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Quaternary Incised Valleys and Low Stand Deltas Imaged with 3D seismic and 2D HR Profiles, Mahakam Delta, Indonesia.

The Late Pleistocene Mahakam delta was analysed using the shallow portions of several 3D seismic surveys combined with 2D high-resolution profiles. This study is particularly focussed on understanding the development of the low stand deltaics and the associated incised valleys formed during the 100 Ky duration high order glacio-eustatic cycles. The depositional geometries, and their morphological changes evolved throughout the relative sea level variations punctuating the Quaternary glacial ages.

Several continuous horizons have been picked manually or tracked automatically and revealed spectacular paleodepositional environment morphologies. The associated paleomorphologies and the observed shapes were compared and matched with the detailed internal sedimentary geometries seen on 2D HR profiles and 3D lines covering a large part of the shelf beyond the modern mahakam delta and also straddling the shelf break and the slope (Fig. 1).

Comparisons were made with the modern Mahakam delta, intensively studied by G.P. Allen and al. (1), which is currently used as an oversimplified analog to the Miocene reservoirs of the Kutei basin. The Mahakam delta is a mesotidal delta located in the Kutei basin (one of the largest Tertiary basin of Borneo) occupying a foreland

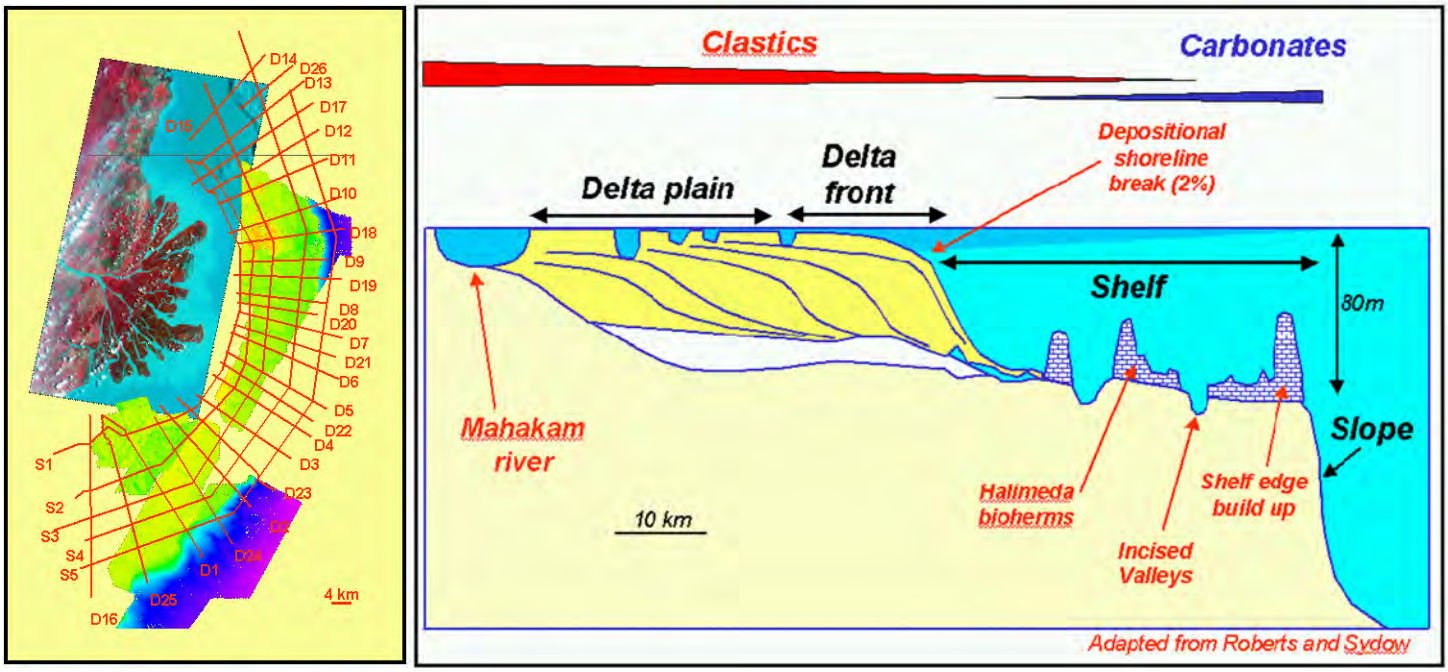

Figure 1 : The modern Mahakam delta has prograded 30 km over the shelf during the last 7000 years and the modern shelf physiography is characterised by mud erosive features and Halimeda Bioherms. Location of overlapping 3D surveys and 2D HR profiles located on the shelf and slope.

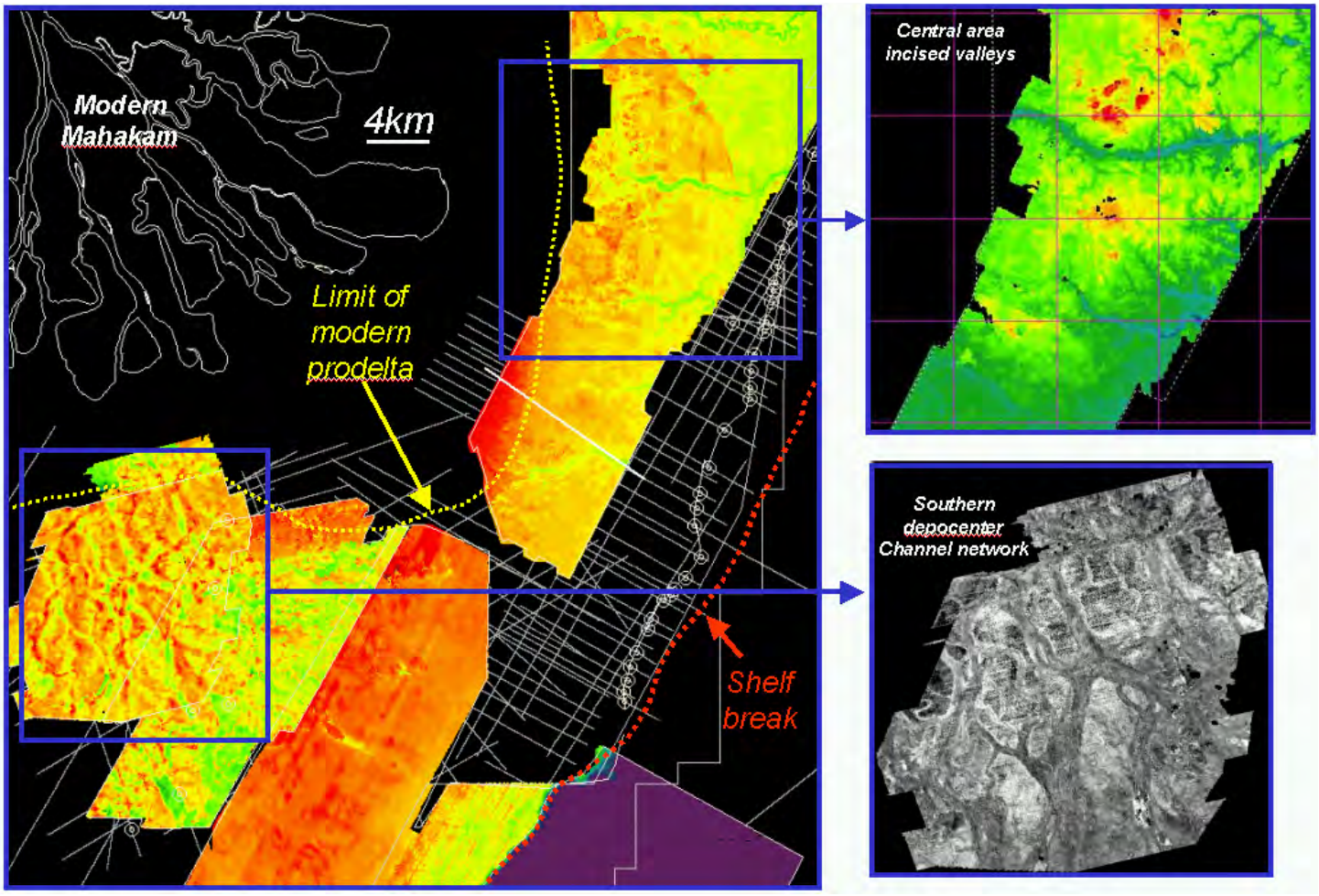

Figure 2 : 3D sea floor view of incised valleys with dendritic tributaries and coeval narrow channel network developed during late low stand on the Mahakam shelf.

depression on the eastern edge of the Malaysian craton. Since the mid-Miocene, the basin has accumulated over 5000 meters of deltaïc sediments on a rapidly subsiding shelf. The subaerial Mahakam delta has a lobate symmetrical geometry with a large intertidal delta plain composed of organic clay incised by distributary and tidal channels.

The late Pleistocene deltaïcs and the modern Mahakam delta deposits record a continuum evolution from an initial sea level rise followed by a period of sea level fall and by a transgressive period ending with the progradation of the modern high stand delta. Stratigraphic architecture of the late Pleistocene to modern Mahakam deltaïcs reflects the subtle interaction of eustacy, subsidence and synsedimentary tectonics and the resulting alternance of deltaïc clastics wedges and carbonate build up. The variety of sinuous shapes observed on 3D seismic images are illustrated (Fig.2) and should be looked with caution and not interpreted solely on the base of morphologies with simple comparison with those observed in the modern Mahakam delta.

Low stand deltas characterised on 2D HR profiles by prograding clinoforms were intensively studied by Roberts and Sydow (2). Clinoforms and associated erosive incised valleys reaching the shelf break, developed beyond the seaward limit of the high stand deltas (Fig. 2, 3 and 4).

During transgressive periods Halimeda alga carbonate buildups grew on the interfluve of incised valleys on the shelf forming irregular patches or narrow pinnacles mainly developed in the northern and central part of the shelf. The Halimeda bioherms are now being buried by the prograding clastics of the modern high stand Mahakam delta (Fig.4

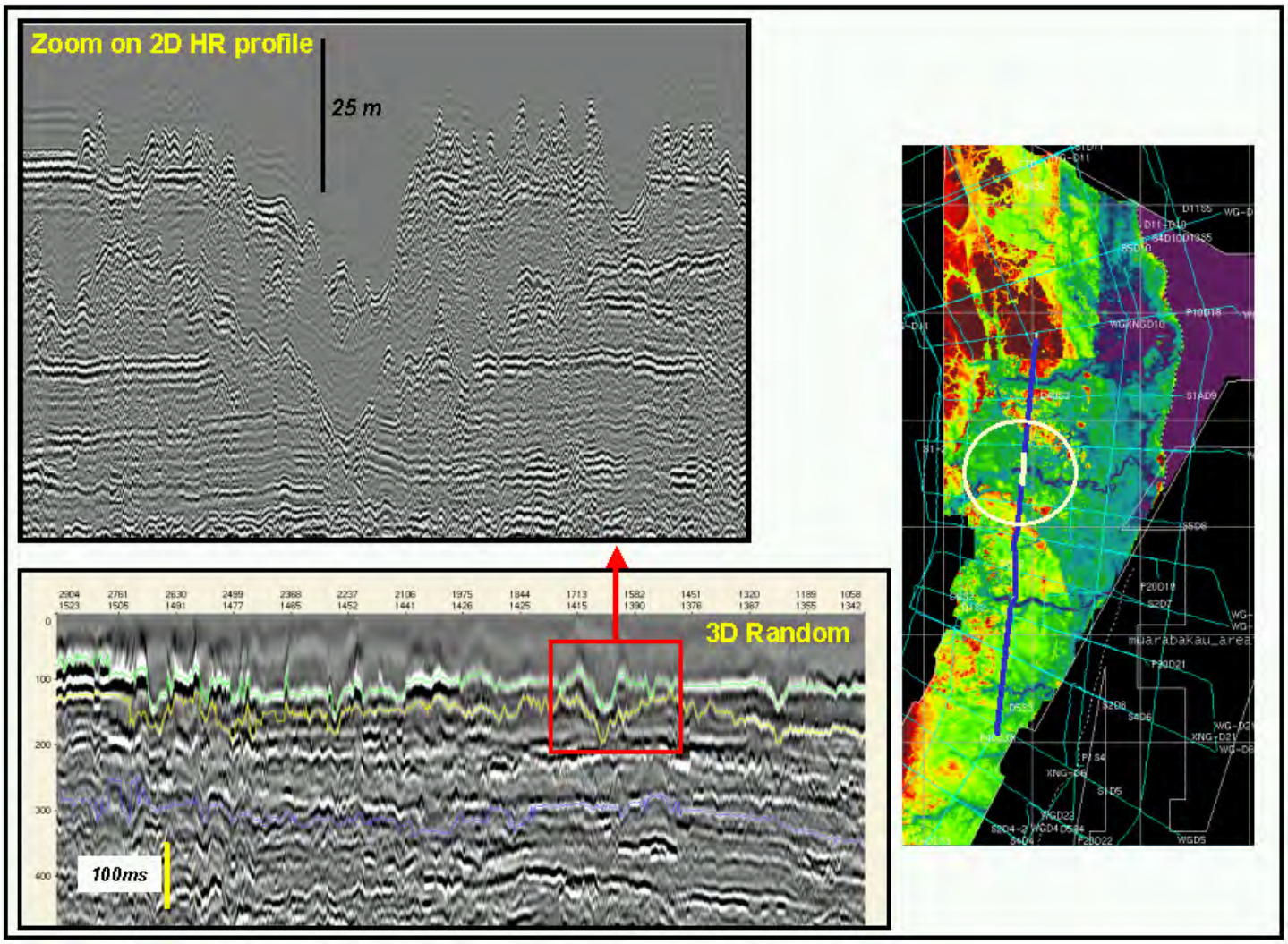

Figure 3 : 3D random and 2D HR profile showing an incised valley. Section location is showed on the amplitude map. At least three main incised valleys are recognised.

and 5).

Despite the differences in quality and some misties between the different 3D seismic surveys it has been possible to merge and pick the same main depositional surfaces on the 3D surveys and on the 2D HR profiles. Several 3D random lines were compared with the same 2D HR profiles. The 2D HR seismic profiles were acquired by Louisiana State University in 1992-93. The survey is widely spaced on a grid covering most of the offshore area between the modern delta and the modern shelf edge. The 2D HR seismic profiles available in numerical format were loaded on Geoframe and worked with Sismage Research software.

While being very different in term of horizontal and vertical resolution, The 3D seismic and the 2D HR lines complement each other in many ways and the combined use of both type of data allow a deeper understanding of the Makakam shelf stratigraphy. The difference in lateral resolution is also obvious between the 3D volume data having a midpoint spacing of 12.5 m while the 2D HR is by definition two-dimensional. The erosive cuts seen on 2D HR with great detail can be interpreted as incised valleys only with the help of 3D images, which provide continuous plan views.

The 2D HR data is thus used mainly as a tool for looking at the internal geometry of the depositional elements while

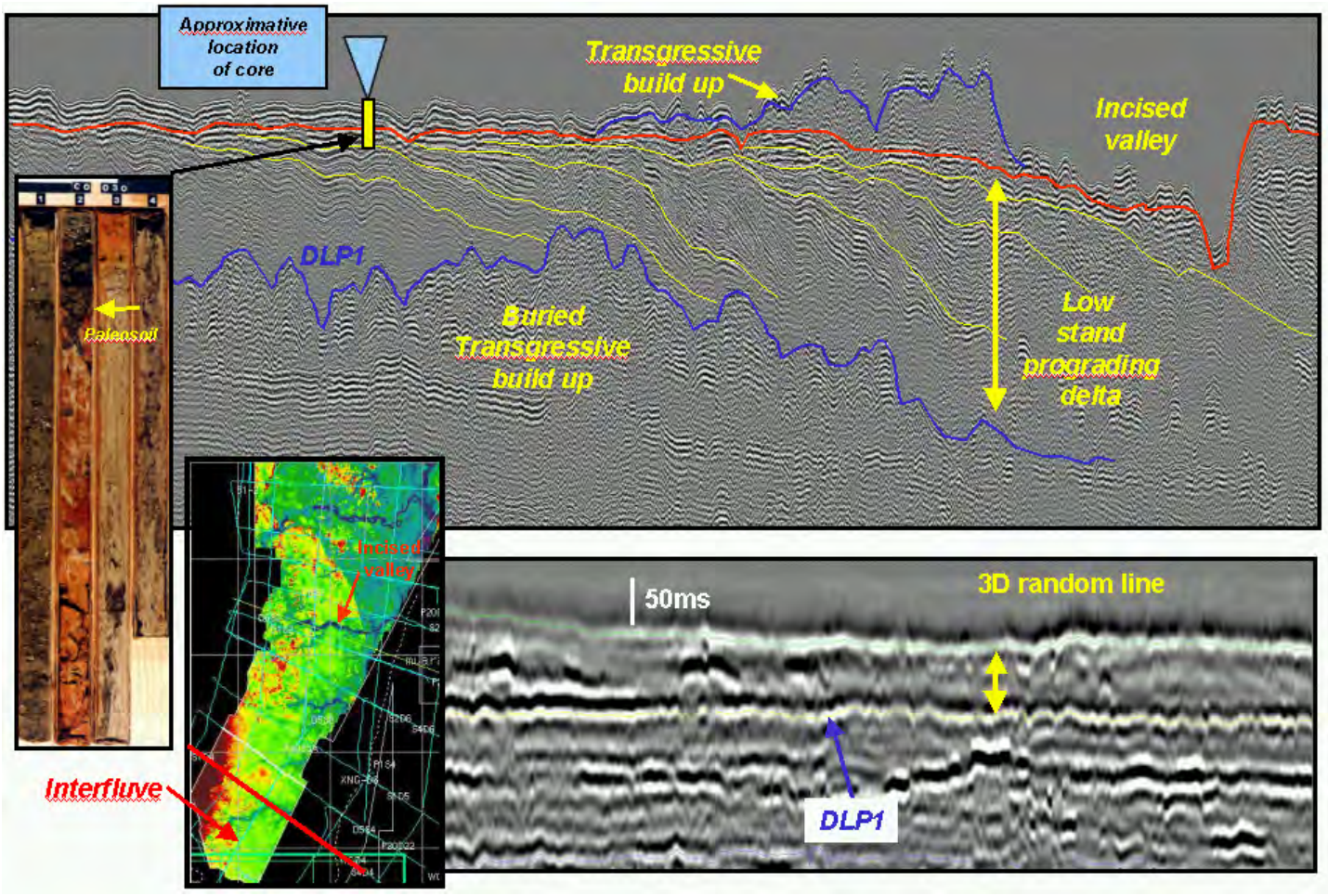

Figure 4 : 3D random and 2D line showing low stand prograding deltaics eroded by incised valleys with paleosoil development as demonstrated by cored section. DLP1 is the " master " S.B.

the 3D data is used to display images of the external architecture (i.e. paleolandscape). The comparison of these data highlights also the limits of stratigraphic and sedimentological interpretations derived from conventional 3D seismic slices and attribute maps.

Extensive mounded bioherms occur on the shelf mainly on the interfluve of the late low stand incised valleys. These bioherms with thicknesses up to 20 to 35 m, locally can form up to 40m large buildups along the shelf break. Halimeda algae are photosynthetic organisms which require clear water conditions for development. These conditions are optimum during transgression on the middle of the shelf and especially on top of uplifted faulted blocks seen on the northern and central part of the shelf. As noticed by Roberts and Sydow, modern Halimeda buildups are probably less active as a result of the activity of the modern Mahakam delta which brings a lot of muddy suspended sediments to the shelf.

The late Pleistocene succession has been subdivided using the most continuous correlatable surfaces (Fig. 3 and 4): These are downlap surfaces which were tracked semi-automatically to produce various time and attribute maps corresponding to the downlapping base of the low stand deltas clinoforms clearly seen on the 2D HR lines but also expressed on 3D seismic.

Similarly to the modern sea bed topography, the buried downlap surfaces are irregular surfaces formed by the

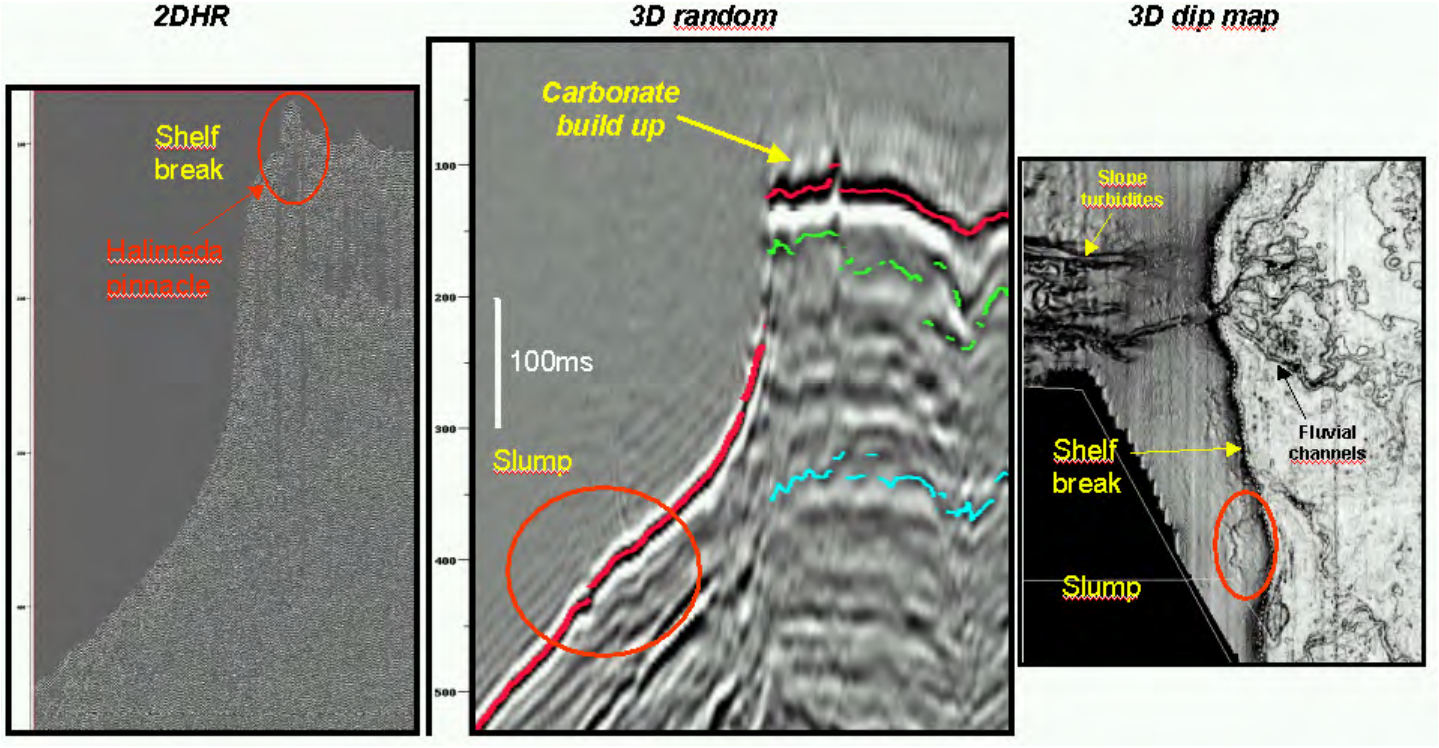

Figure 5 : 3D and 2D line showing shelf break physiography and Halimeda buildups

carbonate buildups buried by the prograding Mahakam delta front deposits and the negative relief of incised valleys. A significant improvement of sedimentary imagery was also obtained using various attributes and the Spectral Analysis tool of Sismage software.

The seismic architecture of the late Pleistocene is characterised by packages of seaward prograding clinoforms (Fig. 4) which are capped to the South by horizontally stratified beds dissected by a network of isolated narrow channels while to the North these are abruptly truncated by large erosional features. These are incised valleys conduits bounded by the mounded Halimeda pinnacles. Clinoform geometries represent the fossilised depositional profile of the prograding low stand deltas with delta front and prodelta deposits. The youngest prograding clinoforms are actually progressively covered by the prodelta mud in a 30 to 80 m water depth. The individual deltaïc clinoforms does not occupy the entire shelf and tend to stack in a compensatory fashion ((2) Roberts and Sydow). The horizontal bedded clinoforms tops were deposited in shallow marine water equivalent to the modern Mahakam delta plain and delta front.

The narrow channels forming the complex network inbedded in parallel strata show clear side-bars on 2D HR lines. These are interpreted as delta plain to delta front distributary channels sligthly incised occurring preferentially in the southern depocenter. A net work of erosive amalgamated shoestring channels were imaged with a contrasting 3D morphology compared with the incised valleys showing dentritic adjacent tributaries only present in the center and Northern part of the shelf (Fig.6 right).

The northern clinoforms have a clear toplap geometry truncated by incised valleys compared with the southern depocenter clinoforms showing a more progressive change from clinoforms into the parallel-bedded strata. This coeval contrasting style of deposition is related to the variation in subsidence style from North to South. The southern part being subject to pronounced active subsidence while to the North, uplifted faulted panels enhanced fluvial incision with paleosoil development in the interfluves during late low stand. The low stand deltaic wedges are

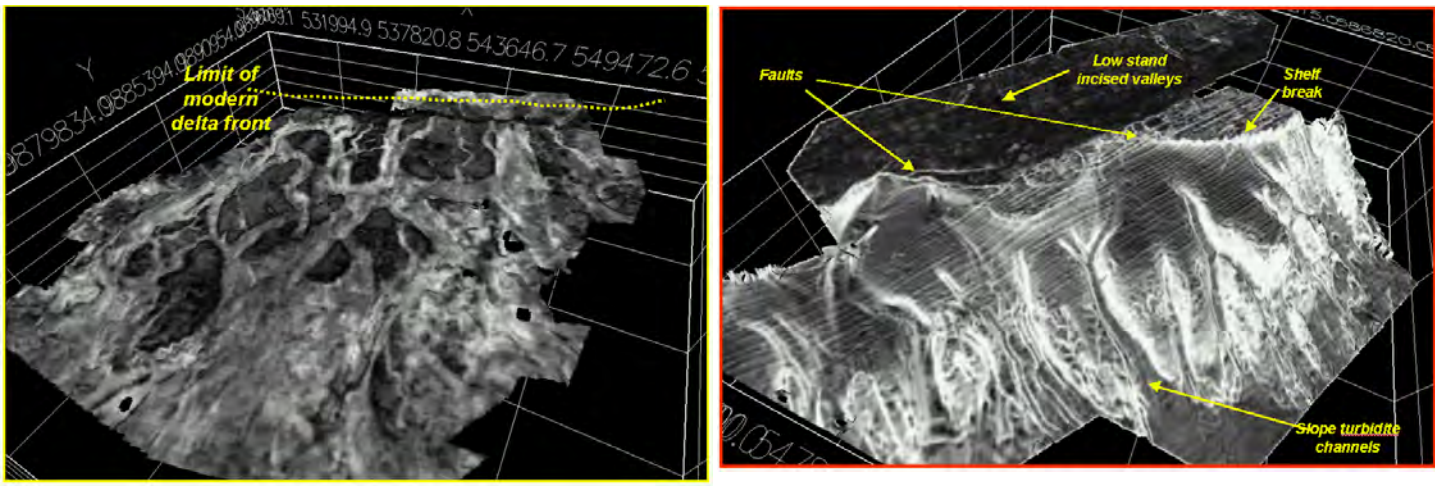

Figure 6 : Sea bed images : Left, shoestring delta plain channels (southern low stand depocenter) Right (see also fig.2), slope turbidite channels 3D view and faulted shelf break (Courtesy of PGS)

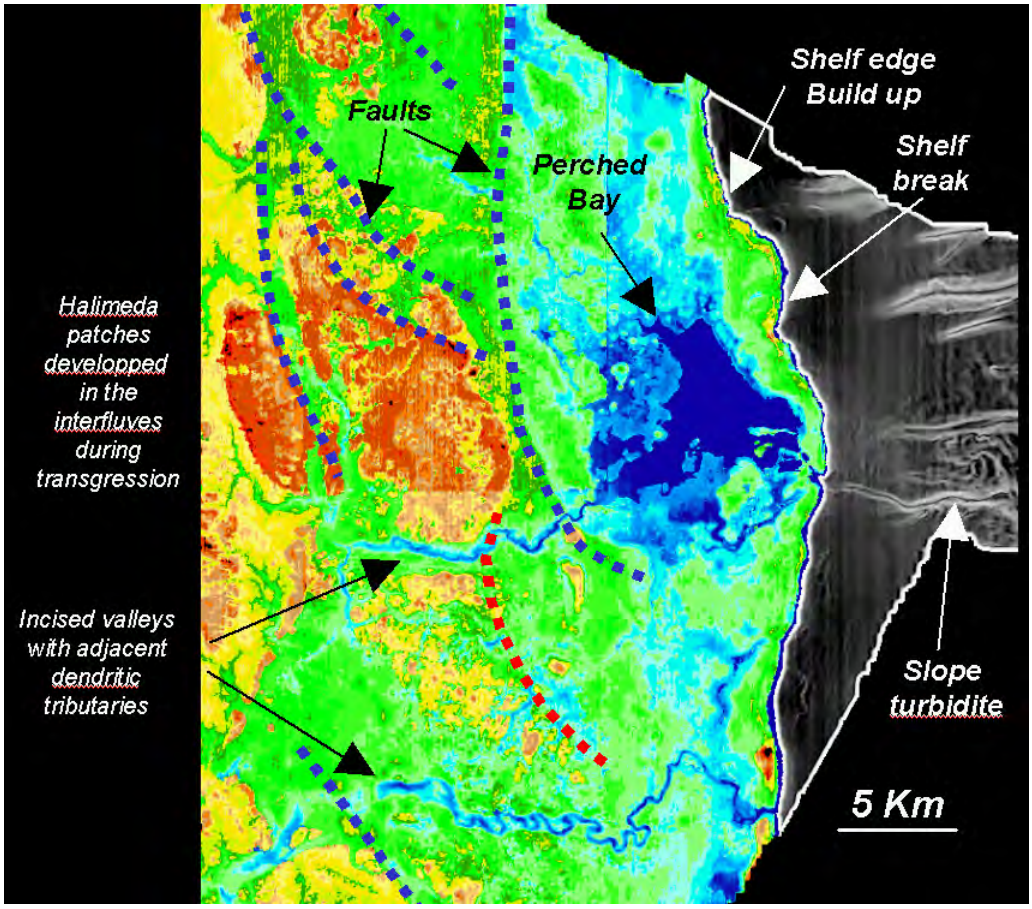

Figure 7 : Bay like perched depression delimited by faulted blocks and Halimeda bioherms.

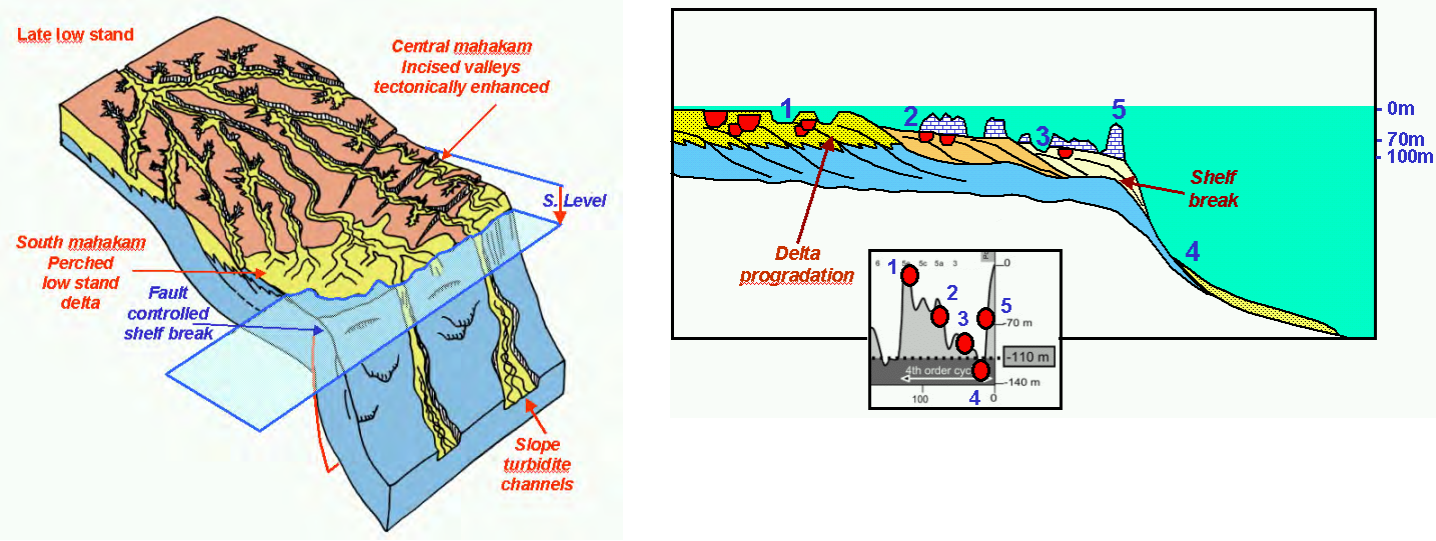

Figure 8 : Coeval contrasting style of low stand deposits recognised on the Mahakam shelf.

prograding near the shelf break during early low stand.

The morphology of the shelf break is also controlled by minor faults as seen on 3D sea floor images. A Large volume of sediments has moved down slope as debris flow and turbidites as the result of the shelf instability features and slump scars. This is due to the steep nature of the shelf break and the synsedimentary movement of faults controlling the geometry of the shelf break. Also sea floor images and horizon maps revealed that river incision occur near the shelf break during the latest Quaternary low stand period : As rivers reached the shelf break, these delivered their sediment discharge as flood related long lived turbidite currents.

The High stand deltaic deposits related to the early phase of progradation are restricted to a landward wedge of sediments partly cannibalised during the low stand period when distributaries formed during high stand are converted into incised valleys. Incised valleys represent by pass conduits for turbidite during late low stand periods and interfluves are the major site for paleosoil developement. The well-expressed regionally mappable surfaces are downlap surfaces corresponding to maximum flooding surfaces and the continuation of the " master " sequence boundary of Allen and Posamentier. These are draped during high stand by a thin drape of shale and buried by downlap clinoforms during early low stand.

Early formed clinoforms are progressively overridden and significantly incised by the advancing and downcutting fluvial system as the delta progrades during the later part of sea level fall. Thus, part of these earlier clinoforms could be located below the major sequence boundary. The fluvial deposits associated with incised valleys on the shelf belong to the late lowstand. Also incorporated in the Late low stand is the major volume of turbidite deposits which are deposited when fluvial incision reached the morphological shelf break.

Several erosional canyons identified on the upper slope (Fig. 6 left) are in continuation with fluvial valleys which incise the morphologic shelf break. Syn-sedimentary faulting created to the north some sort of shelf perched depression tectonically-induced with a bay like geometry. This embayement bay is fed few of the identified sinuous incised valleys clearly imaged with 3D. Seaward the tectonically induced embayement is bordered by a belts of transgressive halimeda reefs mainly buildup during ensuing transgression. To the south it seems that steady more active subsidence occur at the same time with less faulting. This continuous subsidence activity seems to have prevented rivers from being strongly incised and the resulting geometry of channels differ significantly from the deeper incised valleys. The observed channelised features forming smaller shoestring channels were formed in a delta plain during less prolonged period of emersion with less amount of incision as no evidence of dentritic erosive pattern

is observed. The southern more subsiding depocenter is recording a more continuous deposition with less erosion compared to the more tectonically induced northern Mahakam shelf (Fig.8).

The Quaternary sequence of the Mahakam delta display a complete 3D picture of a high sediment-supply fluvial system incising the shelf break with morphological lateral variations resulting from the varying effect of subsidence and fault tectonics developed during a 100Kyears duration cycle.

(1) Allen G.P. , Laurier D., and Thouvenin, J., 1979, notes et memoires, V.15 : Total, Paris 154 p
(2) Roberts H. and Sydow J. Late Quaternary Stratigraphy and Sedimentology of the offshore Mahakam delta , in Press, Deltas of the Asia Pacific Region, SEPM Special Publication.