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A brief note on the latest ichnological studies

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Abstract

Admitting ichnofossil is insitu and has paleoecological significance, then ichnofossil association and ichnofabric variables can used for depositional reconstruction in space and time. We observed six hundred and forty ichnofabric units at the twenty outcrops at Serravallian-Tortonian intervals in Samarinda, Kutai Basin, Indonesia.

Distinguishing ichnotaxa and exploring the five ichnofabric variables such as bioturbation index (BI), ichnodiversity (ID), number of behavior (NB), penetration depth (PD) and ichnofossil diameter (Dm) conducted in all ichnofabric units. Decreasing those variables, the principal component analysis (PCA) executed and the new principal components (PC), i.e., PC-1 and PC-2 presented. All ichnofabric units have PC-1 and PC-2 scores and scatter among PC-1 and PC-2 axes. We can cluster those scattered scores. If the ichnofabric units placed stratigraphically, then that scores can expressed as oscillatory curves. That looks like the wireline logging curves.

Interpreting those ichnological outcomes and integrated it with facies and paleocurrent data, then paleoecological models generated. The models show the change of depositional systems between Serravallian and Tortonian intervals. We can conclude it that the alternative method in the ichnological analysis potentially contributes to the basin analysis.

Introduction

Since published the Seilacher ichnofacies model (Seilacher, 1967), more and more geologist are familiar with ichnology. However, ichnofacies model not be able to provide maximum resolution as paleobatrymeter (Byers, 1982; Ekdale, 1988; Goldring, 1993) because of ichnofossil is a paleoecological function (Seilacher, 1964; Rhoads, 1975).

Our observation in six hundred and forty ichnofabric units at the twenty outcrops at Serravallian-Tortonian intervals in Samarinda, Kutai Basin, Indonesia (**Figure 1** and see in Arifullah, 2019) show that the ichnological studies method should change and improved. Common ichnological studies methods can not apply effectively for high resolution in depositional system analysis (see in Arifullah, 2005, 2019).

Rethink of ichnological concepts

It should keep in mind that ichnofossil is a biogenic sedimentary structure which a product of interaction of all intricate paleoecological parameters. Ichnofossil is not a body fossil. It is not possible that the inventoried ichnofossil will only matched with the existing ichnofossil model to confirm paleobatimery or the position of the sediment deposited (Arifullah et al. *in review*). Thus, a unique approach needed in the modern ichnological studies.

Paleobatimetry is only one of dozen parameters of paleoecological factor (Ekdale, 1988; Savrda and Bottjer, 1994). Ichnofossil affiliated implicitly with number paleoecological factors such as oxygenation (Rhoads and Morse, 1971), salinity fluctuation (Sanders et al. 1965) and temperature fluctuation (Johnson, 1965), community structure (Levinton, 1977; Reise, 1979), food supplies (Bambach, 1983), the way organisms get food (Purdy, 1964; Rhoads and Young, 1970), sedimentology (Howard, 1975; Arifullah, 2019), population strategies and disturbance (Arifullah, 2019). Thus, ichnofossil is nothing to do with paleobatrimetry (*e.g.,* Arifullah, 2005; Arifullah et al. *in review*).

The latest ichnological studies

Elite trace fossil

Perhaps in a basin there are many variations of trace fossils, but only a few of them dominate in the ichnofabric units, which are then referred to as elite trace fossils. For example, in the Kutai Basin, there are only 6 elite trace fossils , such as *Ophiomorpha, Skolithos, Paleophycus, Thalassinoides, Planolites* and *Chondrites* **(Figure 2)** with an appearance of 91.05% (Arifullah, 2019). Thus the elite trace fossil is a symptom of only a handful of trace fossils which often appear in ichnofabric units.

The findings of the elite trace fossil show the general ichnology of the Kutai Basin, and this approach is an important part of basin analysis (Arifullah, 2019). If we carry the same approach out in other basins, then we can compare the ichnology of one basin with another.

Ichnofabric unit and its variables

The interaction of paleoecological factors produces certain characteristics in the substrate which include the ichnotaxa, bioturbation index (BI), ichnodiversity (ID), number behavior (NB), penetration depth (PD) and ichnofossil diameter (DM) (Arifullah et al. 2016) which then called the ichnofabric unit (Arifullah et al. 2019). Based on Ekdale and Bromley (1983), ichnofabric are all aspects of the texture and internal structure of the sediments produced in all phases of bioturbation. Arifullah (2019) define the ichnofabric unit as a substrate unit showing specific ichnofossil (ID) diversity dominated by ichnofossils with certain behaviors that formed relatively together. Each ichnofabric unit characterized by a specific penetration depth (PD) and ichnofossil diameter (DM).

Principal component analysis (PCA)

Since BI, ID, NB, PD and DM are the numbers, then ichnological studies should be endorse to quantitative approach. An enormous amount of data required with the variables BI, ID, NB, PD and DM. It then processes the five data using principal component analysis (PCA) for the benefit of paleoecological studies (Arifullah et al. 2017). Thus, it is the first time using PCA in ichnological studies.

PCA allows the condensation of data on multivariate phenomena to become a major and representative feature by projecting the data into a two-dimensional presentation. The two resource axes created are independent, and although they reduce the number of dimensions (i.e. the original data is complex), they keep the original relationship between the variables significantly (see PCA concept in Keho, 2012). PCA requires normal data distribution, consequently the original data will transform to normal distribution values which show fewer dimensions (see in Arifullah et al. 2017).

Generated paleoecological models and depositional system analysis

The consequence of principal component analysis is to generate a new score from each ichnofabric unit called the PC-1 and PC-2 scores (see Arifullah et al. 2017). The score is a dimension less which allows it to depict as an ichnofabric curve like a log of electrofacies. It adopts the form from common terminology in log analysis, such as irregular, symmetrical, bell, funnel and cylinder. PC-1 and PC-2 scores shown in red and blue stripes. An explanation of the resulting PCA curves has been further described in Arifullah et al. (2017).

The new components produced from PCA are ichnodisparity and space utilization (Arifulah, 2019). If the PC-1 curve is ichnodisparity and PC-2 is the space utilization (Arifullah et al. 2018), then these curves have the potential to differentiate one depositional system from another. Especially related to the magnitude of the in -

fluence of the tidal process between one depositional environment and another (see Arifullah, 2019).

Ichnofossil is a function of paleoecology. The optimization of ichnological data allow to reconstruct unique paleoecological models **(Figure 3)**. Generated ichnological models automatically can reconstruct the paleoecological models. Its integration with lithofacies data (including paleocurrent data) could use for sharp depositional system analysis **(Figure 4)**.

Conclusions

As a function of paleoecology, ichnofossil is an indicator of how organisms interact with an infinite number of environmental parameters. That way, there are many other parameters besides BI, ID, NB, PD and DM can be explored. With the multivariate analysis approach, so many parameters can reduced, so that the key parameters in ichnofossil can determine. We can also interpret key parameters in paleoecology.

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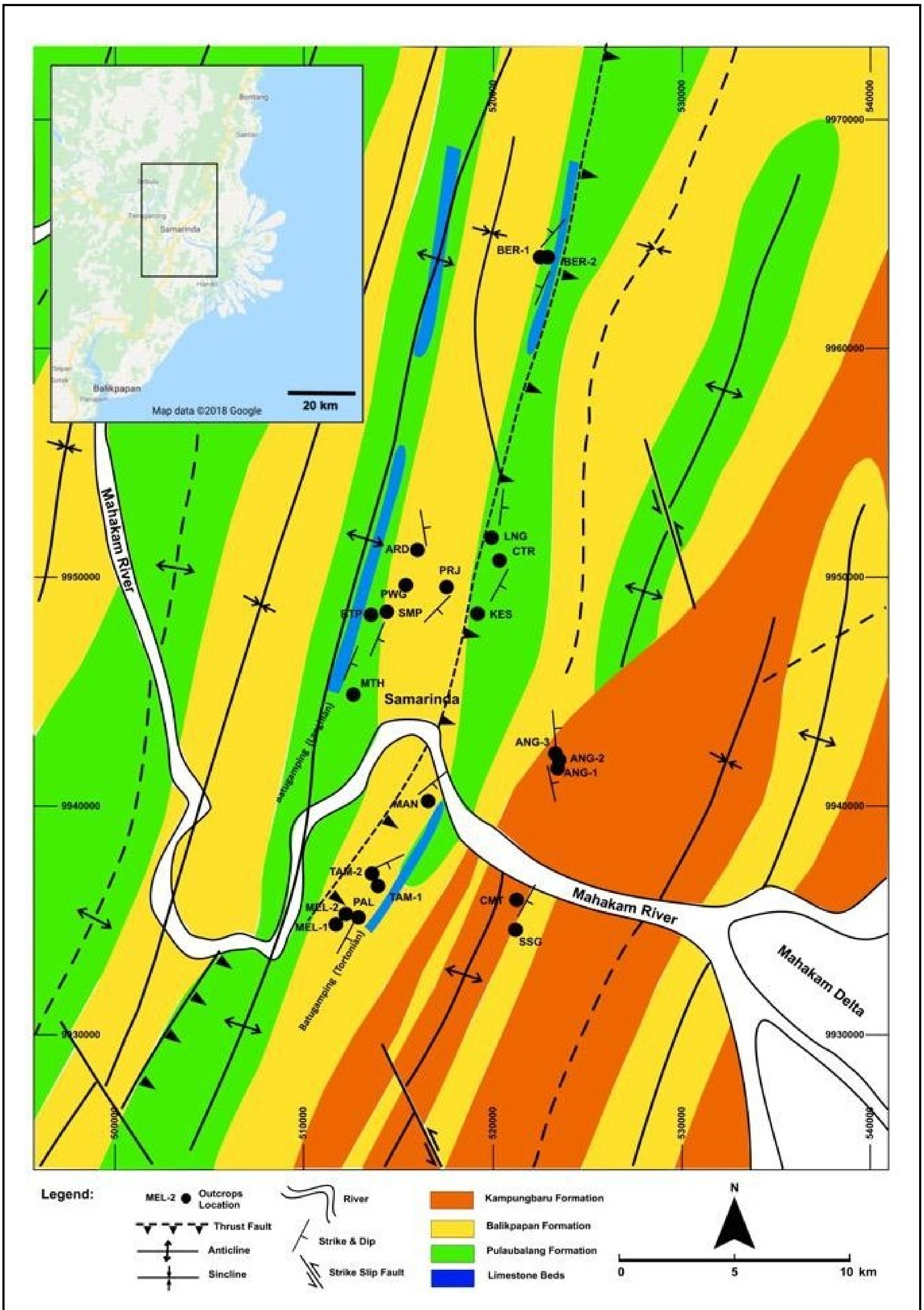

Figure 1: Geological map of Samarinda area and its surroundings (modified from Supriyatna, 1995).

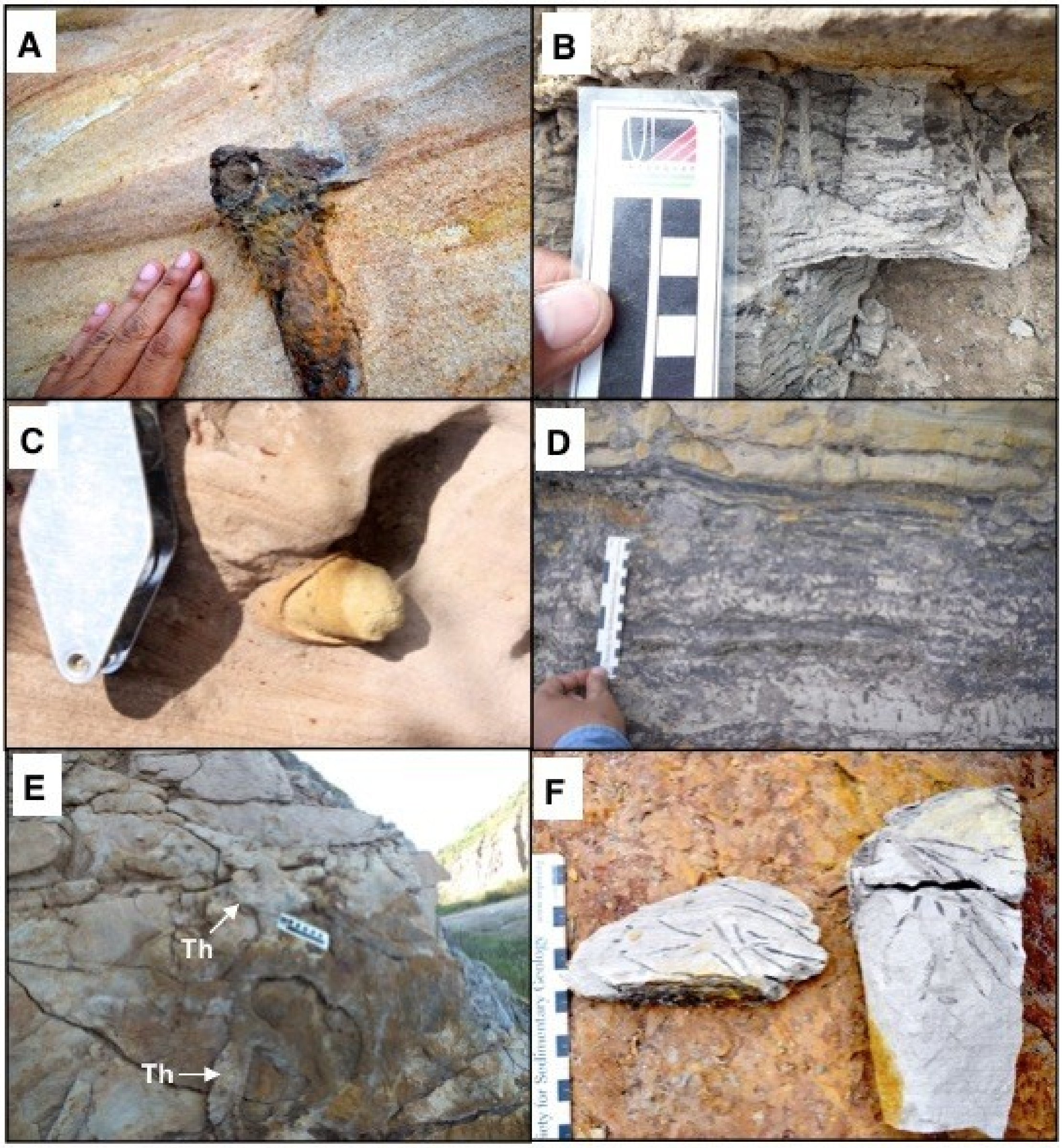

Figure 2: The elite trace fossil. *A) Ophiomorpha, B) Skolithos, C) Paleophycus, D) Planolites, E) Thalassinoides, F) Chondrites.* Adopted from Arifullah (2019).

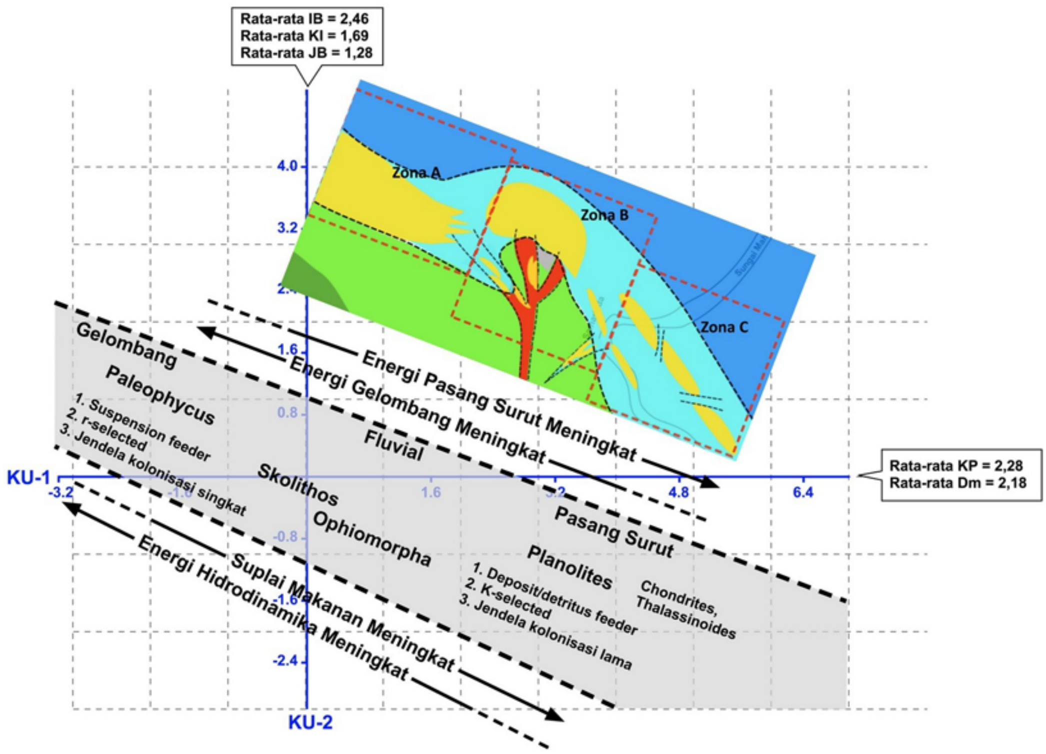

Figure 3: An example of paleoecological model that constructed by PCA analysis (see in Arifullah, 2019).

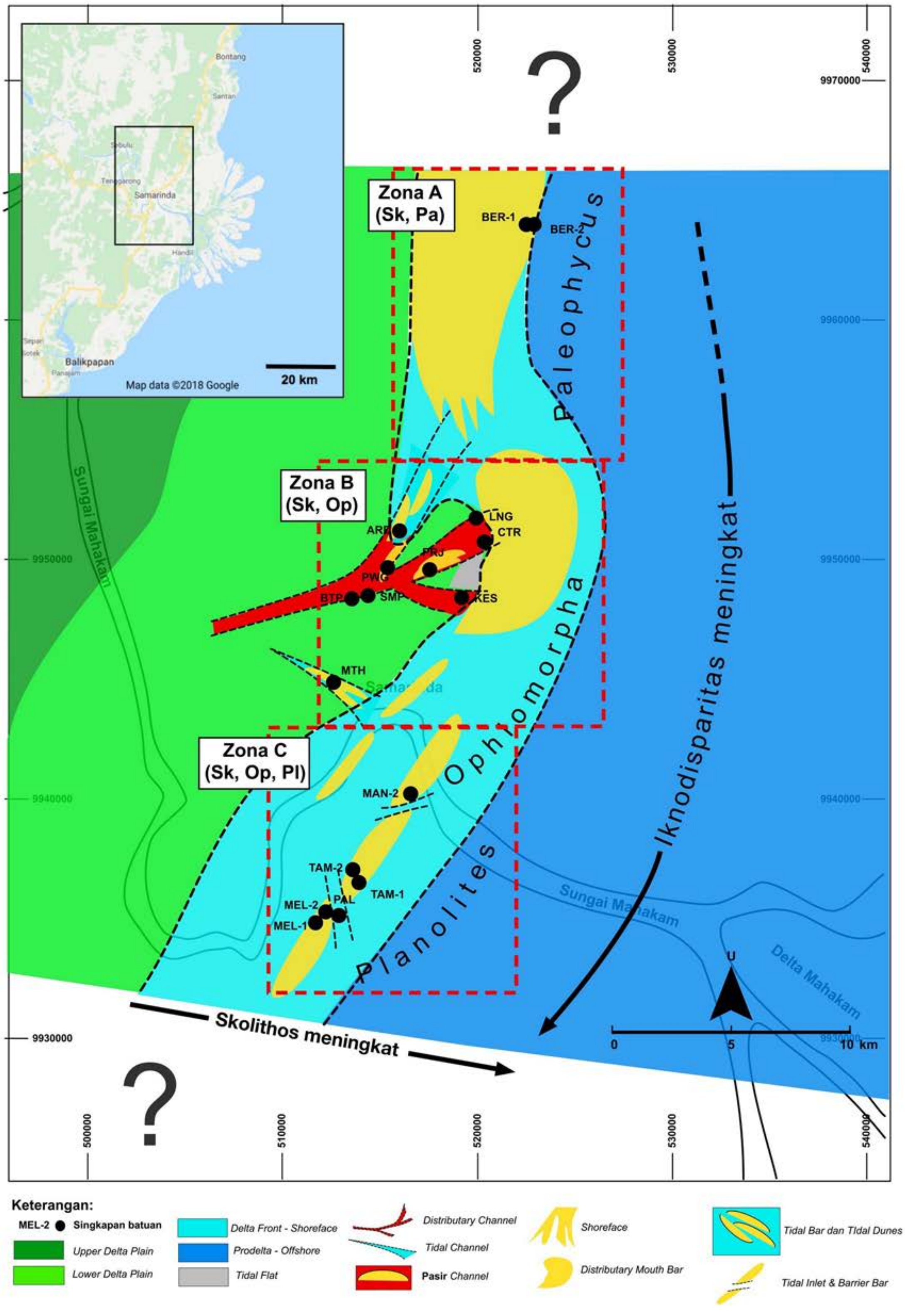

Figure 4: An example of palegeographic map that constructed from paleoecological model of figure 3 (see in Arifullah, 2019).