# AQUIFER AND FERRIC SPRING DEPOSITS SOUTH OF MIRI, SARAWAK: IMPACT ON FACIES CHARACTERISATION OF COASTAL SEDIMENTS

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## ABSTRACT

Observations on artesian springs indicate the presence of at least three groundwater bodies that are chemically distinct. Artesian springs are observed from both high and low iron-content ground waters. $Fe^{2+}$ rich groundwater is rapidly oxidized at surface, and orange deposits of $Fe^{3+}$ minerals are precipitated. These are either parallel-layered, or form concentric ferric conglomerates in coastal caves. Once eroded, Fe-coated pebbles are scattered along the coast and embedded in recent sediments. Similar deposits are also seen in the Late Miocene Lambir and Miri formations. Field observations supportive the idea of a strong tidal influence on the dynamics of aquifers, and iron mobility in coastal areas. Re-deposition of the Fe in oxidized form could be in combination with other metallic cations, anions or even in chelated forms with organics. The reduction and movement of Fe in aquifers, and iron deposits (coated pebbles, filled burrows) could be linked to the facies signature of coastal Miocene rocks, as it does in present-day

sediments. This process might be related to the development of source rocks in coastal offshore deposits.

## INTRODUCTION

The areas south of Miri are characterized by a plateau, where young alluvial sediments overly the folded and monoclinally dipping Late Miocene to Pliocene Lambir and Tukau clastics (Fig. 1A). The uppermost two meters of the plateau sediment is formed by a dark iron oxide stained, and occasionally strongly bleached (podsolized) sand layer. Given that the clastics appear to have undergone several cycles of weathering and lithification, iron in these materials is evidently allochtonous. In addition, it has been often debated to what extent migration of iron-bearing fluids might contribute (directly or indirectly) to the creation of algal source rock in coastal and shallow offshore areas.

The current research was carried out to establish a possible link between fluctuations in ocean tides and the occurrence of springs within a distance of 2 km from the coastline. Another objective was directed to the question if iron deposits, as studied in recent sediments, might qualify as indicator for a specific facies environment.

## MATERIALS AND METHODS

The study area is located in the southern part of Miri, Sarawak. The rock formations here comprise the Mid-Late Miocene sedimentary beds of the Lambir and Tukau Formations that contain Fe-concretions or other forms of Fe accumulation. Representative rock and water samples were collected for evaluation, from the Mio-Pliocene sequences and the overlying plateau sands. Emphasis was given to recent spring deposits within the inter-tidal and supra-tidal realms.

Eight water samples were collected using new 250ml polypropylene containers between the hours of 6:30am and 10:00am on the same day. These were refrigerated and sent for analyses within 24 hours of collection. Most of the samples were brownish in color, a few were colorless. A simple analysis was carried out in the Sarawak Shell Berhad laboratory, but these data have not been released for publication to date. Therefore, the results of the analyses are not presented in this paper. Qualitative observations from 2005 onwards were carried out by the senior author on the brown slicks that were seen appearing on the Kampong Sewajaya lake, which is located ca. 7 m above sea level. The preliminary results of the ongoing study are presented here.

## RESULTS AND DISCUSSION

### Aquifers and Iron Migration

The area south of Miri receives some 5000 – 8000 mm of annual rainfall, which leads to a rapid washout of topsoil layers. As shown in Fig.1B, three aquifer layers are observed:

1. Seawater: changing from fully marine to brackish water, and even freshwater depending on the discharge of the Batang Baram; the rapid changes in salinity characterize an environment where only few species can survive;
2. A layer of groundwater, low in oxygen and rich in $Fe^{2+}$; this level is in pressure communication with the marine realm;
3. A shallow layer of very freshwater, the immediate filtrate from rainfall.

It is to be noted that the term artesian is used when groundwater rises in a well above the level where it was initially encountered (Lutgens and Tarbuck, 2006). This in turn can occur when either the aquifer is exposed to the surface at one end or aquitards are present on either side of the aquifer to prevent the water from escaping. In the study area, pressure-confining layers are formed by claystone layers within the Lambir and Tukau formations. However, the described artesian effect is not only caused by stratigraphy, but equally due to incision by river systems, resulting in elongated remnants of plateau that separate the shoreline from the (low-lying) hinterlands. The Fe-laden aquifers belong to these semi-isolated incised plateaus, and respond with an artesian flow-out, as soon as pressure builds up within the aquifer due to the rising tide

Where permeable sandstone is found in a crestal position, podsolization occurs. As shown in Fig. 2, the sand in the uppermost meters is often thoroughly bleached. $Fe^{2+}$ sulfides in near-surface black clay-stone beds are oxidized, with iron oxides, and smaller clay particles (coherent clay layers resist better) are being mobilized and removed. The iron could migrate to deeper aquifer levels in a process that is poorly understood in this locality, or be leached out onto surrounding areas, not excluding coastal areas.

Qualitative observations from 2005 onwards showed that at a given time of the day, brown slicks were seen appearing on the Kampong Sewajaya lake, which is located ca. 7 m above sea level. In the last year (2007/2008), a systematic check indicated that the appearance of the Fe-rich slick coincided with the onset of high tide, and was fluctuating with changes in tide-levels everyday. It can be concluded that there is no other known process that could cause this shifting pattern, apart from seasonal fluctuations and rainfall etc.

Observations have shown that the $Fe^{2+}$ rich water layer is hydraulically linked to the fluctuations in seawater levels. Artesian spring activity is seen coinciding with the high tide. As shown in Fig. 3, ferric slurry forms every day on the surface of a fishpond on the southern side of the Siwak Jaya plateau. As high tide approaches, tiny platelets of shiny or orange-colored iron oxide precipitates appear on the lake's surface.

Simple weight measurements (Fe-slurry water in comparison to clean tap water) indicate that the $Fe^{3+}$ oxide content is in the order of 6 g/liter. If allowed to dry, the voluminous orange precipitate forms a very thin coating of yellow-orange on any substratum, be it sand, wood, stone or even plastic bottles.

In the lake, the orange precipitate floats on the surface. After an hour or two, a gradual color change from orange to dark green is observed, possibly indicating a sudden algal bloom. Fresh orange-coated water is devoid of any smell; the greenish algal derivate, however, emits a strong organic smell (if left to decay in a sample bottle). Three hours later, the layer sinks to the pond's bottom and the surface is clear again. Potentially, this process (extrusion of iron-rich fluids, algal bloom, deposition) could lead to the formation of source rock, although further evidence is required to support this hypothesis. Variations in the color of the slurry indicate compositional changes that could range from metallic bonds to chelated forms.

Massive outpourings of stained groundwater also occur along the coastline, within or above the intertidal zone (Fig. 4A, 4 B). These waters mix with the incoming tide. Interestingly, the outflow of $Fe^{2+}$ rich fluids is nearly completely independent from precipitation events.

Clear artesian water, however, belongs to the shallowest aquifer, appearing shortly after strong rainfall. No iron-rich deposits originate from these springs.

**Contemporaneous Deposits**

Iron deposits are either layered (Fig. 5A), or concentric-nodular (Fig. 5B).
Layered deposits are characteristic for the supra-tidal realm, where there is little reworking, and the iron oxides can precipitate quietly and form layered carpets.
Nodular accretions and stained conglomerates, however, are formed in inter-tidal subterraneous caves. The coastline between the Tusan and Peliau beaches offers a large number of such caves showing a complete sequence of processes: deposition of iron-oxide precipitation; hardening as layers and coatings. Given the rapid contemporaneous erosion of the coastline, such caves are quickly eroded and iron-stained pebbles and broken-up iron-oxide layers are scattered along the beach by long-shore currents for several hundreds of meters, if not kilometers.

**Fossil Deposits**

The question remains as to how recent Fe-migration and Fe-deposits can be related to similar-looking features of Late Miocene age, found in deposits of the Miri and Lambir formations. These sediments have formed in coastal to shallow-marine settings, and the paucity of fossils (mainly ophiomorpha, occasionally bivalves, absence of echinodermata) suggests a deviation from a steno-haline environment (Fig. 6). Interestingly, the sandstone facies of the Miri formation are very rich in Fe-coated sand pebbles, and ophiomorpha burrows are filled by iron oxides. These suggest early diagenetic iron coating, as documented in the recent sediments. Lee and Taib (2006) concluded that the process of fossilization involving replacement by Fe should be very rapid in order to preserve corals as fossils. Similar situations are encountered in the study area where Fe-coating or replacement of fossils appears to occur within 12 months.

## CONCLUSIONS

The evidence provided in this paper is supportive of a strong tidal influence on the dynamics of aquifers, and iron mobility in coastal areas. Re-deposition of the Fe in oxidized form could be in combination with other metallic cations, anions or even in chelated forms with organics. The reduction of $Fe^{3+}$ forms to $Fe^{2+}$ forms and subsequent mobility in aquifers, and iron deposits (coated pebbles, filled burrows) could have characterized the facies signature of coastal Miocene rocks, as it does in present-day sediments – possibly serving as a distinct facies indicator. Equally, the above-described processes might be potentially related to the development of source rocks in coastal offshore deposits.

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Fig. 1A: Aerial view of the coastal section SW of Miri. Gently dipping sediments of the Miri and Tukau formations are overlain by terraces and young alluvial sediments upon two unconformities. The cover layer on terraces are often completely bleached, or alternatively, dark coated with iron oxides.

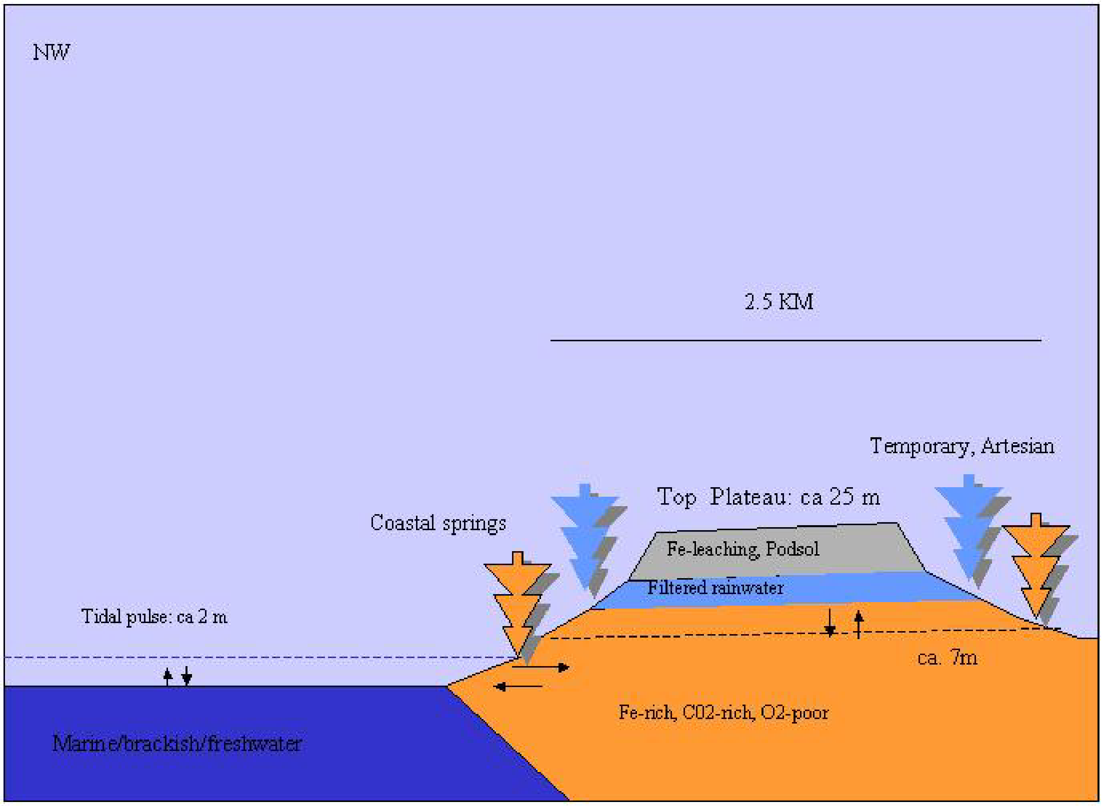


Fig. 1B: Simplified coastal NW-SE section, near Kampong Siwak Jaya.

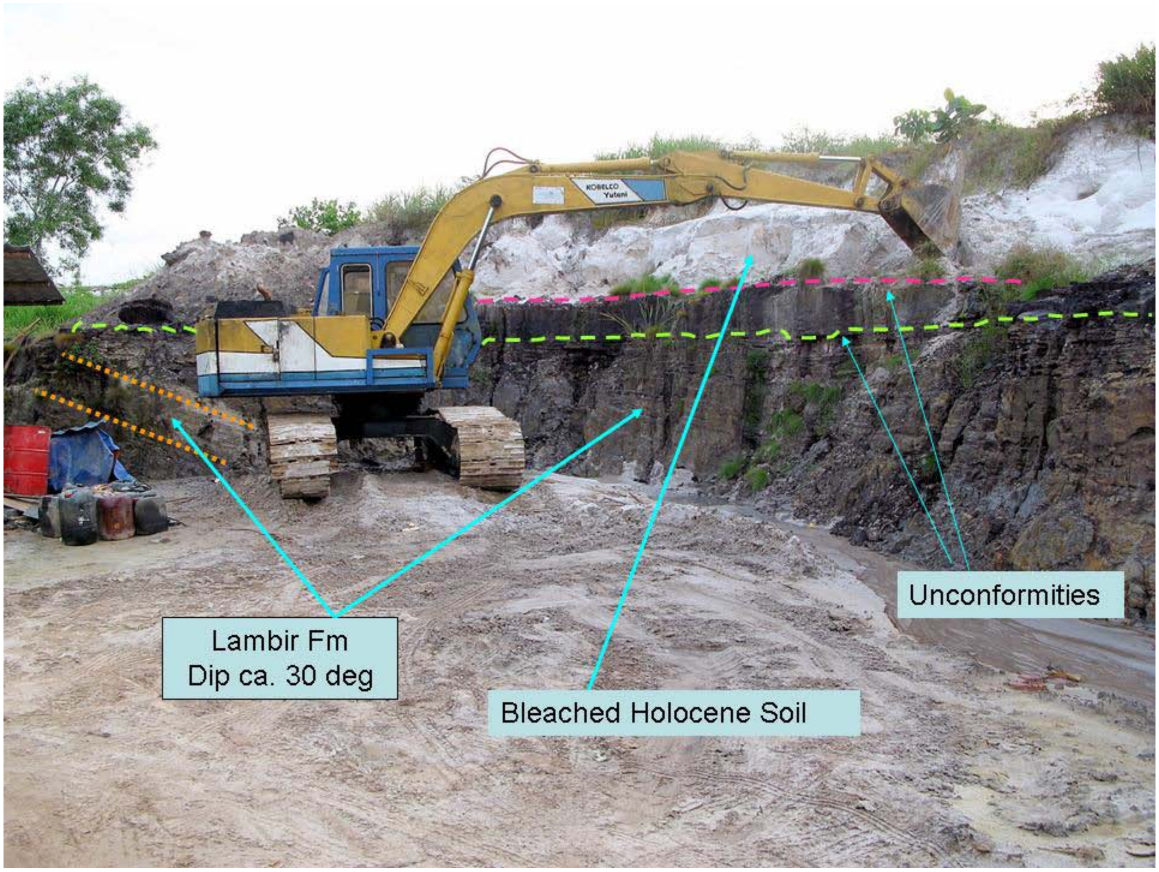


Fig. 2: Soil profile as seen in an outcrop of the Sungai Rait valley. The uppermost layer of the profile is formed by white, bleached sand, indicating that all iron content has been removed.

Fig. 3: As high-tide approaches, a very thin shiny layer of orange-colored $Fe^{3+}$ minerals forms on the lake's surface. In local folklore, these eruptions of red or orange-colored brines are often called as the 'Blood of the Naga.'

Fig. 4A: Massive artesian outpouring of oxidized $Fe^{3+}$ precipitate-rich groundwater, as documented here near to the Tusan cliffs, Headlands II area.

Fig. 4B: puddles of artesian orange-colored $Fe^{3+}$ coated groundwater and sediment, inter-tidal zone, near Tanjung Batu

Fig. 5A. Layered iron mineral carpets, precipitated recently from iron-rich run-offs in the Tusan/Tanjong Batu area. Iron oxide carpets are typical for the supra-tidal realm, where little or no sediment reworking occurs.

Fig. 5B. Small cove near Headland II that shelters pebbles - likely formed from the cave-roof material, or washed in from the vicinity. The brown composite layer is formed by pebbles that are glued together by ferric oxides, precipitating from groundwater seeps in the cave's rear part. Nodular iron-oxide stained conglomerates form in inter-tidal caves: Nuclei are commonly sandstone pebbles originating from the cave’s sandstone walls, whilst the iron oxide coatings are reworked precipitates originating from subterraneous iron-laden springs.

Fig 6: Fe-stained sandstone pebbles and ophiomorpha burrows as seen in the Tanjong Lobang outcrop in Miri, Sarawak. This outcrop (Miri Fm) is of Late Miocene age.