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Geology of Kota Kinabalu and its implications to groundwater potential

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Abstract: The increasing population in Kota Kinabalu is proportional to the demand for water resource. Groundwater is a primary concern because it is the most economical source of water supply. The main objectives of this paper are (1) to evaluate the groundwater resources in the study area, and (2) to study the effects of geology on groundwater.

Kota Kinabalu is underlain by the Late Eocene-Lower Miocene Crocker Formation and Quaternary Alluvium. The Crocker Formation is composed of sandstone, shale and an interlayered sandstone-siltstone-shale sequence. The study area is controlled by heavy structural lineaments representing a complex history of folding, thrust, normal and wrench faulting. Movements along these structures strongly influence the geomorphology and groundwater distribution in Kota Kinabalu. The rocks within the fault zones are highly deformed, sheared, jointed, and fractured.

The geology of the study area indicates that only the sandstone units of the Crocker Formation and Quaternary alluvium can be considered significant groundwater reservoirs. The aquifers within the study area can be divided into three major groups based on host rock and structural parameters, as follows (1) aquifers of Quaternary Alluvium, (2) aquifers within the fault zones, and (3) aquifers of the sandstone units of Crocker Formation. The chemical and physical analysis of the Kota Kinabalu groundwater suggest a meteoric origin and an alkaline type of water.

Both the stratigraphic and structural settings favor a high potential groundwater resource in Kota Kinabalu. These settings facilitate the movement and circulation of groundwater within Crocker Formation and Quaternary Alluvium, affect the continuity of aquifers, enhance secondary permeability, as well as increase the storage capacities of the formations. Such settings also create confined and unconfined aquifer systems.

INTRODUCTION

The area of investigation covers portions of Kota Kinabalu along the western coast of Sabah (Fig. 1).

Geology has a fundamental influence on groundwater. The layered nature of the rocks in the study area makes stratigraphy an essential tool in the search for groundwater. It helps define the nature, location, and extent of aquifers. A knowledge of the depositional and erosional events may indicate the extent and regularity of water-bearing formations. Various combinations of geologic structures and stratigraphy may result in different groundwater systems (Faisal, 1989). However, rock fractures can be very important in increasing secondary porosity, improving storage capacity as well as enhancing permeability in otherwise impermeable rocks (Department of Water Resources, 1978, 1981).

The increasing population in Kota Kinabalu calls for an increase in the demand for water supply. Surface water which is affected directly by seasonal changes is insufficient to meet such demand. Groundwater becomes a primary concern because it is the most economical source of water supply. The main objectives of this paper are (1) to evaluate the groundwater resources in Kota Kinabalu, and (2) to study the effects of geology on groundwater.

STRATIGRAPHY

The exposed rocks in Kota Kinabalu vary in types and ages from Late Eocene-Lower Miocene sandstone and shale of Crocker Formation to very young alluvial materials which are still being deposited. The sedimentological and structural details are provided by Tongkul (1987).

Table 1 shows the composite stratigraphic column of the rock units exposed in the study area and their water-bearing properties. For the present study, several localities were visited and semi-detailed sectioning was conducted to evaluate the stratigraphic and structural controls on groundwater potential (Figs. 2 and 3).

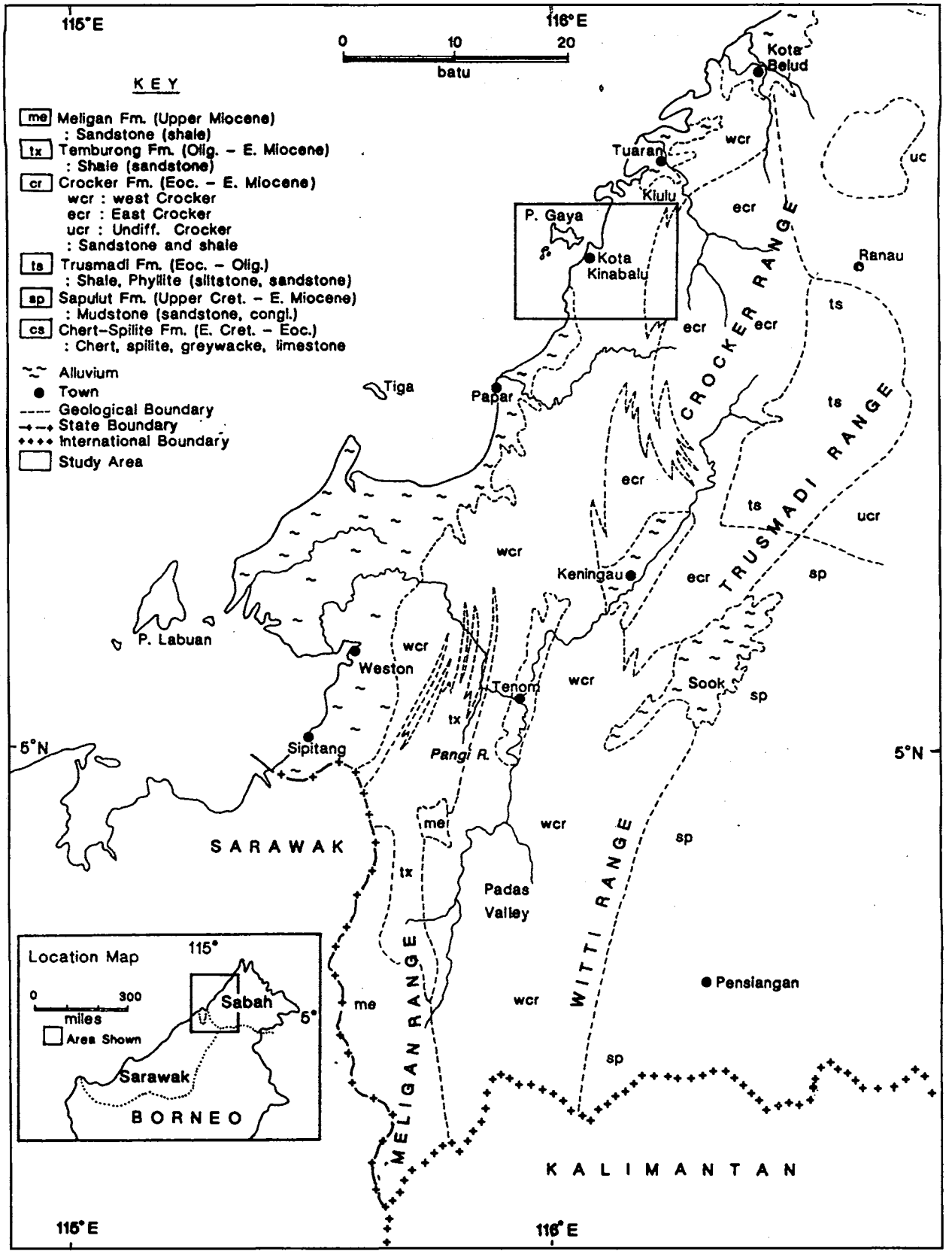

Figure 1. Geological map of western Sabah (modified from Wilford, 1967).

Table 1. Local stratigraphic column.

AGE	ROCK FORMATION	UNIT	GENERAL CHARACTER	WATER-BEARING PROPERTIES
Quaternary	Alluvium	–	Unconsolidated gravel, sand and silt with minor amounts of clay deposited along the rivers or streams and their tributaries. Includes natural levee and flood plain deposit.	Gravelly and sandly, portions are highly permeable and yield large quantities of water. Important to groundwater development.
Late Eocene to lower Miocene	Crocker Formation	Shale	This unit composed two types of shales red and grey. It is a sequence of alteration of shale with siltstone of very fine.	It has no significant to ground water development due to its impermeable characteristic.
		Shale-sandstone interbedded	It is a sequence of interlayering of permeable sediment sandstone with impermeable sediment of shale. The permeability of this unit is quite variable. Ground water in this unit tend to be under semi-confine to confine system.	Little importance to ground water provide some water but not enough for ground water development.
		Sandstone	Light grey to cream colour, medium to coarse grained and sometime pebbly. It is highly folded, faulted, jointed, fractured occasionally cavemous, surficially oxidized and exhibit spheroidal weathering.	Importance to ground water.

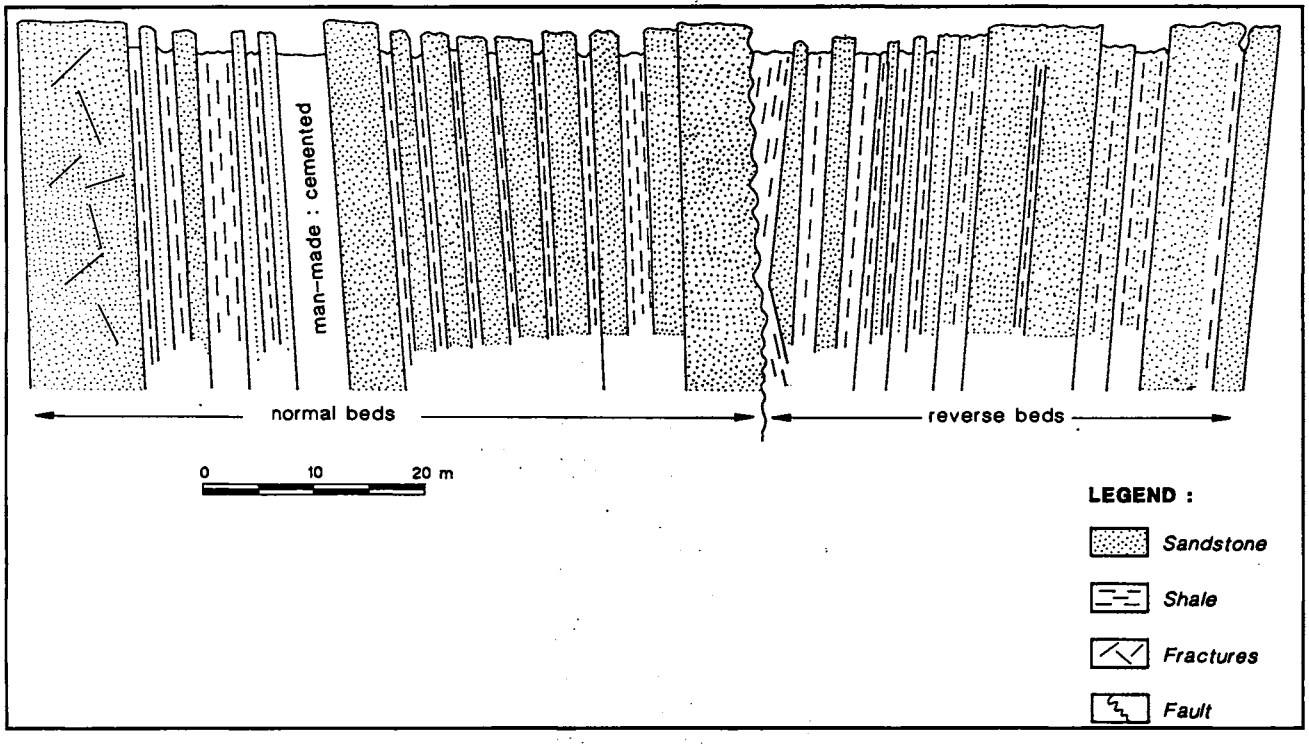

Figure 2. Geologic section — Donggongon.

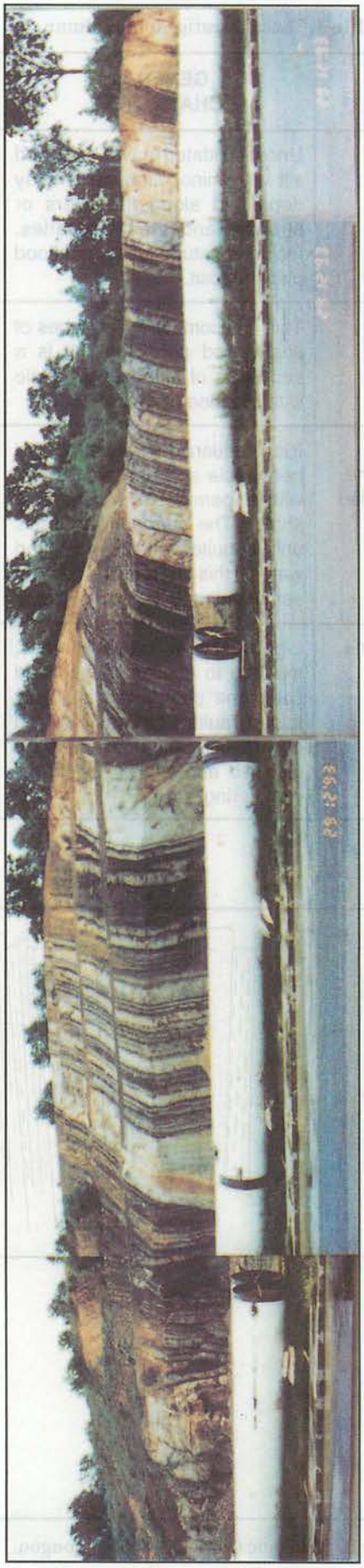

Figure 3. Steeply dipping outcrop repetitions sequence of sandstone and interbedded sandstone and shale. Location: Donggongon, Kota Kinabalu.

Crocker Formation

The study area is generally underlain by the Late Eocene-Lower Miocene Crocker Formation (Fig. 2). It is a submarine fan to basin plain deposit composed of three units of sandstone, shale and the interlayered sandstone-siltstone-shale.

Sandstone Unit

The sandstone unit is the thickest unit in the Crocker Formation. Individual bed thickness exceed 4 meters and occasionally reach a maximum of 25 meters. It is light grey to cream coloured, medium to coarse-grained, and sometimes pebbly. It is highly folded, faulted, jointed, fractured and occasionally cavernous. It is surficially oxidized and exhibit spheroidal weathering. The sandstone occasionally exhibits an incomplete Bouma's sequence starting from graded bedding at the base, followed by parallel lamination and topped by siltstone and shale. The other sedimentary structures observed within the sandstone are mud or clayballs, carbonaceous laminations and cross laminations. In some localities, the sandstone has a pebbly base and displays graded bedding. Thin shale or siltstone layers between 3–30 cm thick occur in-between the thick sandstone beds. The argillaceous layers are frequently sites of shearing while the sandstone beds sites of fracturing or jointing (Fig. 4). The outcrops may be cut by reverse faults resulting in overturned beds.

Petrologic analysis show that the sandstone composition is dominated by quartz with subordinate amounts of feldspars and chloritized, illitized or silicified lithic fragments. Calcareous fractions are rare. These are poorly sorted and well compacted with the pores filled by finer-grained detritus or squeezed lithoclasts resulting in very low to nil primary porosity.

Sandstone-Siltstone-Shale Unit

This unit is defined by an alternating sequence of sandstone, siltstone and shale of variable thickness and ratio. The sandstone beds are fractured and highly jointed while the shale layers sheared (Fig. 5).

Shale Unit

This unit is generally composed of red and grey types of shale. The grey variety is occasionally calcareous. This alternating sequence is commonly interbedded with siltstone or very fine-grained sandstone. The shale comprises about 12% of the total volume of Crocker Formation (Fig. 6).

Quaternary Alluvium

The Quaternary Alluvium is restricted to the low lands of Kota Kinabalu. It is mainly represented by unconsolidated alluvial sediments on river terraces and floodplains consisting of varying proportions of unsorted to well sorted gravel, sand, and silt with minor amounts of clay which were derived from the upstream bedrock.

STRUCTURES

The present geologic structural investigations (Fig. 7) based on photogeologic interpretations and field observations reveal that the study area is controlled by heavy structural lineaments mainly represented by major folds, thrust, normal or wrench faults, and sheared zones. These observations confirm Tongkul's (1987) earlier work that the structures are closely associated with each other and often difficult to separate and describe individually. Movements along these structures strongly influence the geomorphology of the study area. Several secondary faults and fracture systems can be observed traversing the major fault zones and their vicinities. The rock formation within the fault zones and vicinities are highly deformed, sheared and controlled by heavy joints and fractures resulting from major thrusting. This complex structural setting is related to the multi-stage tectonism during the Late Oligocene to Late Miocene structural evolution of the South China sea basin. These events are evident in a middle Late Miocene two-phase folding comprised of an older north-south - trend followed by a broad northeast-southwest orientation. The latter is related to the Crocker Thrust. Superimposed on this structural fabric are Late Miocene east-west trending but relatively gentle folds.

HYDROGEOLOGY

Recharge of Groundwater

The groundwater in the study area is recharged by the infiltration of rainwater through the following media: (1) permeable soil and rock cover, (2) irrigated lowlands, and (3) fault surface. Groundwater supply is also supplemented by stream percolation and by seepage from rice paddies. Stream and deep percolation of rainfall combine to provide a greater amount of recharge than does irrigation water. Recharge by subsurface inflow is considered negligible compared to other sources.

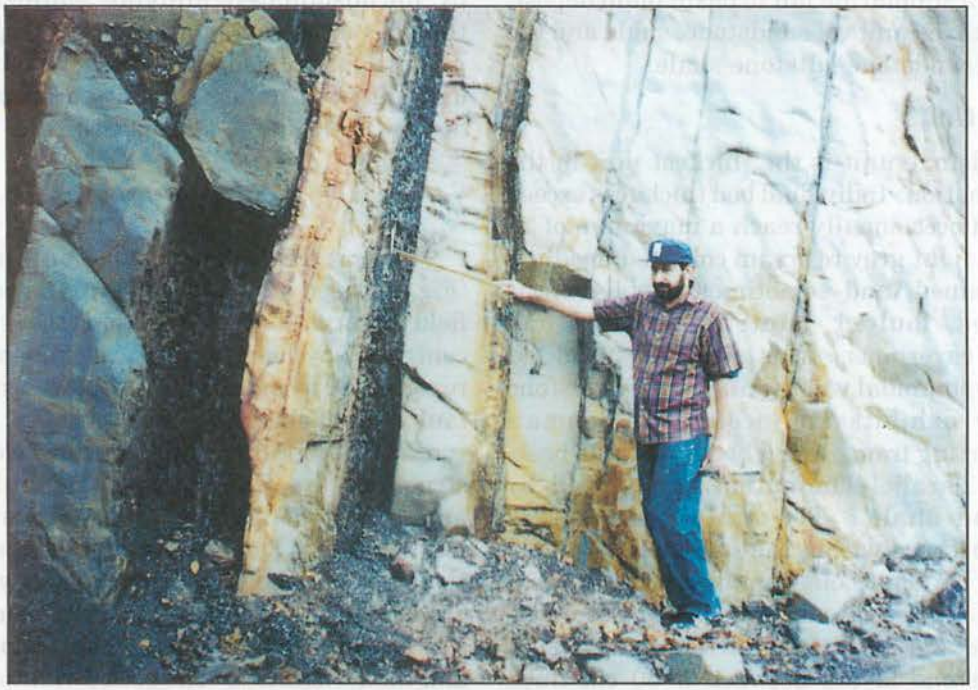

Figure 4. 11 cm thick highly sheared shale; Sandstone jointed or fractured. Location: Donggongon, Kota Kinabalu.

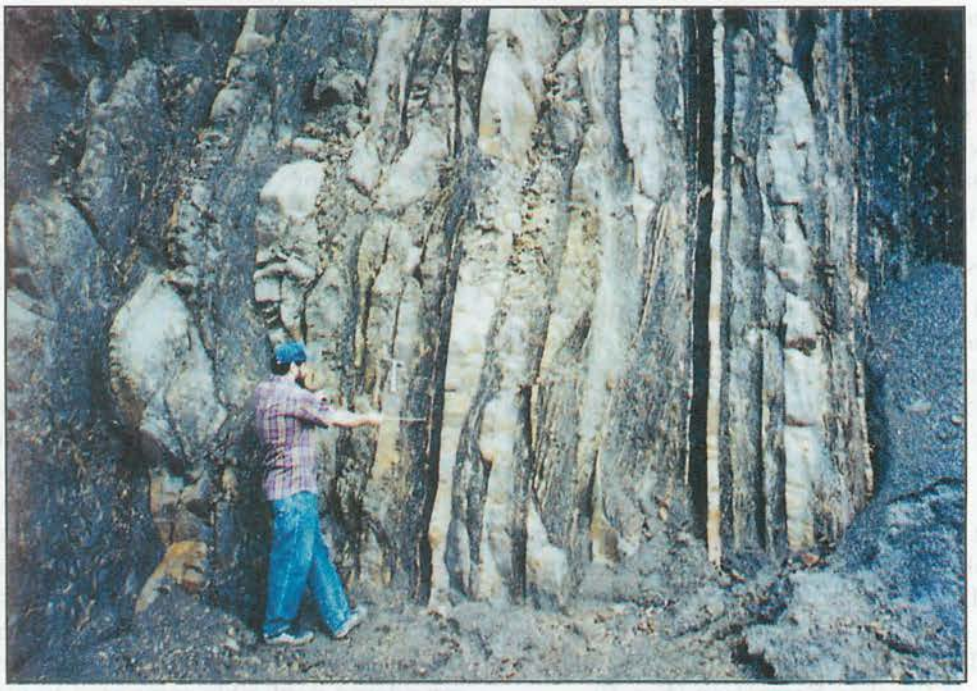

Figure 5. Thinly to medium interbedded sandstone and shale. Location: Donggongon, Kota Kinabalu.

Discharge of Groundwater

Discharge from aquifer occurs naturally in the following ways: (1) transpiration through vegetation, (2) direct evaporation from saturated zones, (3) return to surface drainage through seepage and spring, (4) outflow to the sea, and (5) extraction.

Occurrence of Groundwater

The geology of the study area indicates that only the Quaternary Alluvium and the sandstones of the Crocker Formation can be considered as important groundwater reservoirs. The gravel and sand layers with variable thickness define the major aquifer within the alluvium. Shallow clay beds occasionally act as aquicludes resulting in artesian conditions in some cases.

The permeable sandstone beds of Crocker Formation occur as irregular masses intercalated with impervious beds of siltstone and shale. These units constitute the principal sources of groundwater in Kota Kinabalu. Shale beds or lenses found locally within the sandstone may be extensive enough to separate water-bearing layers into several aquifers. Although cementation and compaction within the Crocker Formation have greatly reduced the primary porosity and permeability of the sandstone units, fracturing related to fault zones have provided secondary permeability subsequently increasing their groundwater productivity. The structural control is manifested in the free movement of groundwater was observed in the open joints and fractures in sandstone outcrops. Groundwater also flows freely along the sandstone-shale contact Moss growths along these planes further indicate water seepage.

Aquifers and their Characteristics

The major aquifers in Kota Kinabalu consist of various layers of gravel and sand within the Quaternary Alluvium and sandstone within the Crocker Formation. The aquifers can be divided into three major groups based on host rock and structural parameters as follows (1) aquifers of Quaternary Alluvium, (2) aquifers of the sandstone units of Crocker Formation, and (3) aquifers within the fault zones.

The permeable layers are interbedded or intertounge with argillaceous layers resulting in unconfined to semi-confined aquifer systems within the alluvium, and unconfined to semi-confined to confined aquifer systems within the Crocker Formation. The depths of the aquifers are variable

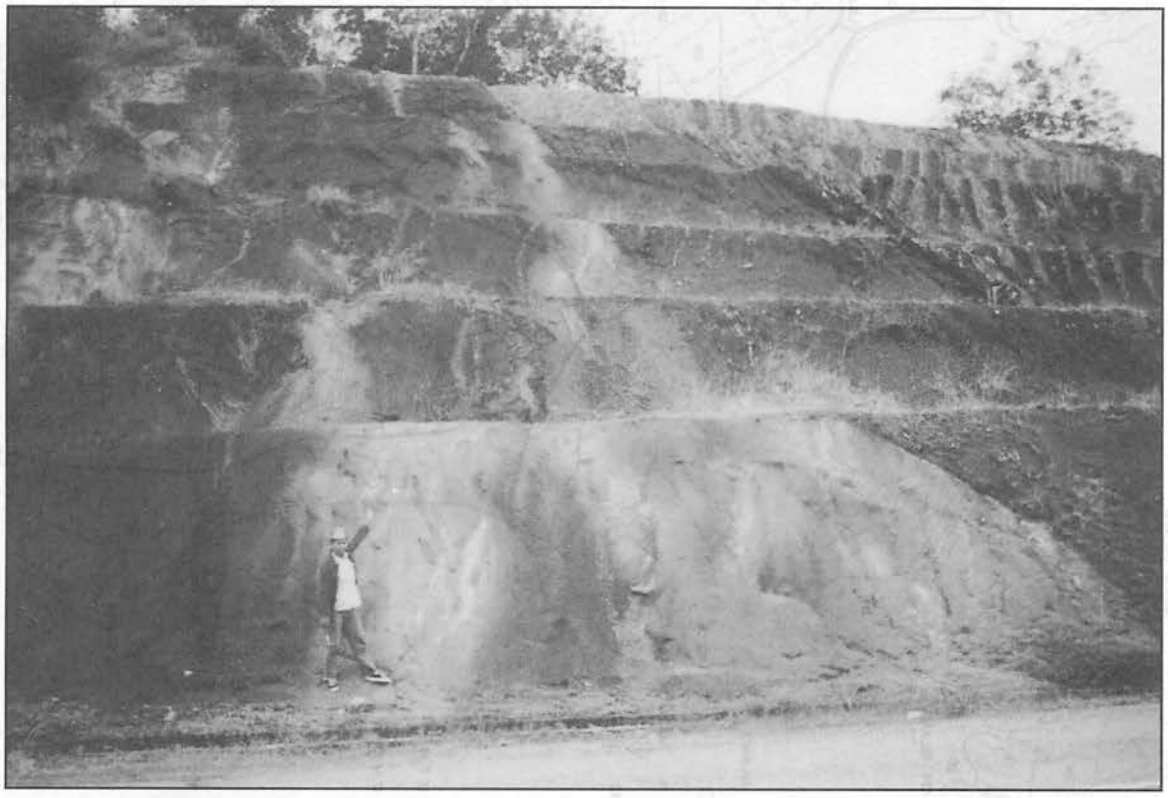

Figure 6. Highly sheared grey and red shale with occasional thin siltstone beds 20 m thick. Upper right: highly sheared grey shale interbedded with fractured sandstone; Shale > sandstone. Fault separating two units: thrust ? Strike N20E; 38SE dip. Location: Kiansom-Inanam Road between K-4 and K-5.

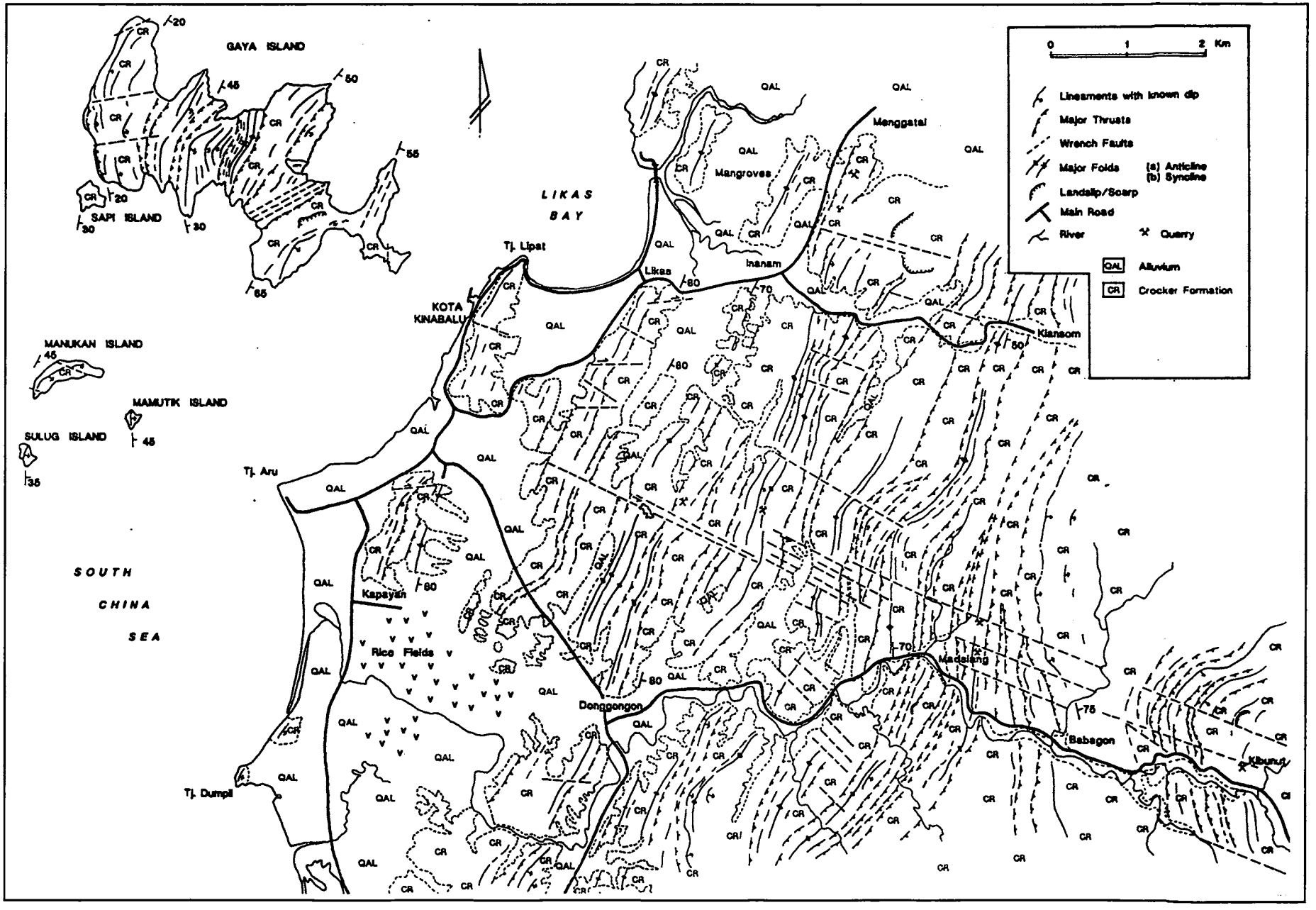

Figure 7. Structural map of the Kota Kinabalu area (after Tongkul, 1987).

even within a small locality due to differences in thickness of sediments and numerous displacements caused by the various types of faults in the study area. The alluvium and sandstones of Crocker Formation contain numerous aquifers of highly variable properties and continuities. The alluvial strata are probably more variable in terms of aquifer properties and their succession comprises of series of partly confined aquifers. The aquifers within the fault zones are quite variable in occurrence depending on the extent of fault movements. They usually consist of sandstone and crushed materials and are often mixed or interbedded with shale. The aquifers likewise occur in varying depths.

GROUNDWATER CHEMISTRY

Chemical and physical analysis of the groundwater samples (Table 2) collected from Crocker Formation indicate that the waters belong to the calcium bicarbonate and alkaline types. The former suggests a meteoric origin for the groundwater. The samples contain relatively high iron concentrations and is probably due to the presence of deep marine, oxidized, red shale.

CONCLUSIONS

Based on the present investigations, the following hydrogeological evaluations can be made in relation to the geological setting of Kota Kinabalu:

1. The stratigraphic and structural setting of Crocker Formation facilitates favorably the movement and circulation of groundwater within Kota Kinabalu. Such setting enhances secondary permeability as well as increases the groundwater capacity of the formation. It affects the continuity of aquifers by creating confined and unconfined aquifer systems.
2. The sandstone unit of Crocker Formation is a major source of groundwater. Most of the aquifers are under artesian conditions. Quaternary Alluvium is another important source of groundwater because of their natural distribution, thickness of aquifer, permeability and proximity to recharge area.

RECOMMENDATIONS

1. In as much as the present study covered Kota Kinabalu only, similar investigations should be conducted in other localities where the Crocker Formation is exposed to be able to observe and evaluate its groundwater potential and correlate future findings with the present data.
2. Seismic reflection, refraction and resistivity depth sounding surveys should be conducted in selected lines within the study area. These surveys will provide data on actual thickness of various layers which are still unknown since drilling has not penetrated sufficiently through the Crocker Formation.
3. Wells proposed within the study area should be sited within the following zones:
   a. Sandstone units of Crocker Formation and Quaternary Alluvium due to the availability of thick and permeable layers of coarse-grained materials.
   b. Along or within the fault zones and complimentary structures particularly in areas where the structures intersect rivers or streams. Such setting provides a direct recharge of the aquifers from the rivers or streams via the permeable fault zone.
   c. Along the lithologic contact of Crocker Formation and Quaternary Alluvium where good permeability is expected.

Table 2. Analysis of water samples collected from the study area.

Element/Property	P1	P2
pH	7.2	7.6
NO_2^- N (mg/l)	0.005	0.004
NO_3^- N (mg/l)	0.06	0.04
PO_4^3 (mg/l)	0.24	0.16
Cl^- (mg/l)	2.5	1.7
TSS (g/l)	0.027	0.005
Conductivity	0.20 mS	0.22 mS
Turbidity	30 + TU	27 + TU
Colour	195 (P + Co)	132 (P + Co)
SO_4 (mg/l)	1	1
NH_4	0.40	0.23
Na (ppm)	1.031	1.020
K	0.874	0.890
Ca	0.766	0.554
Mg	0.330	0.350
Fe	1.064	0.141
Pb	0.00	0.00
Cr	0.00	0.00
Cd	0.00	0.00

REFERENCES

DEPARTMENT OF WATER RESOURCES IN COOPERATION WITH U.S. GEOLOGICAL SURVEY, 1978. Evaluation of Groundwater Resources: Sacramento Valley. *Bulletin No. 118.6.*

DEPARTMENT OF WATER RESOURCES IN COOPERATION WITH SANTA CLARA VALLEY WATER DISTRICT, 1981. Evaluation of Groundwater Resources: South San Francisco Bay. *Bulletin No. 118–1.*

FAISAL, M., 1989. Effects of Marikina Faults on Groundwater. Ph.D. Dissertation, University of the Philippines.

TONGKUL, F., 1987. *Sedimentology and Structure of Crocker Formation in Kota Kinabalu Area, Sabah, East Malaysia.* Ph.D. Dissertation, University of London.

WILFORD, G.E. (compiler), 1967. *Geological map of Sabah, East Malaysia* 1:500,000, 2nd edn. Geological Survey of the Borneo Region, Malaysia.

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