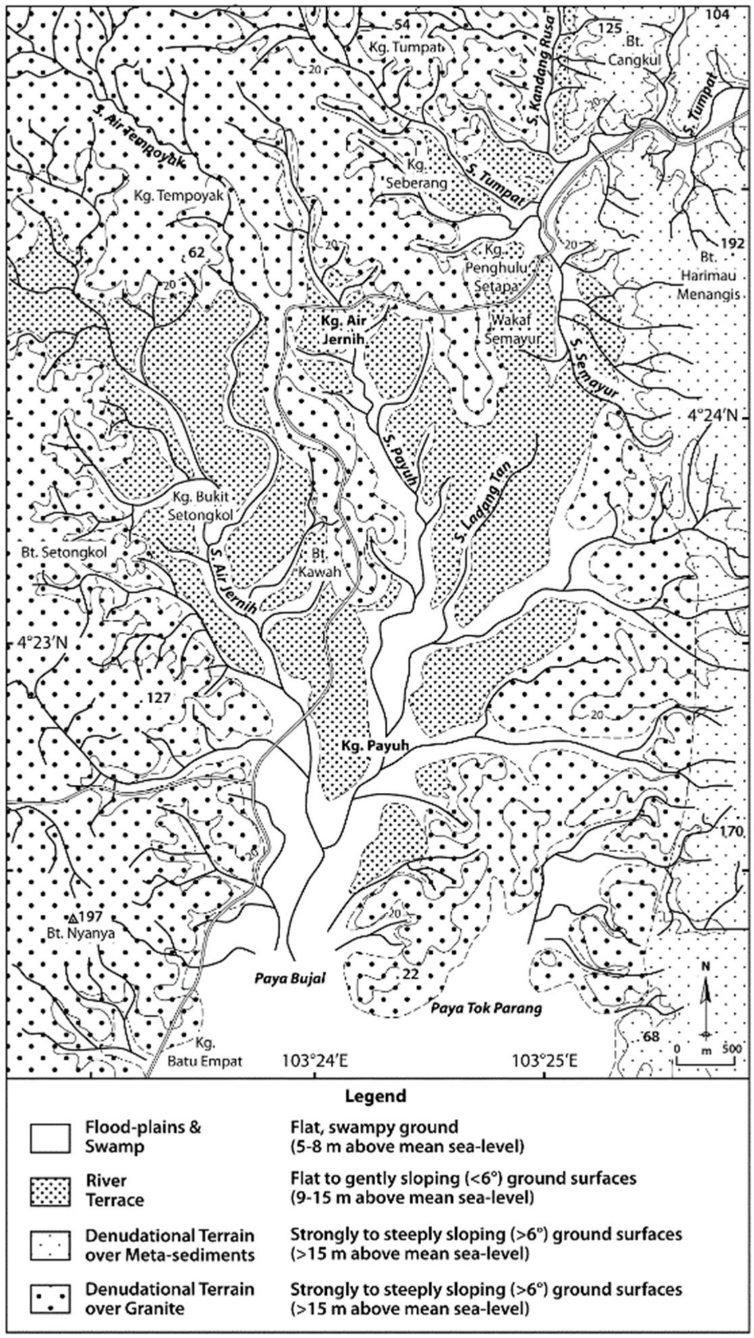


**Figure 3:** Geomorphological units in the Kampung Air Jernih area.

**Table 1:** Log borehole A – Lower floodplain of S. Semayur (RL= 5.75 m).

| Depth (m) | Description | Interpretation |
|---|---|---|
| 0.0-2.0 | Very soft, dark grey, silty Clay with decayed wood. N=2 | |
| 2.0-5.8 | Loose, grey, Sand with decayed wood. N=3-4 | Beruas Formation |
| 5.8-8.5 | Soft, dark grey, sandy Clay with some decayed wood. N<5 | |
| 8.5-12.0 | Firm, grey, silty Clay. N=8 | Weathered S. Perlis Beds |
| 12.0-13.7 | Grey, fractured, Sandstone with iron-stained joints. RQD=0% | S. Perlis Beds |

Note: N = Number of blows in Standard Penetration Test; RQD = Rock Quality Designation.

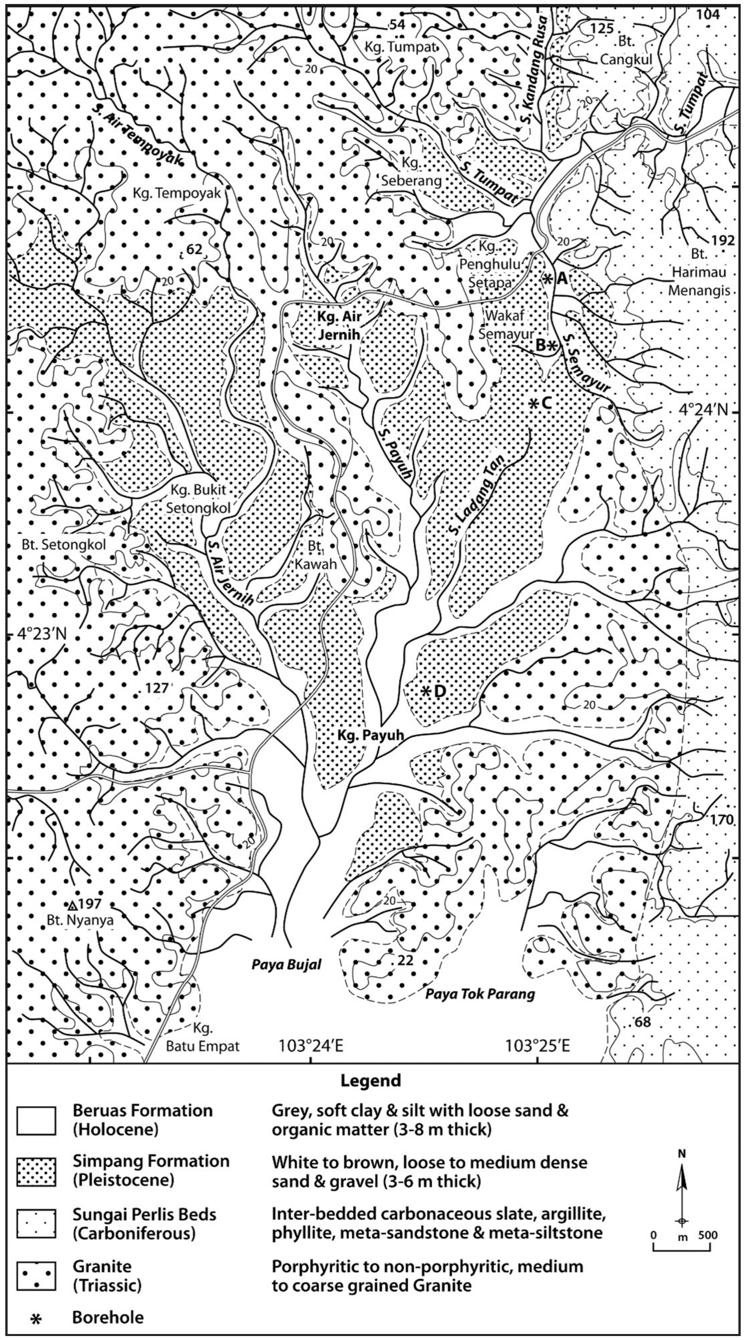


**Figure 4:** Geology map of the Kampung Air Jernih area.

**Table 2:** Log borehole B – Upper floodplain of S. Semayur (RL=7.21 m).

| Depth (m) | Description | Interpretation |
|---|---|---|
| 0.0-2.0 | Soft, brownish dark grey, silty Clay. N=4 | Beruas Formation |
| 2.0-8.5 | Very soft to soft, dark grey sandy Clay. N=<6 | |
| 8.5-10.2 | Firm, dark grey sandy Clay. N=8 | Palaeosol |
| 10.2-13.5 | Firm, grey clayey sandy Silt. N=10-11 | Completely to moderately weathered S. Perlis Beds |
| 13.5-15.0 | Firm, grey clayey sandy Silt. N=13 | |
| 15.0-16.5 | Very dense, grey sandy Silt. Sandstone fragments. N=>50 | |
| 16.5-21.2 | Grey, highly fractured meta-Sandstone. RQD=0% | S. Perlis Beds |

shows an upper, 8.5 m thick, sequence of Beruas Formation sediments overlying a 3.5 m thick, firm, grey silty clay, considered to be completely weathered meta-sediments of the Sungai Perlis Beds with highly fractured sandstone encountered at a depth of 12.0 m.

Borehole B (RL=7.21 m) in the upper floodplain of S. Semayur (Figure 4) shows an upper, 8.5 m thick sequence of Beruas Formation sediments overlying a 1.7 m thick, firm, dark grey sandy clay considered to be a palaeosol for it overlies weathered strata of the Sungai Perlis Beds represented by firm to dense, grey, sandy silts with highly fractured, meta-sandstone encountered at a depth of 16.5 m.

**Figure 5:** Terrace sediments (Simpang Formation) at Kawasan Perumahan Kg. Air Jernih.

### River terraces

At several locations in the study area are found isolated to continuous stretches of flat to gently sloping (<6°) ground that flank the floodplains and are some 9 to 15 m above mean sea-level (Figure 3). These ground surfaces are river terraces for their immediately underlying, loose to medium dense, sands and gravels (3 to 6 m thick) are best correlated with the Pleistocene Simpang Formation of JMG (Figure 4). The Simpang Formation refers to the clay, silt, sand, gravel and peat deposited in a terrestrial environment before the most recent major low sea-level some 15 to 18 ka BP (Suntharalingam, 1987; Bosch, 1988).

Slope cuts show the Simpang Formation sediments to be white to brown in color and poorly sorted with sub-rounded to angular, pebble sized, vein quartz clasts in a medium to coarse sand matrix. An increase of grain size with depth is sometimes seen with subangular pebbles and cobbles reported at the foot of a 3 m high cut at Kawasan Perumahan Kg. Air Jernih (Mohd Farid, 2001). At this cut, the top 1.5 m of the sediments is stained orange to brown, indicating prolonged exposure to pedological processes (Figure 5).

Various sedimentary structures are seen in the Simpang Formation and include graded bedding, pebble imbrications and indistinct cross-bedding as well as channel fills in the form of pebbly sand lenses. These sedimentary structures and the coarse texture of the sediments indicates that they were deposited by braided rivers. A similar origin has also been proposed for the Simpang Formation at Teluk Intan in Perak State where the mainly coarse sand and gravelly sediments are said to comprise alluvial fan - braided river deposits (Loh, 1992).

Plots of various statistical measures as graphic skewness versus graphic standard deviation, graphic mean versus graphic standard deviation, and graphic skewness versus graphic kurtosis, have been compared with published plots, and led to the conclusion that the Simpang Formation in the Kg. Air Jernih area was deposited by rivers (Mohd Farid, 2001). Binocular microscope examination of heavy minerals collected by bromoform separation show them to consist of tourmaline, ilmenite, siderite and pyrite; minerals that are indicative of a provenance including weathered granite and meta-sedimentary bedrock (Mohd Farid, 2001).

Boreholes show the Simpang Formation to be weathered with an upper pedological soil as borehole C (RL≈12.0 m) in the drainage divide between S. Semayur and S. Ladang Tan (Figure 4). At this borehole, an upper, 2.4 m thick, loose, silty sand representing surface wash sediments and soil, overlies a 2.7 m thick sequence of medium dense, sand of the Simpang Formation that overlies in turn a 3.4 m thick, soft, brown, sandy clay layer. This brown sandy clay layer is considered to be a palaeosol for it overlies 7.0 m of dense to very dense, silty fine sand (representing moderately to completely weathered granitic bedrock) with grey, fractured and weathered granite, encountered at a depth of 15.5 m.

At borehole D (RL=10.4 m) to the east of Kg. Payuh (Figure 4), the top 4.0 m thick, brown, loose sand of the Simpang Formation overlies a 4.7 m thick, soft, pale brown, silty sandy clay that is considered to be palaeosol and completely weathered granite, for it overlies 6.3 m of grey to greenish, dense to very dense, silty sands (representing moderately to highly weathered granite) with fractured granite encountered at a depth of 15.0 m.

### Denudational terrain over meta-sediments

Strongly to steeply sloping (>6°) ground surfaces in the eastern side of the study area (>15 m elevation) give rise to the broad, N-S trending ridge that rises to 192 m at Bt. Harimau Menangis (Figure 3). Surface soils here are characterized by orange to brown colors with silty to sandy textures, and have been mapped as the Kuala Brang Soil Association (Panton, 1958). This Soil Association is found in undulating to steep hilly country and developed over parent rocks that are chiefly argillaceous sediments of Carboniferous age, including shales and sandy shales, some of which are highly indurated (Panton, 1958). The ridge has thus developed from denudational processes (weathering and erosion) operating on meta-sedimentary bedrock.

Slope cuts show the meta-sediments to comprise sequences of inter-bedded carbonaceous phyllite, argillite, shale, meta-sandstone and meta-siltstone. These meta-sediments are very similar to those in the Ulu Paka area to the NE where they have been named the Sungai Perlis Beds (Fateh Chand, 1978). The Sungai Perlis Beds are of a Carboniferous age and consist mainly of sequences of inter-bedded carbonaceous slate, argillite, phyllite and schist, together with minor bands and lenses of quartzite, meta-conglomerate, and calc-silicate hornfels (Fateh Chand, 1978).

The meta-sediments of the study area are also very similar to those mapped as Unit A in the adjoining Chukai Map Sheet to the east, where they comprise inter-bedded sequences of mainly phyllite, slate, quartzite, indurated sandstone and minor schist (Tyebally Fazle Hussein, 1977). The meta-sedimentary rocks here commonly form NNW-SSE trending ridges and have been affected by folding, quartz veining and minor faulting (Tyebally Fazle Hussein, 1977).

Fossils have not been reported in the study area, though plant fossils in similar meta-sediments of the Sungai Perlis Beds to the SE at Tanjung Sulong in Kemaman (Goh, 1972; Tyebally Fazle Hussein, 1977), and at Tanjung Gelang in Pahang State (Yap, 1976), indicate a Lower Carboniferous age.

### Denudational terrain over granite

Strongly to steeply sloping (>6$^o$) ground surfaces in the central, western and northern sectors of the study area (>15 m elevation) give rise to low hills and ridges that are characterized by orange to brown surface soils with sandy clay to clayey sand textures (Figure 4). These surface soils have been mapped as the Rengam Sandy Clay Loam (or Rengam Soil Series) which is a well-structured, free draining soil developed from deeply weathered granite in undulating country (Panton, 1958). The low hills and ridges have thus resulted from denudational processes (weathering and erosion) operating on granitic bedrock (Figure 4).

Granite outcrops are not seen, though some deep cuts expose distinctive relict textures that indicate in situ, highly to completely weathered granitic bedrock. Boreholes also have shown the presence of granitic bedrock (Tables 3 and 4). A quarry, close to the SW corner of the study area, exposes a grey, porphyritic to non-porphyritic, granite; the main minerals being quartz, alkali feldspar, plagioclase and mica, whilst the accessory minerals include zircon, tourmaline, epidote, apatite and zeolite. Acidic igneous intrusives in the adjoining Chukai Map Sheet to the E are reported to be medium to coarse grained and commonly granitic to ademellitic in composition (Yew, 1974), whilst granitic rocks in the Kijal area, to the NE, comprise biotite and hornblende-biotite bearing granite and adamellite with minor amounts of granodiorite (Tyebally Fazle Hussein, 1977). Granite at Paka, to the NE of the study area has been dated as Triassic, whilst that at Chukai is early Triassic and that at Kemaman is Permian (Azman, 2009).

## RIVER CAPTURE

An anomalous feature of the geomorphology and geology maps is the presence of Simpang Formation sediments in an area where rivers are now not present, i.e., the topographically low (<15 m elevation) drainage divide between the south flowing S. Ladang Tan, and the

**Table 3:** Log borehole C – Drainage divide S. Semayur and S. Ladang Tan (RL≈12.0 m).

| Depth (m) | Description | Interpretation |
|---|---|---|
| 0.0-2.4 | Very loose, brown silty Sand & organic matter. N=1 | Surface wash & Soil |
| 2.4-4.0 | Loose, brown & grey, medium to coarse, Sand. N=9 | Simpang Formation |
| 4.0-5.1 | Medium dense, pale grey, medium Sand. N=11 | |
| 5.1-8.5 | Soft, pale brown, very sandy Clay. N=5; 7 | Palaeosol |
| 8.5-11.0 | Medium dense, pale grey, silty Sand. N=17; 12 | Completely to moderately weathered Granite |
| 11.0-13.0 | Dense, greenish grey, silty fine Sand. N=35 | |
| 13.0-15.5 | Dense, pale grey, silty fine Sand with some gravel. N=>50 | |
| 15.5-18.4 | Grey, fractured, Granite with chlorite on joints. RQD=0% | Weathered Granite |

**Table 4:** Log borehole D – Terrace – East of Kg. Payuh (RL=10.4 m).

| Depth (m) | Description | Interpretation |
|---|---|---|
| 0.0-4.0 | Loose, brownish, silty medium to coarse, angular Sand. N=8 | Simpang Formation |
| 4.0-6.0 | Soft, pale brown & grey, silty sandy Clay. N=7 | Palaeosol |
| 6.0-8.7 | Soft, pale brown & grey, silty sandy Clay. N=5 | Completely to moderately weathered Granite |
| 8.7-9.5 | Medium dense, greenish, clayey silty Sand. N=13 | |
| 9.5-15.0 | Dense, greenish, silty fine Sand. N=>50 | |
| 15.0-18.0 | Fractured Granite with iron-stained joints. RQD=0% | Weathered Granite |

north flowing S. Semayur (Figures 3 and 4). A borehole here (borehole C in Figure 4) shows an upper, 2.4 m thick, loose, silty sand (surface wash sediments and soil) overlying a 2.7 m thick sequence of medium dense, sand (Simpang Formation) that overlies in turn a 3.4 m thick, soft, brown, sandy clay layer (Table 3). This soft, brown sandy clay layer is interpreted to be a palaeosol for it overlies 7.0 m of dense to very dense, silty fine sand, representing moderately to completely weathered granitic bedrock. Identification of the palaeosol indicates sub-aerial exposure and operation of pedological processes on weathered granite before deposition of the Simpang Formation.

Drainage patterns in the study area furthermore, have suggested that S. Tumpat and S. Kandang Rusa could have been tributaries of S. Payuh if they had flowed south through S. Semayur into S. Ladang Tan (Section 3). The Simpang Formation sediments in the drainage divide could then have been deposited during southward flow of S. Semayur; cessation of flow occurring when there was river capture (stream piracy). River capture has in fact, been earlier proposed to explain the contrary flow directions of S. Tumpat (in the N), and S. Kandang Rusa (in the NE); these rivers (and their tributaries) having been captured by, and now forming the headwaters of, the east flowing S. Kemasik (Section 3).

The site of river capture is distinctly seen on topographic maps; the elbow of capture located in the flat-bottomed, infilled valley to the immediate SE of Bt. Changkol where S. Tumpat flows through the N-S trending ridge in meta-sediments (Figure 6). Boreholes in this valley, and in similar valleys along the Kuantan–Kertih railway line, show the valley fill to be of a partly marine origin for shells and shell fragments have been seen at depths of between 5.5 and 8.5 m. The valley fill is therefore, of a Holocene age for sediments in the immediately fronting coastal plain have been mapped as the Holocene Gula Formation by JMG (Bosch, 1988). The Gula Formation is defined as the clay, silt and sand with minor amounts of gravel, shells and coral deposited in a marine environment after the most recent major low sea-level some 15 to 18 ka BP (Bosch, 1988; Kamaludin, 1989).

The Holocene age of the S. Tumpat valley fill, and coastal plain sediments, indicates that they were deposited during the global rise in sea-level (Termination I) from about -120 m at circa 20 ka BP (LGM) to some +5 m at the mid-Holocene high-stand at circa 5 ka BP (Parham, 2016). During the mid-Holocene high-stand, the S. Tumpat valley, and coastal plain, were inundated by the South China Sea; deposition of coastal and marine sediments giving rise to the Gula Formation.

From the available geological and geomorphological evidence therefore, it is concluded that S. Tumpat and S. Kandang Rusa once flowed south through S. Semayur into S. Ladang Tan and then into S. Payuh (Figure 6) which drained into S. Kemaman and into the South China Sea. The N-S trending ridge in meta-sediments was then continuous and

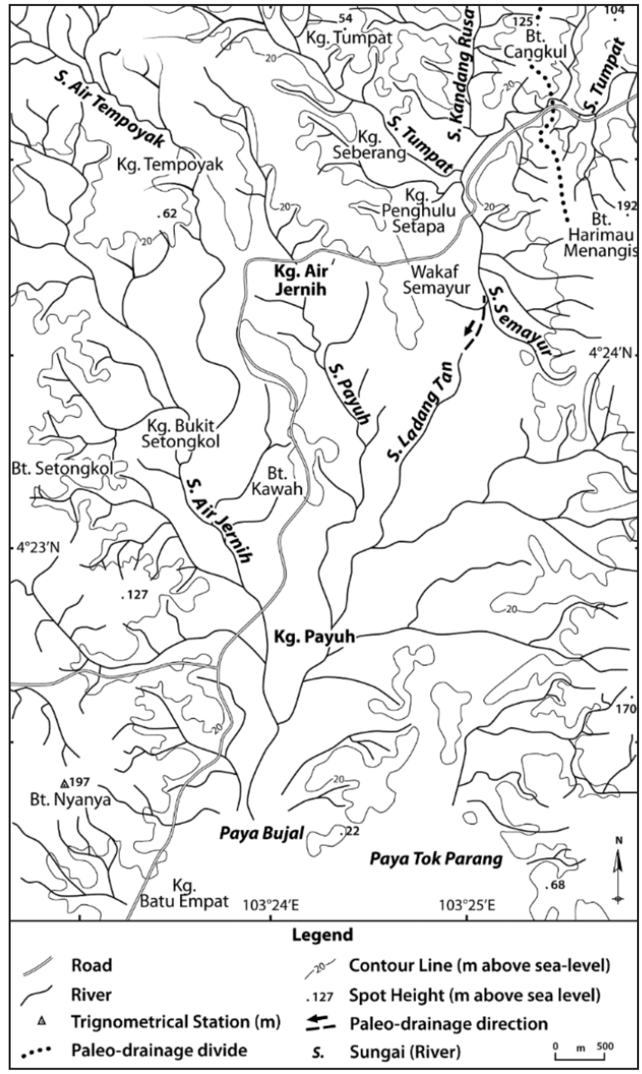


**Figure 6:** Palaeo-drainage of the Kampung Air Jernih area.

formed the eastern palaeo-drainage divide for rivers in the study area (Figure 6). In view of the Holocene age of the S. Tumpat valley fill sediments, it is also concluded that this palaeo-drainage system was in existence during the early stages of the last glacial period; the drop in global sea-level (Alqahtani *et al*., 2015) from some +6 m (circa 120 ka BP) to -120 m (circa 20 ka BP) giving rise to headward erosion by S. Kemasik and capture of S. Tumpat, S. Semayur and S. Kandang Rusa.

## DENUDATIONAL CHRONOLOGY

### Impacts of global sea-level changes

Global sea-level changes influence the development of landforms as they indirectly or directly impact several geomorphological controls as the base-level of erosion of rivers. Falling sea-levels will result in the lowering of base levels of erosion of rivers, and their down-cutting or incision into their floodplains, whilst rising sea-levels will lead to their deposition of sediments and aggradation.

The well documented, global sea-level rise (Termination I) from some -120 m at circa 20 ka BP to the mid-Holocene high-stand of +5 m (circa 5 ka BP) has thus been considered responsible for deposition of the Holocene Gula Formation sediments in the study area and adjacent coastal plain (Section 5). The global sea-level fall from about +6 m (circa 120 ka BP) to -120 m (circa 20 ka BP) during the last glacial period has furthermore, been considered responsible for the formation of river terraces, as well as headward erosion of S. Kemasik and river capture, in the study area (Section 5). Extending these interpretations thus leads to the contention that the global sea-level rise (Termination II) from some -120 m at circa 140 ka BP (Penultimate Glacial Maximum or PGM) to the high-stand of +6 m at circa 120 ka BP led to deposition of Simpang Formation sediments in the study area.

Global sea-level changes also result in variable areas of sub-aerially exposed continental shelf and different distances of inland sites from coastlines. Low global sea-levels result in large areas of sub-aerially exposed continental shelf, and substantial distances of inland sites from coastlines, whereas high sea-levels result in minimal areas of exposed continental shelf and small distances of inland sites from coastlines. In the case of the Sunda Shelf for example, the 120 m bathymetric contour is presently located some 600 km off the East Coast of the Peninsula, whilst the 60 m bathymetric contour is about 200 to 300 km distant. During the LGM (circa 20 ka BP) and PGM (circa 140 ka BP) when global sea-level was some -120 m (Alqahtani *et al*., 2015; Railsback *et al*., 2015), the study area would have been about 600 km from the then South China Sea coastline. During the mid-Holocene high stand (circa 5 ka BP), however, when sea-level was about +5 m (Parham, 2016), the study area would have been about 3 km from the then coastline. From circa 30 ka BP to circa 20 ka BP, Sundaland is said to have been sub-aerially exposed to its maximum extent; this large continent being about double the current land area, though coalescence of many modern islands resulted in reduction of the coastline length by some 50% (Bird *et al*., 2005).

Global sea-level changes and variations in areas of sub-aerially exposed continental shelf can be expected to impact climates at inland sites; Verstappen (1975; 1997) proposing that climatic variations of great magnitude occurred in SE Asia during the Quaternary when glacial and inter-glacial periods alternated at higher latitudes. These climatic variations were attributed to shifts in the Inter-Tropical Convergence Zone (ITC) as well as global changes in air and sea-water temperatures, and the emergence of the Sunda and Sahul Shelves during the glacial periods. Drier conditions with lower precipitation values and longer dry seasons were thus considered to prevail in Malesia during the glacial periods (Verstappen, 1975; 1997).

A review of available evidence from geomorphology, palynology and biogeography as well as vegetation/climate modelling has concluded that a N-S savanna corridor existed through Sundaland at times of low global sea-level during the last glacial period (Bird *et al*., 2005). This savanna corridor was some 50-150 km wide and formed a land-bridge between the Malay Peninsula and the islands of Sumatra, Java and Borneo. The savanna corridor was said to connect similar open vegetation types north and south of the equator, and provided a convenient route for the rapid early dispersal of modern humans through the region and on into Australasia (Bird *et al*., 2005).

Geomorphic evidence indicating drier, more seasonal climates in Sundaland during glacial periods in the later Quaternary, is said to include the thick boulder beds, braided river and alluvial fan sediments of the Older Sedimentary Cover deposited widely in Malaysia and Indonesia during the Late Pliocene and early Pleistocene (Verstappen, 1975; 1997; Batchelor, 1979). Other geomorphic evidence that has been cited, includes active slope pediment formation and coarse valley fill sediments deposited by braided stream systems, indicating more seasonal and arid environments, rather than the valley incision characteristic of rivers in humid tropical environments (Bird *et al*., 2005). Interpretation of this evidence is said to indicate that vegetation at the time of sediment deposition was relatively sparse savanna-woodland that allowed seasonally heavy rains to erode large quantities of sediment from upland regions, temporarily depositing them in river valleys during dry periods (Verstappen, 1997; Bird *et al*., 2005).

Glacial periods in the northern hemisphere have also been found to be characterized by intensified winter-monsoon, and weakened summer-monsoon, circulations in SE Asia, but strengthened summer-monsoon, and weakened winter-monsoon, winds during the Holocene and other inter-glacial periods (Wang *et al*., 1999; Liu *et al*., 2003). Pollen assemblages in a 504 m long core in the northeastern South China Sea furthermore, show that grasslands covered the exposed northern continental shelf during the cooler and drier glacial periods, though tropical and subtropical evergreen forest and mangrove still survived in coastal areas (Sun *et al*., 2003).

### Circa 500 ka to circa 140 ka BP

Global sea-levels have varied throughout the Quaternary, but did not reach nor exceed the present-day level from circa 500 ka to circa 140 ka BP (Marine Isotope Stages 13a to 6a) (Alqahtani *et al*., 2015; Railsback *et al*., 2015). During this period, denudational processes were predominantly operative in the study area; fluvial depositional processes minimal or absent as the base level of erosion of rivers was below the minimum ground elevation of 5.5 m above sea-level (Table 5). Weathering processes therefore, led to pedological soils and saprock (weathered bedrock) in the study area.

The geomorphology of the study area at circa 500 ka BP is unknown, though the relatively thin Simpang, and Beruas, Formation sediments, and their distribution that is related to the present drainage pattern, suggests a landscape similar to that of the present-day. The study area at circa 500 ka BP is thus considered to consist of broad N-S trending valleys in granitic and meta-sedimentary bedrock with intermittent to perennial streams and moderately sloping valley sides. To the east, the study area was separated from the South China Sea by the N-S trending ridge in meta-sediments of the Sungai Perlis Beds; this ridge then forming a continuous drainage divide.

In view of its inland location, and considerable distance from the then coastlines, the study area likely experienced a tropical savanna climate from circa 500 ka to circa 140 ka BP; a climate similar to that proposed for SE Asia during the last glacial period (Verstappen, 1975; 1997; Bird *et al*., 2005). Relatively sparse, savanna-woodland vegetation was then likely present; the vegetation allowing seasonally heavy rains to erode large quantities of sediment from upland regions and depositing them downslope and in river valleys (Verstappen, 1997; Bird *et al*., 2005). Intermittent to perennial streams with very variable discharges due to seasonally distributed rainfalls were then present; the main rivers all flowing in a N-S direction.

### Circa 140 ka to circa 120 ka BP (Termination II)

From circa 140 ka (PGM) to circa 120 ka BP (Marine Isotope Stages 6a to 5e), there was a rapid rise in global sea-level (Termination II) from some -120 m to +6 m (Alqahtani *et al*., 2015). This rise in sea-level led to a corresponding rise in the base-level of erosion, and aggradation by the then N-S flowing rivers in the study area (Table 5). Decreasing areas of sub-aerially exposed Sunda Shelf furthermore, resulted in more continuous and heavy rainfalls and establishment of a tropical rainforest in the study area.

As the study area had a sparse savanna-woodland vegetation at the start of Termination II, the more continuous and heavy rainfalls would have led to extensive sheet wash and large volumes of sediments eroded from hill slopes; these sediments transported downslope and redeposited by braided rivers giving rise to the sediments now mapped as Simpang Formation (Figure 4). Interpreted palaeosols in borehole logs show that the Simpang Formation sediments were deposited on exposed ground surfaces in weathered granitic and meta-sedimentary bedrock (Tables 3 and 4). As the rivers were flowing in a N-S direction at this time, sands and gravels were deposited in the present-drainage divide between S. Ladang Tan and S. Semayur (Figure 6).

### Circa 120 ka to circa 20 ka BP

From circa 120 ka to circa 20 ka BP (Marine Isotope Stages 5e to 2), i.e., during the last glacial period in higher latitudes, there was a gradual but irregular, drop in global sea-level from a high of some +6 m to a low of about -120 m at the LGM (Alqahtani *et al*., 2015; Railsback *et al*., 2015). During this lowering of global sea-level, increasing areas of sub-aerially exposed Sunda Shelf resulted in a tropical savanna climate with more seasonal rainfalls in Sundaland (Bird *et al*., 2015). Denudational processes were thus predominantly operative in the study area with weathering processes giving rise to pedological soils and saprock (weathered bedrock) in undulating to hilly terrain (Table 5).

Lowering of global sea-level (and the associated lowering of base-level of erosion) would furthermore, have led to rivers down-cutting into their floodplains and isolating the landforms now mapped as river terraces (Figure 3). Down-cutting and headward erosion by the east-flowing S. Kemasik through the N-S trending ridge in meta-sediments on the east during this period furthermore, led to capture of S. Tumpat, S. Semayur and S. Kandang Rusa and their tributaries (Section 5). The shorter distance to the South China Sea for these rivers via S. Kemasik (rather than the longer distance via S. Payuh and S. Kemaman) is likely to have been the main reason for their capture. Following river capture, S. Semayur flowed northwards and a new drainage divide was created in the low-lying terrain between S. Semayur and S. Ladang Tan (Figure 6). The present-day drainage system and drainage divides were thus established by the end of this period at circa 20 ka BP (LGM).

### Circa 20 ka to circa 5 ka BP (Termination I)

From circa 20 ka to circa 5 ka BP (Marine Isotope Stages 2 to 1), there was a gradual rise in global sea-level (Termination I) from the LGM low at some -120 m to the mid-Holocene high-stand of +5 m (Alqahtani *et al*., 2015; Railsback *et al*., 2015). A corresponding rise in the base level of erosion thus led to aggradation by rivers in the study area and deposition of the Beruas Formation sediments underlying the present-day floodplains and swamps (Figure 4). The rise in global sea-level also resulted in an increasing area of the South China Sea and decreasing distances of the study area from coastlines. This then led to more continuous and heavy rainfalls in the study area, giving rise to a humid tropical climate and establishment of a tropical rainforest.

During Termination I, the present-day (but then non-existent) coastal plain fronting the N-S trending ridge in meta-sediments and the valleys of S. Kemasik and S. Tumpat were inundated by the South China Sea. This then led to deposition of the coastal and marine sediments of the Gula Formation. At the mid-Holocene high-stand furthermore, the coastline was located close to the inland edge of the coastal plain, where two sets of beach ridges are now seen and mapped as the Matang Gelugur Member of the Gula Formation (Bosch, 1988).

### Circa 5 ka BP to present-day

The most recent, well documented global sea-level change is the gradual drop from the mid-Holocene high-stand of +5 m at circa 5 ka BP to the present-day level at about 1 ka BP (Parham, 2016). This drop in sea-level, which resulted in lowered base levels of erosion, thus led to down-cutting (incision) by rivers into their floodplains in the study area (Table 5).

**Table 5:** Denudational chronology of the Kampung Air Jernih area.

| Period | Marine Isotope Stages (MIS) / Global Sea-Levels & Impacts | Kg. Air Jernih Area |
|---|---|---|
| Circa 500-140 ka | a) MIS 13a-6a.<br>b) Varying global sea-levels, but always lower than present level.<br>c) Large areas sub-aerially exposed Sunda Shelf.<br>d) Inland sites far from then coastlines. | a) More arid climate with seasonal rainfalls.<br>b) Tropical savanna climate.<br>c) Savanna woodland vegetation.<br>d) Denudational processes predominant.<br>e) Main rivers flowing N-S.<br>f) Braided rivers. |
| Circa140 ka | a) MIS 6a (Penultimate Glacial Max.).<br>b) Global low sea-level (-120 m). | a) Tropical savanna climate.<br>b) Savanna woodland vegetation. |
| Circa 140-120 ka | a) MIS 6a-5e (Termination II).<br>b) Rapidly rising global sea-level.<br>c) Decreasing areas sub-aerially exposed Sunda Shelf.<br>d) Inland sites close to then coastlines. | a) Wetter & less seasonal climate.<br>b) Tropical rainforest climate.<br>c) Tropical rainforest vegetation.<br>d) Aggradation by N-S flowing rivers.<br>e) Deposition Simpang Formation. |
| Circa 120 kPa | a) MIS 5e.<br>b) Global high sea-level (≈+6 m). | a) End deposition Simpang Formation.<br>b) Tropical rainforest vegetation. |
| Circa 120–20 ka | a) MIS 5e-2.<br>b) Irregular but gradual drop in global sea-level.<br>c) Drop in base level of erosion of rivers.<br>d) Increasing areas sub-aerially exposed Sunda Shelf.<br>e) Inland sites far from then coastlines. | a) More arid climate with seasonal rainfalls.<br>b) Tropical savanna climate.<br>c) Savanna woodland vegetation.<br>d) Terraces isolated by down-cutting rivers.<br>e) Headward erosion by S. Kemasik from east side cuts through N-S ridge.<br>f) S. Tumpat, S. Kandang Rusa & S. Semayur captured by S. Kemasik. |
| Circa 20 ka | a) MIS 2 (Last Glacial Maximum).<br>b) Global low sea-level (-120 m). | a) Tropical savanna climate.<br>b) Savanna woodland vegetation. |
| Circa 20-5 ka | a) MIS 2-1 (Termination I).<br>b) Rapidly rising global sea-level.<br>c) Decreasing area sub-aerially exposed Sunda Shelf.<br>d) Inland sites close to coastlines. | a) Wetter & less seasonal climate.<br>b) Tropical rainforest climate.<br>c) Tropical rainforest vegetation.<br>d) Aggradation by rivers.<br>e) Deposition Beruas Formation sediments.<br>f) Flood-plains developed.<br>g) Gula Formation deposited in S. Tumpat valley & coastal plain. |
| Circa 5 ka | a) MIS 1 (Mid-Holocene).<br>b) Global high-stand (≈+5 m). | a) End deposition sediments of Beruas & Gula formations. |
| Post circa 5 ka | a) Post MIS 1.<br>b) Sea-level drop to present level. | a) Incision of rivers into floodplains. |

Note: 1. Period in thousands of years (ka) BP (Before Present).
2. Marine Isotope Stage (MIS) after Railsback *et al*. (2015).

## SUMMARY AND CONCLUSIONS

Field mapping and interpretation of aerial photographs and topographic maps allowed differentiation of four main geomorphological units with distinctive subsurface earth materials in the Kampung Air Jernih area, i.e., (a) flood-plains and swamps over Holocene Beruas Formation sediments (5-8 m thick), (b) terraces over Pleistocene Simpang Formation sediments (3-6 m thick), (c) denudational terrain over meta-sediments of Carboniferous Sungai Perlis Beds, and (d) denudational terrain over Triassic granitic bedrock.

The flood-plains and swamps are some 6 to 8 m above mean sea-level and located adjacent to the three main rivers that drain the area, i.e., (a) the east flowing Sungai Tumpat and its tributaries in the northern sector, (b) the south flowing Sungai Payuh and its tributaries in the central and eastern sectors, and (c) the south flowing Sungai Air Jernih and its tributaries in the western sector. The terraces occur as isolated to continuous stretches of flat to gently sloping (<6°) ground that flank the floodplains and are some 9 to 15 m above mean sea-level. The Simpang Formation sediments underlying the terraces have textures and structures that indicate deposition by braided rivers.

Denudational terrain over the Sungai Perlis Beds is seen in the eastern sector where strongly to steeply sloping (>6°) ground surfaces give rise to a broad, N-S trending ridge in inter-bedded sequences of carbonaceous phyllite, argillite, shale, meta-sandstone and meta-siltstone. Denudational terrain over granitic bedrock is seen in the central, western and northern sectors where strongly to steeply sloping (>6°) ground surfaces form low hills and ridges over a weathered, grey, porphyritic to non-porphyritic, granite.

Correlating the development of landforms with Quaternary global sea-levels indicates that from circa 500 to circa 140 ka (MIS 13a-6a), the study area experienced a tropical savanna climate and was covered by savanna-woodland. At this time, the main rivers all flowed south with the N-S trending ridge in the east forming a continuous drainage divide. Denudational processes were predominant and gave rise to pedological soils and saprock (weathered bedrock) in undulating to hilly terrain.

From circa 140 to circa 120 ka BP (MIS 6a-5e), the rapid rise in global sea-level (Termination II) first resulted in deposition of sands and gravels of the Simpang Formation by braided streams, followed by gradual establishment of a tropical rainforest climate. From circa 120 to circa 20 ka BP (MIS 5e-2), the gradual, but irregular, drop in global sea-level resulted in down-cutting by rivers and isolation of river terraces under a tropical savanna climate. Down-cutting and headward erosion by S. Kemasik through the N-S trending ridge in meta-sediments during this period then led to capture of S. Semayur, S. Tumpat and S. Kandang Rusa and their tributaries. The present-day drainage system and drainage divides were thus established by circa 20 ka (LGM).

From circa 20 ka to circa 5 ka BP (MIS 2-1), the rise in global sea-level (Termination I) led to establishment of a tropical rainforest climate and deposition of Beruas Formation sediments. Coastal and marine sediments of the Gula Formation were also deposited during this period when the coastal plain and S. Tumpat valley were inundated by the S. China Sea at the mid-Holocene high-stand. From circa 5 ka BP to the present-day, the gradual drop in global sea-level has resulted in rivers down-cutting into their floodplains.

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## CONFLICTS OF INTEREST

The author has no conflicts of interest to declare that are relevant to the contents of this article.

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