Extensional Tectonic on the Asymmetrical Formation of the Makassar Basin

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Abstract

Several problems in the Makassar Strait area related to the type of extension tectonic at the opening of the Makassar Strait and the formation of the Makassar Basin until now have never met a solution. The purpose of this review is to convey latest views and descriptions in Systematic Literature Review (SLR) based on articles published from 1985 to 2020. The current overview consists of research objectives, methodology, results, and limitations. This SLR uses Scopus as a database to save and analyze existing research on the opening of the Makassar Strait and the formation of the Makassar Basin, including the overview of the geological order relationships on the mainland of West Sulawesi and the eastern Makassar Strait. The main finding is that the Makassar Basin is interpreted as a basin with an asymmetric structuration (horst and graben) with simple shear kinematics, namely the east block mechanism (West Sulawesi) which stretches and moves eastward through mega-shear electric faults. The use of primary data as supporting data from writing this article also conveys a new interpretation of the presence of marine shale source rocks in West Sulawesi and source rocks of lacustrine shale in the eastern Makassar Strait.

Keywords: Makassar Strait, Makassar Basin, asymmetrical, simple shear.

Introduction

The Makassar Strait is located between the islands of Kalimantan and Sulawesi in the central part of Indonesia. It is part of the North and South Makassar Basin which is divided into northern and southern parts. The western part of Indonesia is geographically separated from the eastern part of

Indonesia by the Makassar Strait. This strait was formed by rifting in the eastern part of Sundaland, resulting in the separation of West Sulawesi from the outer arc of Sundaland (see Fig. 1). The Makassar Basin problems that have been widely discussed so far are generally only based on historical modeling of subsidence, gravity, magnetism, and plate tectonics [1].

Previous researchers stated that the Makassar Strait was formed by an extensional process [2, 3, 4,5, and 6] which began with rifting during the Middle Eocene [4, 7, 8, 6, 9, 10]. Reference [3] indicated the presence of an oceanic spreading center that extends along the Makassar Strait and is interpreted by several transform faults with a northwest-southeast trend. Reference [11] also interpret the existence of oceanic crust in the northern and southern parts of the Makassar Strait, while [5] argues that the oceanic crust is only in the northern part of the Makassar Strait.

The Makassar Strait is also interpreted as a residual oceanic basin [12] or as a back-arc basin ([13]. Reference [6] argues that the extension in the Makassar Strait is caused by the trench rollback and the sinking of the plate subducting the eastern part of the magmatic arc beneath West Sulawesi. Another opinion was also conveyed by [14 and 4], that the rifting that occurred in the Makassar Strait never reached the stage of expansion of the ocean floor.

As far as our observations are concerned, no research has been reported about the Makassar Strait in the form of SLR. Therefore, this research has the general aim of conveying new views and descriptions that are carried out systematically, which is related to the opening of the Makassar Strait and the formation of the Makassar Basin, including the overview of the relationship between the geological arrangements on the mainland of West Sulawesi and the eastern Makassar Strait. At the end of the study, the results will be correlated with the primary data used as supporting data.

Fig. 1.North and South Makassar Basins to the mainland of West Sulawesi.

This SLR will focus on several research questions. They are related to the tectonic model of stretch formation of the basin which is most suitable to be applied to the Makassar Basin, tectonic evolution and paleo facies of Eocene source rocks in the eastern Makassar Strait and West Sulawesi.

Method

This paper is written in a systematic literature review (SLR). This study was conducted to provide a better study of the opening of the Makassar Strait and the formation of the Makassar Basin, including the description of the relationship between the geological arrangements on the mainland of West Sulawesi and the eastern Makassar Strait. The purpose is to provide a summary and interpretation of the findings and new insights. This review is based on the systematic literature review guidelines provided by [15 and 16] following the other systematic review formats dealing with the Makassar Strait. Specifically, this process was organized into three main phases, namely selecting, identifying, and synthesizing [17].

Search strategy

This systematic review of the literature was carried out using the electronic Scopus as the primary database for the international literatures. The selected keywords were identified in the title and abstract of the paper. In this systematic review, the search strings used are as follows: Scopus: TITLE-ABS-KEY ((“digital competence*" OR “digital abilit*" OR “digital skill*") AND (“higher education” OR “universit*" OR “college*")).

Study selection

Several stages were carried out in the study selection process to obtain the latest research trends and results regarding the opening of the Makassar Strait and the formation of the Makassar Basin. The initial search yielded 418 related documents. Then from Scopus articles and international journals/publications, restrictions were given from publication year of 1985-2020 and the journal article version. The final results were 100 documents obtained.

Inclusion and exclusion criteria

Inclusion and exclusion criteria (Table 1) were made in order to obtain answers to the submission of several research questions. First of all, 418 papers were reviewed based on inclusion and exclusion criteria, so that 100 document results were obtained. Furthermore, the 100 articles (Scopus and international journals/publications) that were restricted from 1985-2020 were read and reviewed with quality criteria to ensure that the selected articles met the inclusion and exclusion criteria and met the requirements to answer research questions. A total of 77 articles had to be excluded because they are not related to Makassar Basin, then the other 4 were also excluded since they are not discussed the rifting of Makassar Basin. The final result of the limitation of inclusion and exclusion is a number of 19 articles used as research data.

Quality criteria

Papers that meet the inclusion criteria were reviewed as well as the criteria for quality. The focus of the criteria on quality is on a description of how the definition of the opening of the Makassar Strait and the formation of the Makassar Basin is, research objectives, description of the research area, research samples, answers to research questions, conclusions, limitations, results and discussion, and recommendations for future research development. This data extraction procedure is represented by the PRISMA flow in Fig. 2.

Table 1. Inclusion criteria and exclusion criteria

Inclusion criteria	*Exclusion criteria*
Research work related to the opening of the Makassar Strait and the formation of the Makassar Basin.	The research work is not related to the opening of the Makassar Strait and the formation of the Makassar Basin.
There is a discussion about the tectonic evolution of the eastern Makassar Strait and West Sulawesi, both tectonostratigraphically and changes in tectonic types.	There is discussion of tectonic evolution, but not in the eastern Makassar Strait and West Sulawesi, and not tectonostratigraphically or tectonic type changes.
A new interpretation of paleofacies differences between the eastern Makassar Strait and the mainland of West Sulawesi	The new interpretation does not relate to the paleofacies difference between the eastern Makassar Strait and the mainland of West Sulawesi
Research papers are limited to 6 years from 2015-2020.	Research papers are not limited to 6 years from 2015-2020.
Research papers are limited to scope and international journals/publications from 1985-2020.	Research papers are not limited to scope and international journals/publications from 1985-2020.
The research follows a research structure that is in accordance with the research method	The research does not follow a research structure that is in accordance with the research method

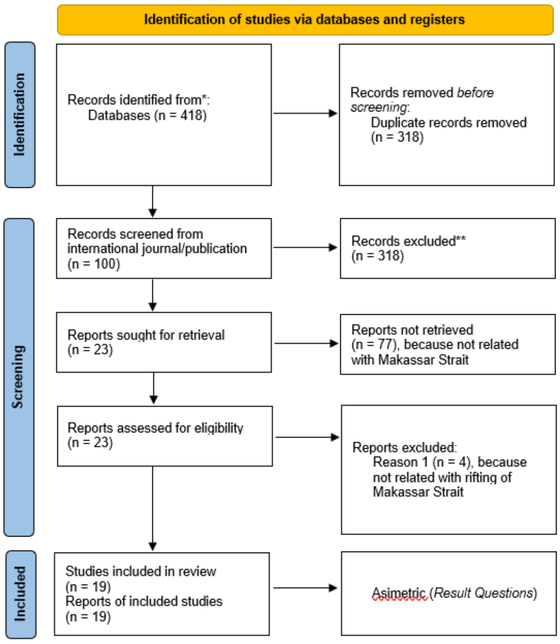

Fig. 2 Prisma Flow: data extraction procedure.

Result and discussion

In this section, we provide answers to research questions through analysis of selected articles. It is structured according to the questions posed by presenting the results of the SLR. Furthermore, it is combined with the acquisition of existing primary data as supporting data.

The most suitable extensional tectonic model of basin formation to be applied to the Makassar Basin

The interpretation of the type of extensional tectonic at the opening of the Makassar Strait and the formation of the Makassar Basin has not been studied to date. There are three articles that describe extensional tectonics, namely the lithospheric stretching model written by [18]. Reference [18] divides the strain tectonics of basin formation in continental plates into three main types, namely the symmetrical basin type known as the model of [19] with pure shear kinematics (a) and the asymmetric basin type known as the model of [20]. Meanwhile, the third model is a crustal delamination model with a small-angle shear zone that cuts through the mantle [21] (Fig. 3).

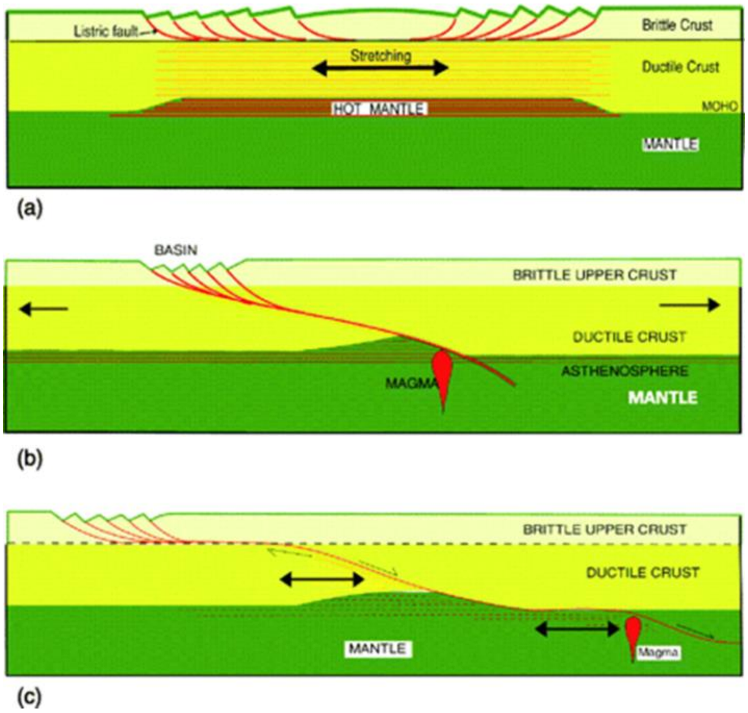

Fig.3.The lithosphere stretching model (rift to margin passive) by [18], (a) Simultaneous stretching of the crust and mantle [19]; (b) Asymmetric stretching model with wide-angle shear zone, up to cut the mantle [20]; (c) Model of crustal delamination with small angular shear zones, to cut the mantle [21].

The discussion related to the formation mechanism of the Makassar Basin is divided into two, namely Makassar Basin tectonogenesis and Makassar Basin tectonostratigraphy. This discussion will focus more on the discussion of the tectonogenesis of the Makassar Basin.

Tektonogenesis of Makassar Basin

The Makassar Basin is interpreted as a basin with an asymmetric type of structuration (horst and graben), in accordance with [20] model, namely the strain tectonic type with simple shear kinematics [22]. Several articles that support this interpretation are the article written by [23], namely the analysis of the gravity map which shows no thinning of the continental crust in the center of the basin, [24] article on the graben structure map showing the distribution of the graben dominantly located in the eastern part of the basin with an oblique (not parallel) orientation to the opening side of the Makassar Strait, [22] article on bedrock maps showing the present depositor of the Makassar Basin, and isochronous maps showing the thickness of graben infill sediments (synrift sediments, Fig. 4). According to the article written by [19] with a pure-shear kinematics model, the main features of symmetrical basin tectonogenesis are not visible, namely the center of horst and graben structuration and the center of sediment deposition (depocenter) which is located in the middle of the expansion of the basin with the direction of the depositor axis which should follow the opening axis of the Makassar Strait, namely northeast-southwest (Fig. 5).

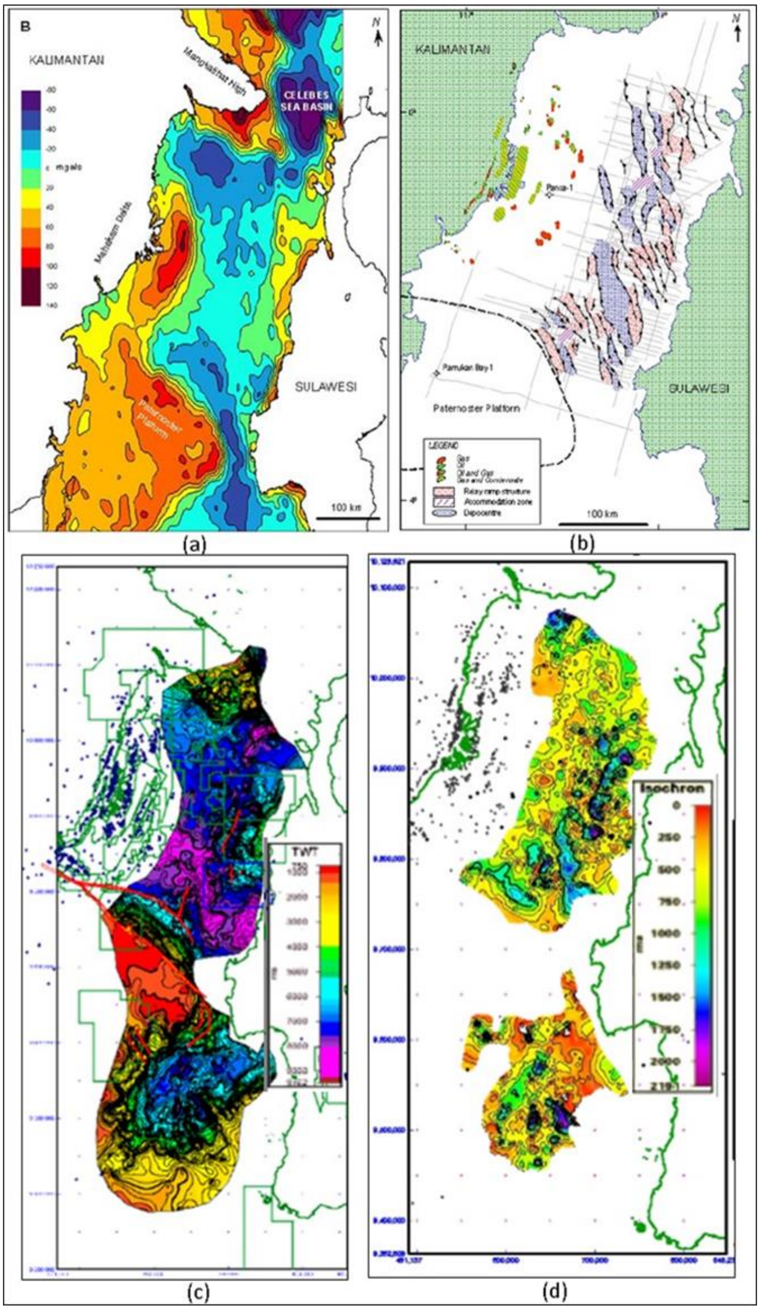

Fig. 4 (a) Gravity map in North Makassar Basin ([23]; (b) Structure map and depocenter of graben [24; (c) Map of bedrock structure (time) of the Makassar Basin [22]; (d) Synrift sediment isochron map (TWT thickness time) of graben-fill sediment in Makassar Basin [22].

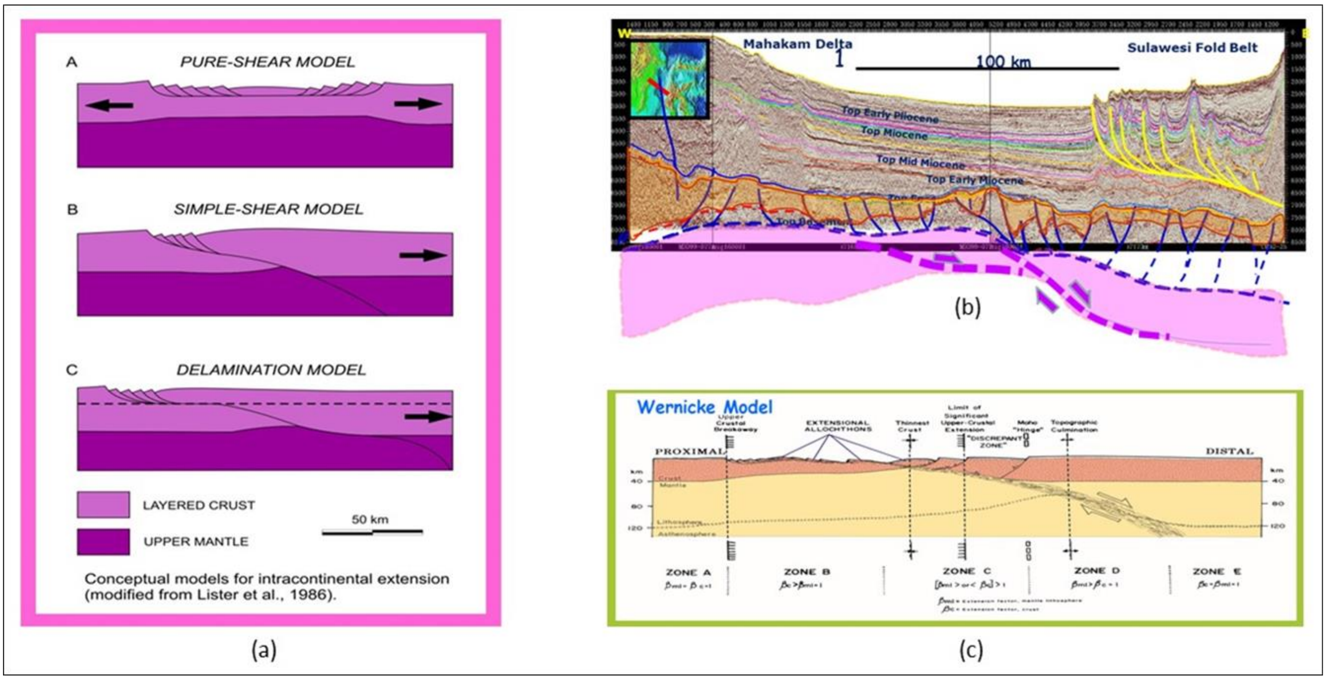

Fig. 5 Several extension models of continental basin formation (a); asymmetric horst-graben geometric association in the Makassar Basin (b); according to [20] model of simple shear kinematics on the formation of basins (c).

The genesis of tectonization in the Makassar Basin is interpreted as stemming from a escape tectonic event that occurred due to the collision of the Indian Plate which resulted in the indentation of the Eurasian Plate to the east-southeast and the indentation of the Indochina microplate to the southeast through a horizontal red-river fault [22]. The lateral motion of the Indochina microplate causes a horizontal fault and segmentation motion that spreads to the southeast. This makes the tectonic presence due to the dominance of the horizontal motion of the microplate fragments (wrench/strike-slip tectonic) dynamically influencing to Kalimantan and Sulawesi. Indications of faulting and horizontal segmentation with WNW-ESE and NW-SE moves that are recognized in the Natuna, Tarakan, East Kalimantan, to Makassar Basin and Sulawesi mainland, prove the influence of extrusion and horizontal faulting of the Indochina microplate to the Kalimantan, Makassar Strait, and Sulawesi (Fig. 6).

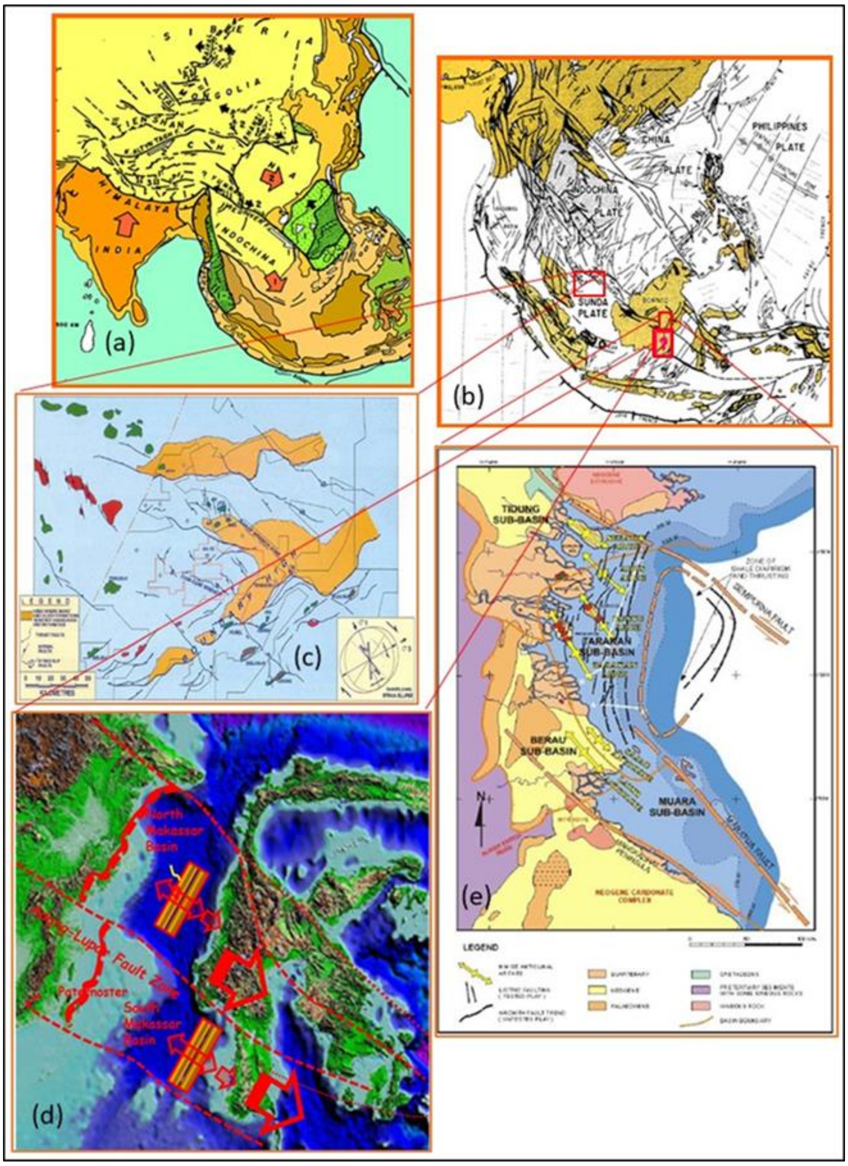

Fig. 6The tectonogenesis of the Makassar Basin starts from the indentation of the Eurasian Plate to the southeast due to the collision of the Indian Plate [25], resulting in fault and dispersal in the southeastern part of the Sunda Shelf (b), which causes tectonic horizontal faults, among others in the Natuna Region [26], Makassar Basin and Tarakan [26] (c, d, e).

[22] stated that the initial opening of the Makasar Strait and the Makassar Basin began when the escape tectonic movement from Indochina to the southeast resulted in the initiation of a northwest-southeast horizontal wrench fault which accompanies the segment rifting initiation from the western Kalimantan to the east-southeast. The pair of horizontal wrench fault supports the movement of the East Kalimantan segment to the southeast which is accompanied by rifting to form an asymmetrical horst and graben structuration.

Research outcomes

In the last stage of the review, correlation with primary data is carried out as supporting data for the existing SLR results. Fig. 7 shows that the position of the K-1 well is on the horst slope with a steep change in the depositional slope angle at a short distance, so that the terrestrial sedimentary material from the paleo-high horst is easily eroded and undergoes reworked deposition [27].

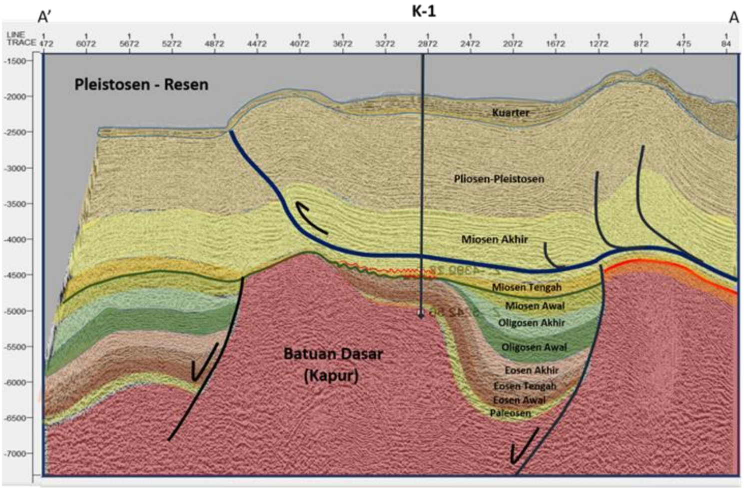

Fig.7The reinterpretation of seismic data passing through the K-1 well position (modified by [27]).

The description of the geological arrangement in the eastern Makassar Strait and the mainland of West Sulawesi was obtained by performing a composite reinterpretation between marine seismic passing through the K-1 reference well and land seismic passing through the LYS reference well (Fig. 8). The structuration of horsts and grabens resulting from rifting during the Paleogene was not only found in the Makassar Strait, but also formed on the mainland of West Sulawesi. Thus, the coverage area of the Makassar Basin does not only cover the Makassar Strait, but also includes the mainland of West Sulawesi.

Regionally, the horst and graben structuration at the opening of the Makassar Basin is more developed in the eastern part of the Makassar Basin, namely in the eastern Makassar Strait and the mainland of West Sulawesi, compared to the western and central Makassar Basin. This is illustrated in the results of the reconstruction of the sea-to-land composite seismic reinterpretation (Fig. 8). This supports the asymmetrical rifting model with simple shear kinematics with the east block mechanism (West Sulawesi) stretching and moving eastward through the mega-shear of the electric fault (Fig. 5).

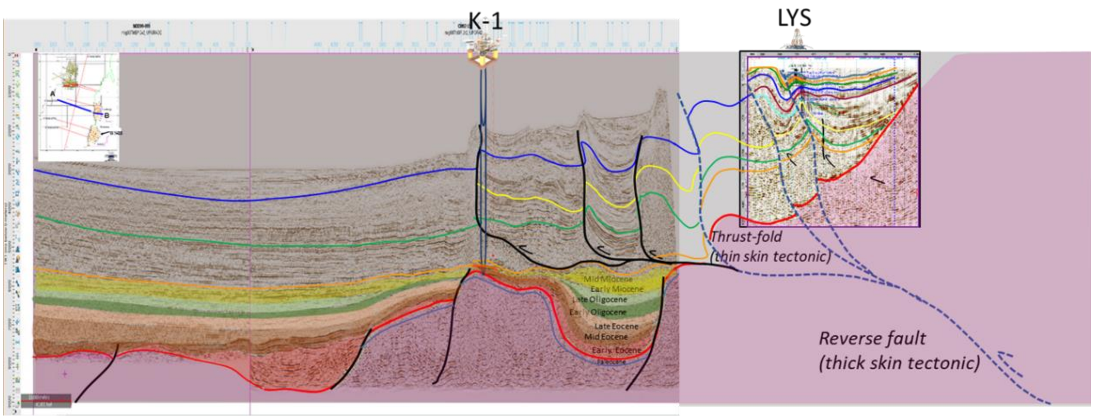

Fig. 8 The offshore geological setting of the eastern Makassar Strait and the mainland of West Sulawesi based on composite seismic reinterpretation passing through the K-1 and LYS reference wells [27].

West Sulawesi experienced compressive tectonics from the east which resulted in deformations and collisions in the eastern part of Sulawesi which started at the lower Late Miocene age and peaked in the Pliocene-Pleistocene era. In that era, the compressive tectonic influence in the sea (eastern Makassar Strait) was in the form of thin-skinned tectonic ([28], as a fault and thrust-fold with a detachment zone in the plane the lower Late Miocene (Neogene) bed (Fig. 8).

Grabens in the eastern Makassar Strait do not appear to have experienced thick-skinned tectonic deformation during the Paleogene age (Fig. 8, [28]). On the other hand, there is a thick-skinned tectonic on the mainland of West Sulawesi, in the form of a reverse fault and a thrust fault accompanied by folding. The intensity of compressive tectonic deformation from the east is very strong, so that the Paleogene grabens on the lower part of the mainland of West Sulawesi, which were originally parallel to or lower than the grabens in the sea, were uplifted and became higher, and some grabens also experienced an inversion (Fig. 8).

According to the rifting mechanism of [20] model, the mainland of West Sulawesi experienced a faster subsidence than the Makassar Strait. Based on these data, in the Middle Eocene age, it is interpreted that the paleofacies in West Sulawesi are different from the paleofacies in the eastern Makassar Strait. The eastern Makassar Strait is still in lacustrine paleofacies, while the mainland of West Sulawesi is already in marine paleofacies [29]. Thus, it can be interpreted that there are differences in the peleogeographic environment between the eastern Makassar Strait and the mainland of West Sulawesi.

Conclusion

The most suitable extensional tectonic model for the formation of the basin to be applied to the Makassar Basin is the asymmetrical stretching one. During the Eocene, there were differences in paleofacies between the eastern Makassar Strait and the mainland of West Sulawesi, in this case the eastern Makassar Strait had lacustrine paleofacies, while in West Sulawesi it had become marine (middle-outer neritic).

The author hopes that this systematic writing of articles can be useful for many parties, and can be used as a support for research in this area. Thus, exploration activities can be increased, in addition to minimizing risks to exploration activities in the area.

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