Seismic Facies of Pleistocene–Holocene Channel-fill Deposits in Bawean Island and Adjacent Waters, Southeast Java Sea

Fasies Seismik Endapan Pengisi Alur Pleistosen - Holosen di Perairan Pulau Bawean dan Sekitarnya, Laut Jawa Bagian Tenggara

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ABSTRACT: The late Pleistocene-Holocene stratigraphic architecture of the Bawean Island and surrounding waters, southeast Java Sea has been analyzed by using sparker seismic profiles. Geological interpretation of these seismic profiles revealed the widespread distribution of paleochannels with different shape and size in the present-day Java Sea. Two channel types can be distinguished based on its morphology: U-shaped channels in the western part and V-shaped channels in the eastern part. The stratigraphic successions were grouped into two major seismic units separated by different seismic boundaries. Characters of marine and fluvial deposits were determined based on seismic boundaries and internal reflectors. Three seismic facies can be identified within late Pleistocene – Holocene incised channel fills associated with SB2. The internal structure of incised-channels consist of chaotic reflector at the bottom, covered by parallel–sub parallel and almost reflection-free indicating the homogenous sediment deposited during the succession.

Keywords : Pleistocene-Holocene channel fills, sparker seismic profiles, seismic boundaries, incised–channel, Java Sea.

ABSTRAK: *Rekaman seismik sparker digunakan untuk menganalisis endapan stratigrafi berumur Plistosen Akhir–Holosen di Perairan Pulau Bawean dan sekitarnya. Berdasarkan interpretasi geologi dari rekaman seismik tersebut teridentifikasi sebaran alur purba yang berbeda bentuk dan ukuran dengan kondisi Laut Jawa sekarang. Berdasarkan morfologinya, dua tipe alur purba yang terdentifikasi adalah alur purba berbentuk U di bagian barat dan berbentuk V yang terbentuk di bagian timur daerah penelitian. Suksesi stratigrafi kemudian dibedakan menjadi dua grup unit seismik utama yang dibatasi oleh perbedaan batas seismik, yaitu endapan asal darat dan laut yang ditentukan berdasarkan batas sikuen dan reflektor internal. Pada unit Pleistosen–Holosen teridentifikasi tiga tipe fasies seismik yang berkorelasi pada batas sikuen SB2. Struktur internal alur purba yang tertoreh terdiri dari reflektor kaotik yang di bagian bawah, kemudian ditutupi oleh reflektor paralel - sub paralel sampai hampir bebas refleksi yang mengindikasikan terendapkannya sedimen homogen selama suksesi tersebut.*

Kata kunci : *Pengisi alur Plistosen - Holosen, penampang seismik sparker, batas seismik, alur tertoreh, Laut Jawa.*

INTRODUCTION

The study area is located surrounding Bawean Island in southeast Java Sea (Figure 1), part of the Sunda Shelf which has been drowned since the Last Glacial Maximum, approximately 20,000 years ago (Solihuddin, 2014; Setyawan and Nuryana, 2016). The southeast Java Sea forms the submerged part of the Sunda Shelf and lies on a relatively stable continental shelf (Susilohadi and Soeprapto, 2015). Furthermore, Tjia (1992) also mentioned that the Sunda Shelf has been largely tectonically stable since early Tertiary. Physiographically, the Sunda Shelf occupied by a numbers of islands, which were formerly high parts on the Sunda peneplain. Therefore, they are nearly all rocky islands, often covered by a deep crust of lateric weathering. The arrangement of these islands forms an indication of the major structural trendlines which connect SE Asia with the three Larger Sunda Islands : Sumatra, Java and Borneo (van Bemmelen, 1949).

Indriastomo et al. (1995) have compiled seismic data collected from Java Sea yet has never been interpreted properly. Certain interpreting 2D seismic profile might be complicated. However, such work is a challenge in order to identify quaternary history in Sunda Shelf, the largest shelf outside polar regions which was exposed due to approximately 135 + 2 m sea level drop during the Last Glacial Maximum (Hanebuth et al., 2000; 2009). During sea level drop, incised valley system is commonly developed, providing the most

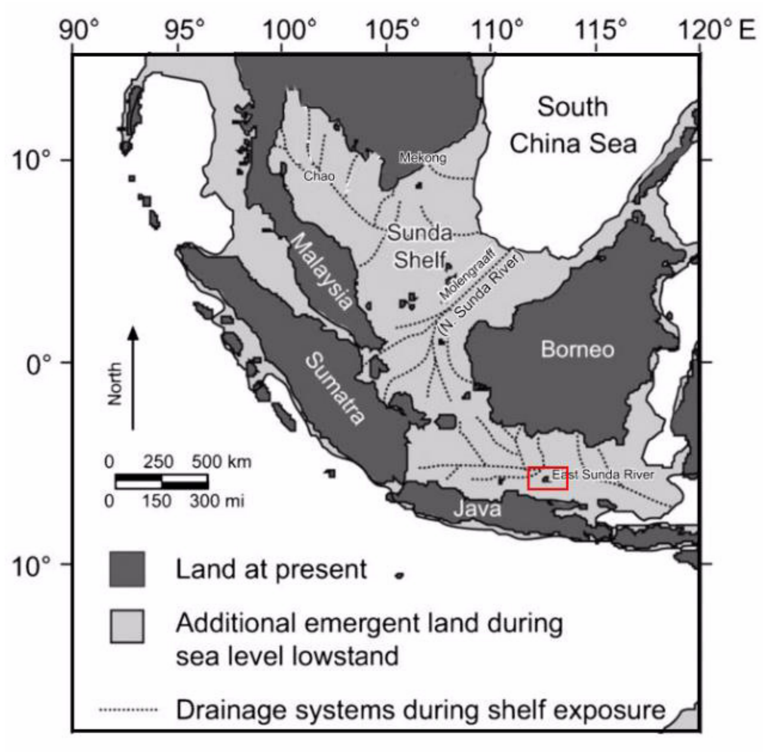

Figure 1. Regional overview of Sunda Shelf and location map of the study area (shown in red box) superimposed with Molengraaff paleo-rivers system surrounding Java Sea and Sunda Shelf during last glacial maximum (after Darmadi et al. 2007; Reijenstein et al. 2011)

complete evidence of lowstand to trasgressive deposition in shelf – slope and/or shallow – ramp in the marine depositional setting (references therein in Zaitlin et al., 1994). Therefore, this study was conducted with purpose to identify regional paleo-channel on the shallow of Late Pleistocene – Holocene systems, and identifying the incised valley system occurrence, which probably related to the previous study of Indriastomo et al., (1995), where the study area of this paper is also the part of main submerged East Sunda River by Molengraaff (Kuenen 1950) and Voris (2000).

Geological Setting

The Island of Bawean in the southeastern part of the Java Sea is the only island in the Sunda Shelf area which consists of marine tertiary strata and alkaline volcanic rocks (Aziz et al., 1993). This part of the Java Sea does not belong to the more or less stable Sunda Land, but it has been subjected to tertiary processes of diastrophism. It bears a close resemblance to the Muria on the North coast of Java. This extinct volcano was also an island, but it has been linked to the mainland in historical time by the silting up of the Semarang-Rembang passage (van Bemmelen, 1949).

The paleo-river systems of the Sunda Shelf are vast submerged river systems that extend present-day river systems and may be interpreted to follow topographic lows in a down-slope direction. During the driest of the Pleistocene era (about 17,000 years before present) some four distinct catchment areas form the Malacca, Siam and Sunda River Systems (Voris, 2000). The Siam River System consists of a northern and a western arm. The northern arm extends the Chao Phraya River to drain the Gulf of Thailand. The western arm forming out of some rivers in central Sumatra flows through the Singapore Straights before joining up with the northern arm to empty into an estuary and the South China Sea to the north of North Natuna Island. The Malacca straights river system is formed by a conflux of waters from Northeastern Sumatra and the West of the Malayan Peninsula draining into the Andaman Sea. The Northern Sunda River System is also known as the Great Sunda River System or Molengraaff River System. The river, arising between Belitung Island and Borneo, flew in a northeasterly direction, where it collected waters from some rivers in Central Sumatra and the rivers in Western and Northern Borneo, before flowing into the South China Sea between the North and South Natuna Islands (Tjia, 1992; Hanebuth et al., 2000). Finally the Eastern Sunda River System empties Northern Java and Southern Borneo (Figure 1), flowing in an easterly direction between Borneo and Java into the Java Sea (Voris, 2000; Sathiamurthy and Voris, 2006).

METHODS

Seismic reflection profiles used in this study comprise over 9000 kilometers of sparker profiles acquired by Marine Geology Institute of Indonesia using RV Geomarin I during 1991 – 1993 cruises (Figure 2). The seismic system used is a single channel 500 Joule sparker system, firing rate every 1 second (Raharjo and Arifin, 2007; Susilohadi and Soeprapto, 2015). The seismic profiles were then filtered by band pass filter (80-120, 800-1200 Hz) before interpreted. The analysis and interpretation of the selected seismic data (L-45C etc, Figure 2) were based on the configuration of the reflectors, by applying general concepts established in the field of seismic stratigraphy (Veeken, 2007; Catuneanu et al., 2011). The assumption of sound velocity in sediments is 1,650 m/s to apply the thicknesses of the sedimentary units (Weschenfelder et al., 2010).

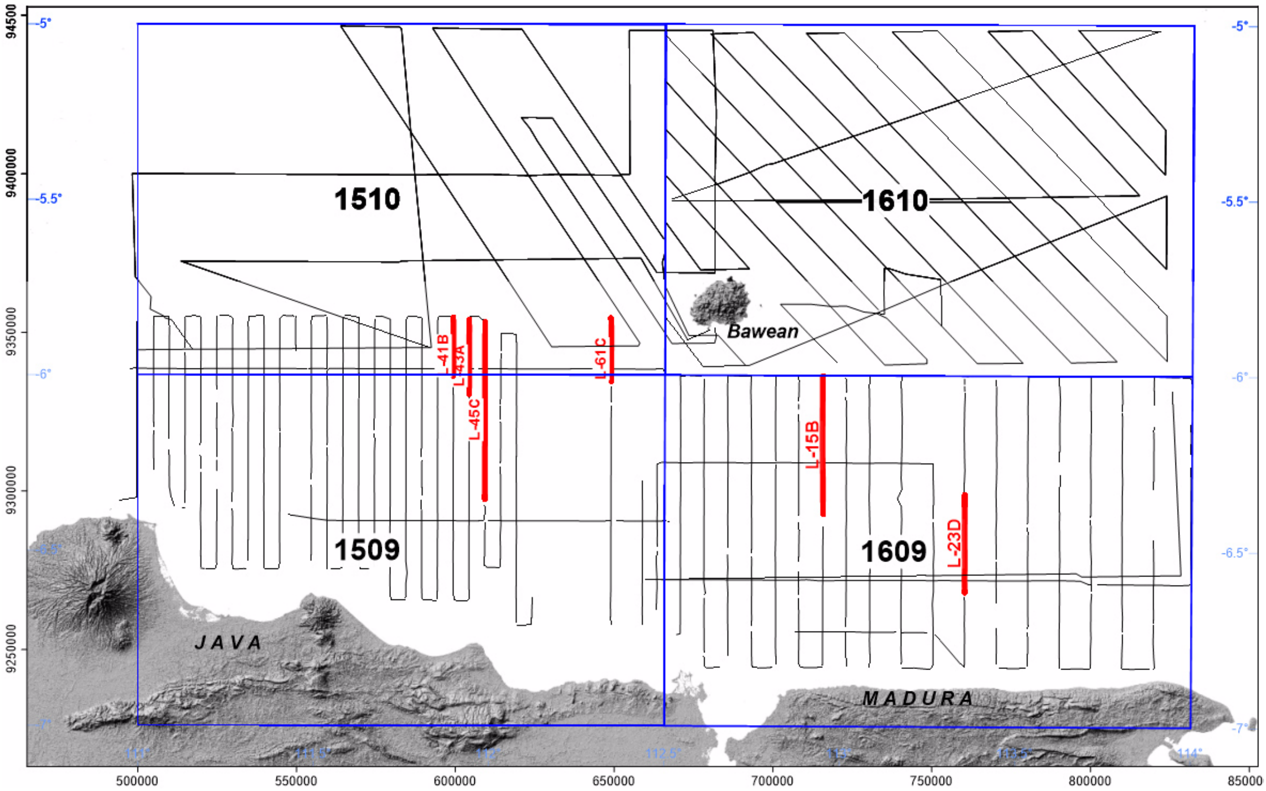

Figure 2. Track lines of sparker seismic survey in Bawean Island and surrounding waters consist of 4 sheets map (1509,1510,1609 and 1610 – shown in blue box). Red lines are parts of seismic lines presented in this paper for discussion.

RESULTS

Systematic mapping of the seismic surfaces reveal the presence of paleo-channels systems shown in Figures 3 - 7. The most prominent paleo-channel is about 4 km wide and sedimentary filling is at least 30 m thickness (Figure 3). This large paleo-channel is shown in profile L-45C, L-43A, L-41B and continues to profile L-61A in western part of Bawean Island (Figures 3 and 8).

The older paleo-channels system are buried by a sedimentary unit up to 50 m thickness. The seismic reflectors of the older paleo-channel system are intersected by the reflectors of the younger, indicating the relative timing of incision, i.e., the incision and infilling of the older paleo-channel system. The smaller paleochannels detected in profile L-15 B (Figure 4), usually cutting only the uppermost strata, could be tributaries of the main river courses or independent smaller drainage courses. Various buried channels of the older system are detected in profile L-23D (Figure 7). They are some hundreds of meters wide and the sedimentary infill reaches thicknesses up to 15 m. Paleo-channels are in-filled with seismic facies units filling a negative relief in the underlying strata. The underlying reflections are mainly parallel to sub-parallel and continuous to discontinuous, showing truncation along the continuous base surface of the channels. The upper reflectors of the seismic facies filling up these paleo-channels are truncated by a strong and continuous reflector of the overlying strata. The overlying strata are composed of continuous, parallel to sub-parallel, gently dipping reflectors (Figure 7).

Late Pleistocene–Holocene Incised Channel Fills

Three seismic boundaries (SB) are recognized on the study area, which are Present Sea Floor (PSF), SB2 and SB1 as the oldest (Figure 4). At the bottom was identified SB1 which represents Plio-Pleistocene sequence boundaries. It is characterized by U shaped incised channels and high amplitude acoustic returns. SB 2 represents the Late Pleistocene sequence boundaries, characterized by its distinctive erosional surface marked by V shaped incised channels and medium amplitude acoustic returns (Susilohadi and Soeprapto, 2015).

Three seismic facieses (SF1 to SF3) are identifiable within late Pleistocene – Holocene incised channel-fill deposits associated with SB2 (Figures 5-7). These may not be presented in all incised valleys, but occur in some combination throughout the study area.

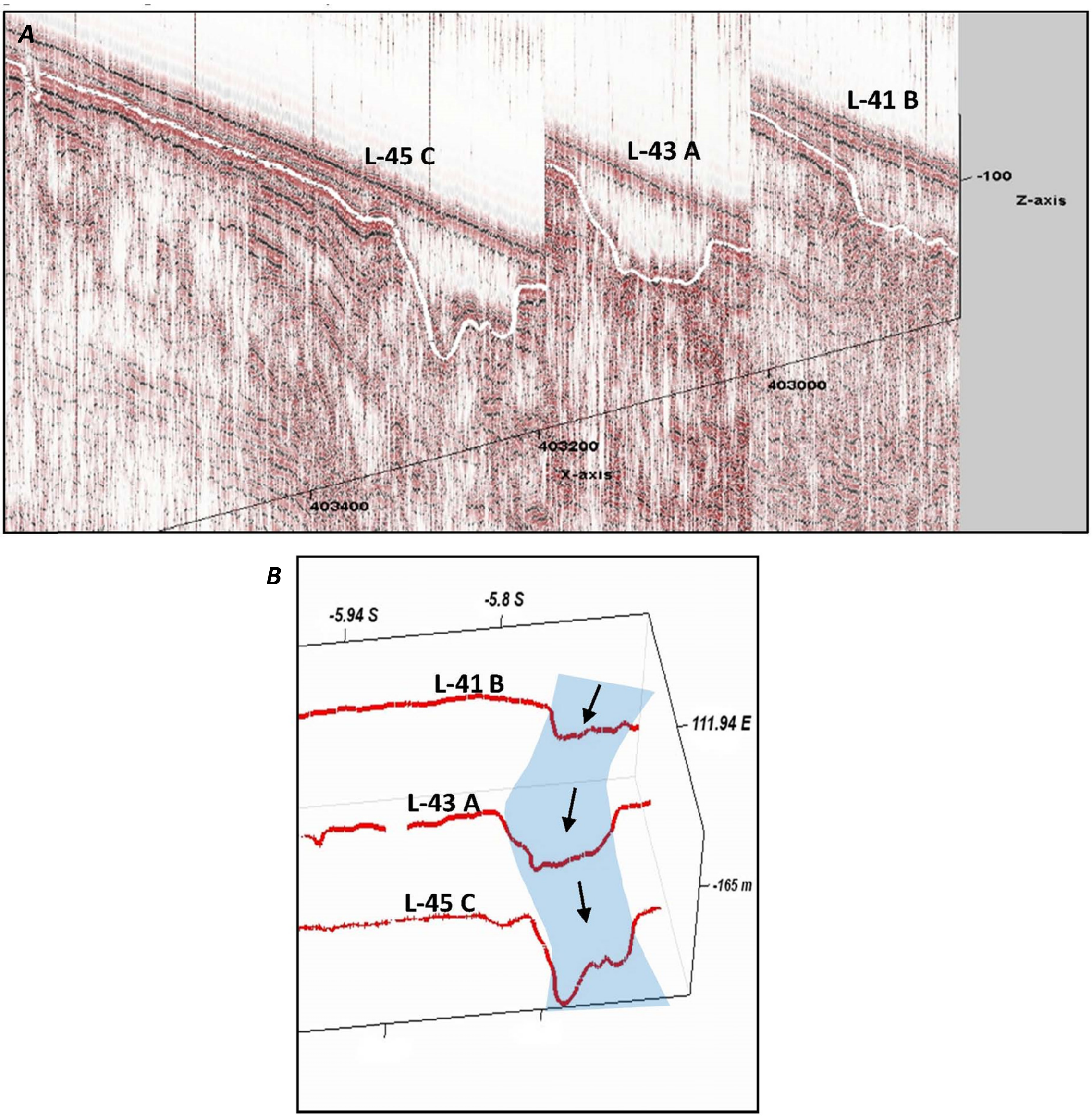

Figure 3. The most prominent paleo-channels identified in western part of Bawean Island shown in seismic record (A) and illustration diagram (B). The width of these paleo-channels is about 4 km and buried by Pleistocene-Holocene sediments up to 30 meters thickness.

These are described on the basis of internal reflector configuration and the character of the bounding seismic surfaces. It outlines the incised-channels occuring in both coastal perpendicular and coastal parallel depicting U- and V-shaped channels, indicating channel bending.

Seismic Facies 1 (SF1). SF1 is characterized by chaotic, low-medium amplitude reflectors which form the base seismic unit of each channel-fill deposit. The best feature of SF1 is in channel which is incised more than 20 m vertically into the underlying sediments. SF1 is strongly expressed in the south-west Bawean Island incised channel which attains a maximum thickness of 10 m (Figure 5).

Seismic Facies 2 (SF2). SF2 comprises wavy to sub-parallel, variable to high amplitude reflectors which downlap SF1 and onlap the channel flanks. Along the channel flanks, SF2 comprises smaller clinoforms that form aggradational–progradational mounded deposits of up to 14 m thickness. The seismic expression of SF2 becomes less pronounced further north towards Bawean Island.

Seismic Facies 3 (SF3). SF3 consists of single reflection-free sequence of possibly homogeneous mudstone with maximum thickness about 20 meter with a less variation on the western part of the study area. The fluvial channel system at its base in some areas are very pronounced.

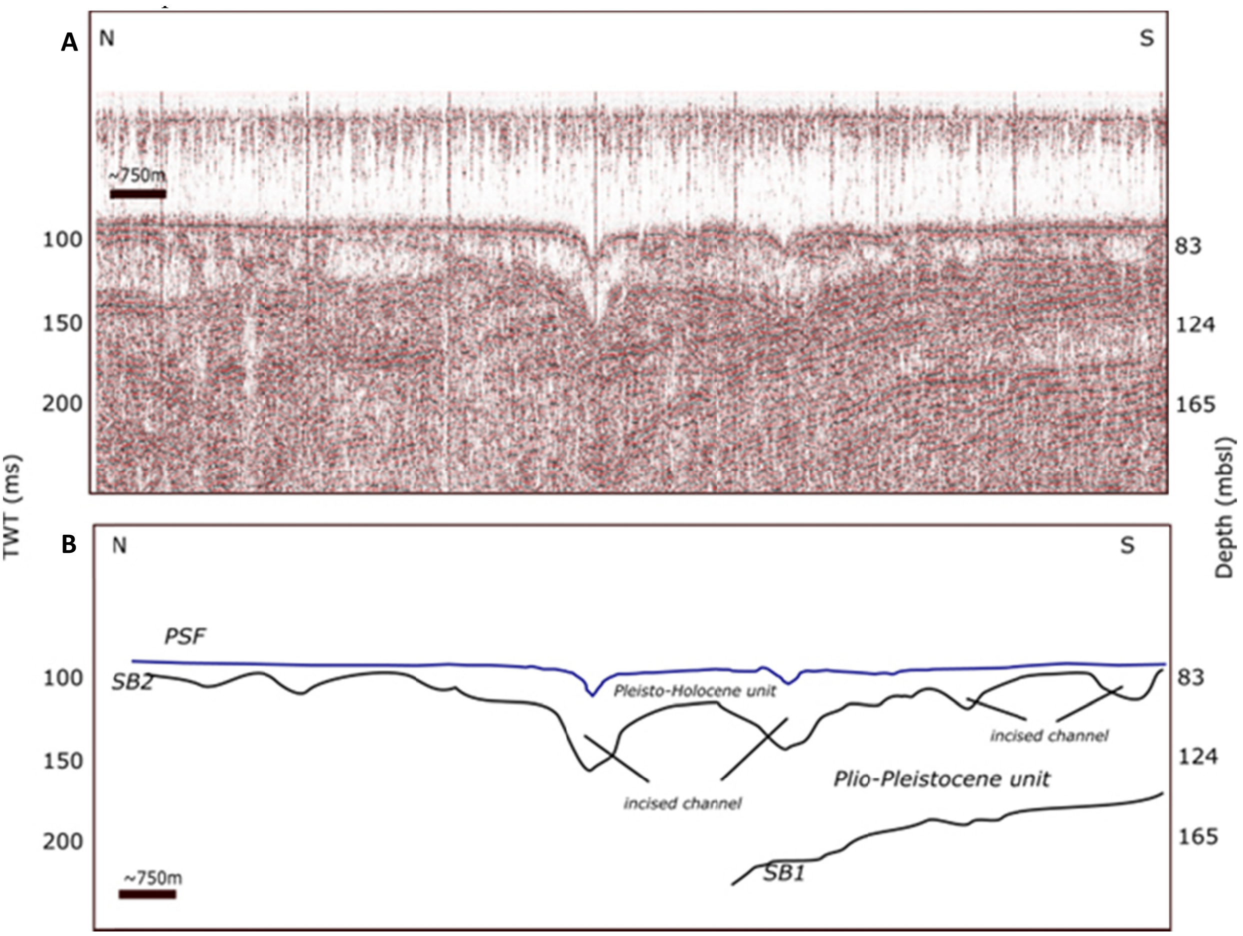

Figure 4. Seismic profile L-15B on eastern part of study area revealing a V-shaped channel on the south-eastern Bawean. (**A**) Whole seismic record. (**B**) Interpreted seismic record.

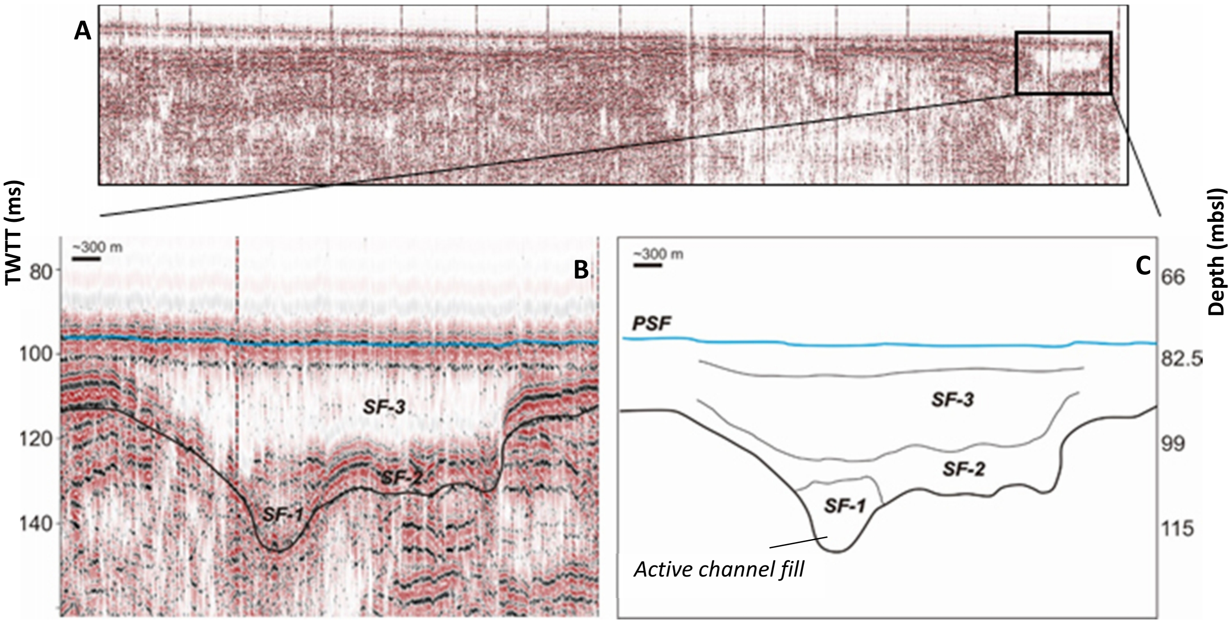

Figure 5. Seismic facies interpreted from profile L-45C showing the character of internal reflector on the paleochannel. (**A**) Whole seismic profile L-45C. (**B-C**) Interpreted paleochannel in seismic profile L-45C.

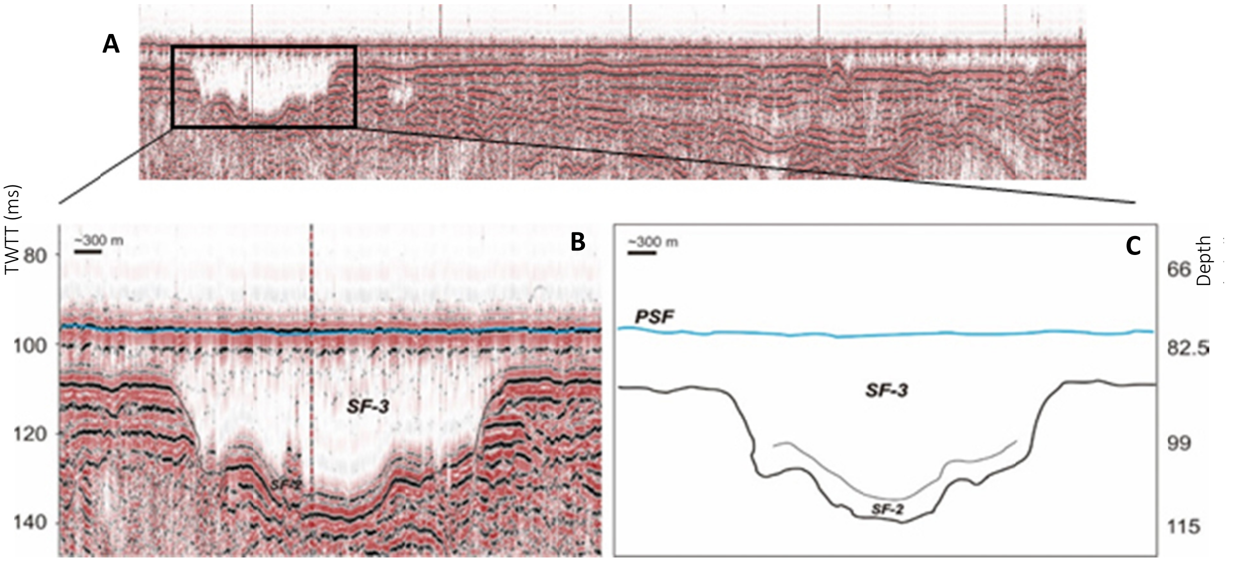

Figure 6. Seismic facies interpreted from profile L-61C showing the character of internal reflector. (A) Whole seismic profile L-61C. (B-C) Interpreted paleochannel in seismic profile L-61C.

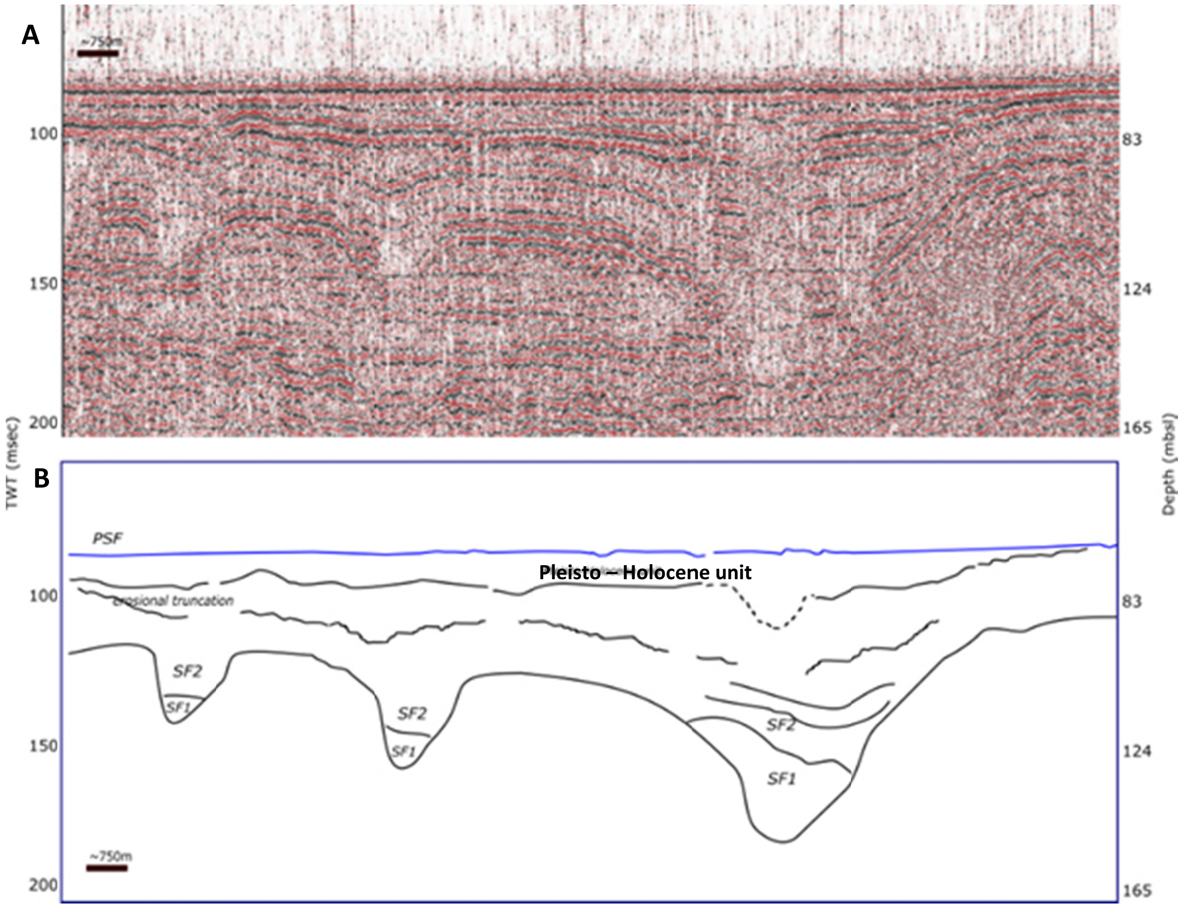

Figure 7. Seismic profile L-23D revealing older paleochannel on the south-eastern Bawean with internal structures showing vertical aggradation. (A) Whole seismic record. (B) Interpreted seismic record.

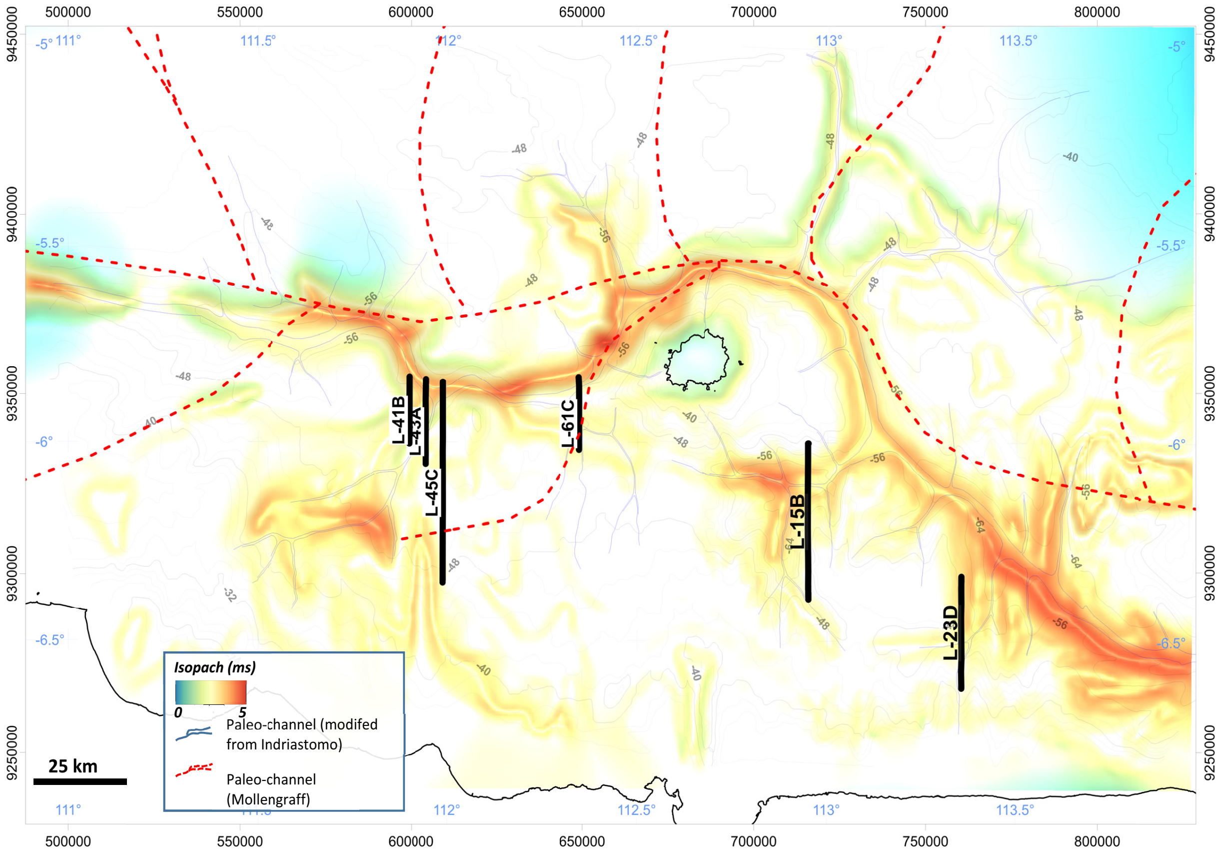

Figure.8. Paleochannel (*shown in blue pattern*) overlay with isopach of youngest sediment *(shown in blue – red color, low to high thickness*), and contour map of basal youngest sediment interpreted from seismic data (modified from Indriastomo *et al.*, 1995). Red dash line are Molengraaff river system of the last glacial period, which has been deduced from the first Snellius expedition. Black lines are parts of seismic lines presented in this paper for discussion. The higher thickness in south-east area (northern part of Madura) indicate the faster subsidence and sedimentation rate than western area.

DISCUSSION

The seismic boundaries and architectural elements are valuable information that can be used to correlate the incised-valleys to episodes of sea level variation as well as to identify the paleo-channels types. Paleo-channels plan view map resulted from previous study are shown in Figure 8. Generally, the main paleo-channels directed from west to east, encircle Bawean Island and then turned to south-east (Indriastomo et al, 1995). From isopach map we could also see that in the south-east area (northern Madura) faster subsidence and higher sedimentation rate occurred. This condition probably controlled by basin configuration developed on this area (Susilohadi and Soeprapto, 2015). Tjallingii et al (2010) discussed the relation of incised-valleys and their infill with variations in sea level. He also suggests that channel sinuosity is highly dependent on shelf slope and that channel lateral migration is correlated to periods of relative stable sea level. We use similar incised-channels as the infill of Tjallingii et al (2010) and correlate them to the sea level variations. As a result, three distinct stages of sea level were found: lowstand, transgression (rising in sea level) and “maximum transgression”. The fill of the incised-channel indicates a decrease in river flow competence due to the elevation of the base level during TST (Catuneanu et al, 2011), which resulted on vertical aggradation (Figure 7). During this phase, base level rose rapidly not allowing the channel to laterally move and sedimentation was concentrated on the deeper parts of the channel.

The Pleistocene-Holocene units distributed widely because of deposition on a relatively flat lying area. Mostly, the seismic character is similar, comprising subparallel reflection or almost reflection-free patterns at the bottom which represent marine sediments, topped by vast fluvial channeling. This succession repeated frequently, represent highstand and lowstand periods of sea level respectively. The fluvial channelling may be correlated with the major sea level lows during the Pleistocene - Holocene since the average water depth in the study area is about 60 meters (Indriastomo et al, 1995). Susilohadi and Soeprapto (2015) mentioned that the bases of youngest subunits, which correlated with facies SF3, SF2 and SF1 on this paper included are tentatively correlated with the glacial periods during oxygen isotope stages 6 of Harland et al (1989). During the glacial periods the Sunda Shelf became widely exposed, and river systems such as the Molengraaff river (Kuenen, 1950; Voris, 2000; Sathiamurthy and Voris, 2006) may have developed in the last glacial period. However, the acquisition of more precise chronostratigraphic information at incised-channels is necessary to confirm this hypothesis.

CONCLUSION

The internal structure of incised channels consists of chaotic reflector at the bottom, covered by parallel – sub parallel and almost reflection-free indicating the homogenous sediment deposited during the succession. The fill of the incised-channel indicates a decreasing river flow competence caused by elevation of base level during transgressive system tract, which resulted on vertical aggradation, The rapid rise of the base level did not allow the channel to laterally move and sedimentation was concentrated on the deeper parts of the channel. The Quaternary units distributed widely on a relatively flat lying area. Facies SF3, SF2 and SF1 are tentatively correlated with the glacial periods during oxygen isotope stages 6.

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