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Correlation of Sequences and Changes in Facies across Shelf Margin using Core and Seismic Data Offshore Canterbury Basin

Kachalla, Aliyuda [α], Helen Lever [σ], Musa Bappah Usman [ρ], Usman Abubakar [ω] & Abdulwahab Mohammed Bello [¥]

Abstract- Canterbury basin covers an approximate area of 40,000 km², Canterbury basin is largely an offshore basin extending slightly onshore southward across Canterbury plains and to the Southern Alps. This work aimed to correlates seismic sequences boundaries earlier interpreted with sedimentary sequence surfaces observed in cores recovered from the four sites drilled across the shelf by expedition 317. This work utilises well data obtained from Integrated Ocean Drilling Program (IODP) expedition 317. The expedition which targeted stratigraphic seismic sequences earlier interpreted from the seismic data acquired on the eastern margin of the south island of New Zealand (offshore Canterbury). Three synthetic seismograms were created from well U1351B, U1353C and U1352B which both contain sets of sonic and density logs at variable length, this is to provide a direct means of comparison between the sequence boundaries interpreted on seismic and the depth on cores recovered from holes transecting on the seismic profiles. From the interpretation, nineteen boundaries were identified (U1-U19), these boundaries can be broadly divided into two large units. From U19-U11 (the upper units), it's dominated by downlapped seismic termination pattern along the paleoshelve and truncation surfaces across the shelve edge around site U1351B, a number of channel incisions were observed in this profile. The lower units (from U10-U5) consist of less truncation but more common onlap on paleoshelves, it features more drift deposits with sigmoidal reflection pattern. The nineteen seismic sequences boundaries correlate perfectly with sharp contacts between sandstone and mud/shale on the core sections, however few are gradational contacts.

I. Introduction

The study area lies in the eastern side of south island of New Zealand, part of a continental fragment that consist the Canterbury plain to the North, Campbell plateau to the Southeast and Chatham rise slightly northeast (Fig. 1). Canterbury basin covers an approximate area of 40,000 km², accumulating sediment since the rifting of the shelf margin from Antarctica in Cretaceous.

This research utilises well data obtained from Integrated Ocean Drilling Program (IODP) expedition 317. The expedition which targeted stratigraphic seismic sequences earlier interpreted from the MCS seismic data acquired on the eastern margin of the south island of New Zealand (offshore Canterbury).

This work aimed to correlates seismic sequences boundaries earlier interpreted by Lu and Fulthorpe (2004) with sedimentary sequence surfaces observed in cores recovered from the four sites drilled across the shelf by expedition 317. From the earlier acquired MCS EW00-01 data, nineteen seismic sequences were interpreted, ranging from Miocene to Recent in age. Such interpretation was based on standard interpretation techniques identifying reflection termination patterns such as onlap, downlap and truncations.

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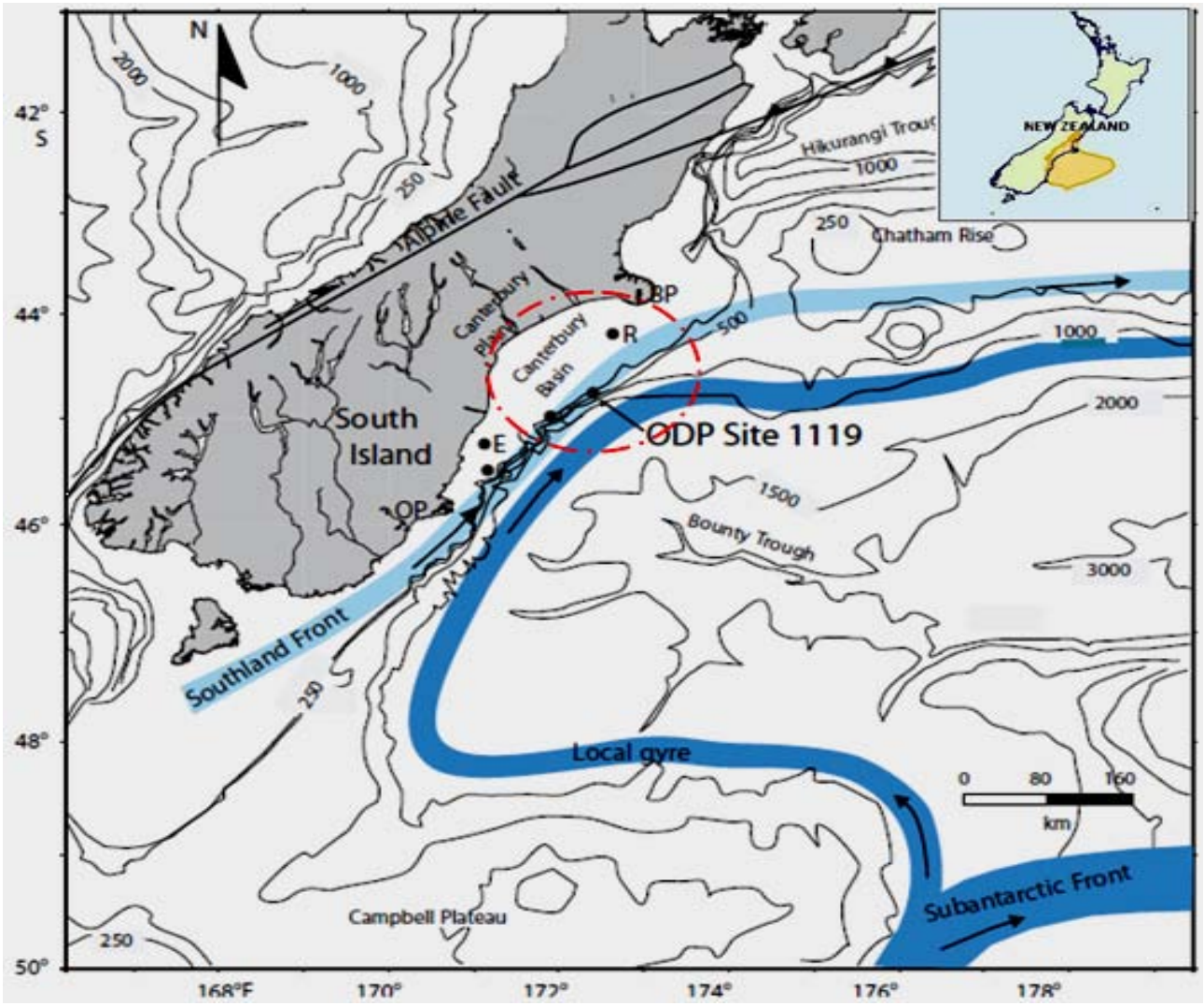

Fig. 1: Location map of the study area, Canterbury basin is circled in black; the Alpine fault is at the boundary of Australian plate with Pacific. Directions of oceanographic currents are shown in thick blue and light green. Also location of four exploration wells, Resolution =R, Clipper =C, Endeavour =E, and Galleon =G as well as Ocean Drilling Program (ODP) Site 1119 (modified from Fulthorpe et al, 2011).

a) Stratigraphy / Sedimentation

Sedimentation and stratigraphy of the basin consists traceable records of tectonic activities which created accommodation space for sediments infill. Hence, stratigraphy and sedimentation history would be discussed alongside tectonics. Sedimentation began about 80 Ma ago, before the rifting phase, the basin's variable facies reflect transgressive to regressive cycles with the Onekara, Kekenodon and Otakou Groups being the major packages deposited in various phases of sea level as transgressive, highstand and regressive deposits respectively (Carter and Carter, 1982; Lu and Fulthorpe, 2004).

Deposition of the regionally extensive pelagic to hemipelagic Amuri and weka pass Bioclast limestone Formations collectively called the Kekenodon group, consequently results from reduced terrigeous influx at maximum transgressive phase approximately 30 Ma. Marshall Paraconformity separates the two formations (Fig. 2C). Marshall paraconformity is confirmed from drill sites to be a regional paraconformity, extending to adjacent basins and throughout the east of the Tasmanian gateway. It is considered to represent the onset of thermohaline circulation from Separation of Australian and Antarctica about 33.7 Ma. The overlying Otakou Group is predominantly terrigenous with little amounts of mudstone and very fine to fine grained sandstone. It is dominated by siltstone and silty mudstone (Carter et al, 2004).

In Late Oligocene to Early Miocene Regression owing to Strike-slip movement that initiated Alpine fault increased rate of sediment supply. Rakaia, Rangitata, Pereora and Waitaki have provenance tied to the Southern Alps. These units are mainly coarse-grained sediments deposited in a river system (Fig. 2) (Lu and Fulthorpe, 2004).

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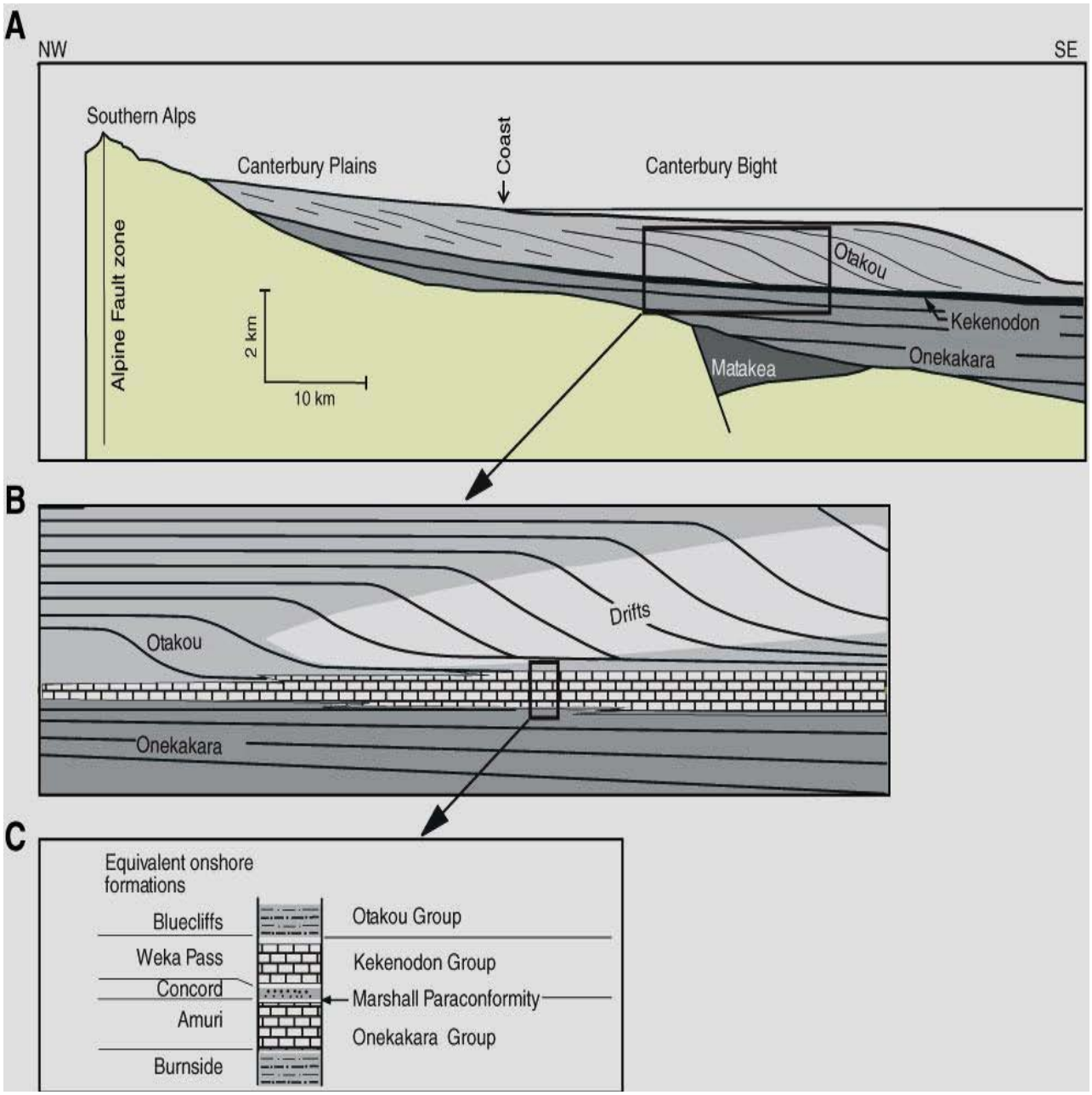

Fig. 2: Stratigraphy of the study area drilled by expedition 317 at three scales. A. large scale stratigraphy of the area at postrift phase showing the three major groups discussed above, Onekakara, Kekenodon deposited during transgression and high stand respectively while Otakou was deposited at regressive phase. B. At seismic scale, showing Otakou as drift deposits, limestone as distal facies. C. At outcrop scale showing the different facies of the various groups with their onshore equivalence (Lu and Fulthorpe, 2004).

II. Data

a) 2D Seismic Data

Data available for this project are obtained from the integrated Ocean Drilling Project Expedition 317. However, the two-dimensional high resolution seismic data was acquired by Maurice Ewing in January 2000. The EW00-01 grid lies between the Banks and the Otago peninsulas along the middle to outer shelf and slope offshore in water depth of 40-1100 m (Fig. 3). Source for the seismic acquisition of EW00-01 is two GI air guns (45/45in3). The survey yielded a total of 57 profiles approximately 3250 line-km with approximately 4840 km2 coverage. Spacing of seismic lines perpendicular to the margin is 0.7-3 km in the dip direction while along the strike direction 5.5km parallel to the margin. Vertical resolution is sufficient, within the upper 0.5 s which is approximately 5 m, sufficiently penetrated the Oligocene to Holocene section below the sea floor.

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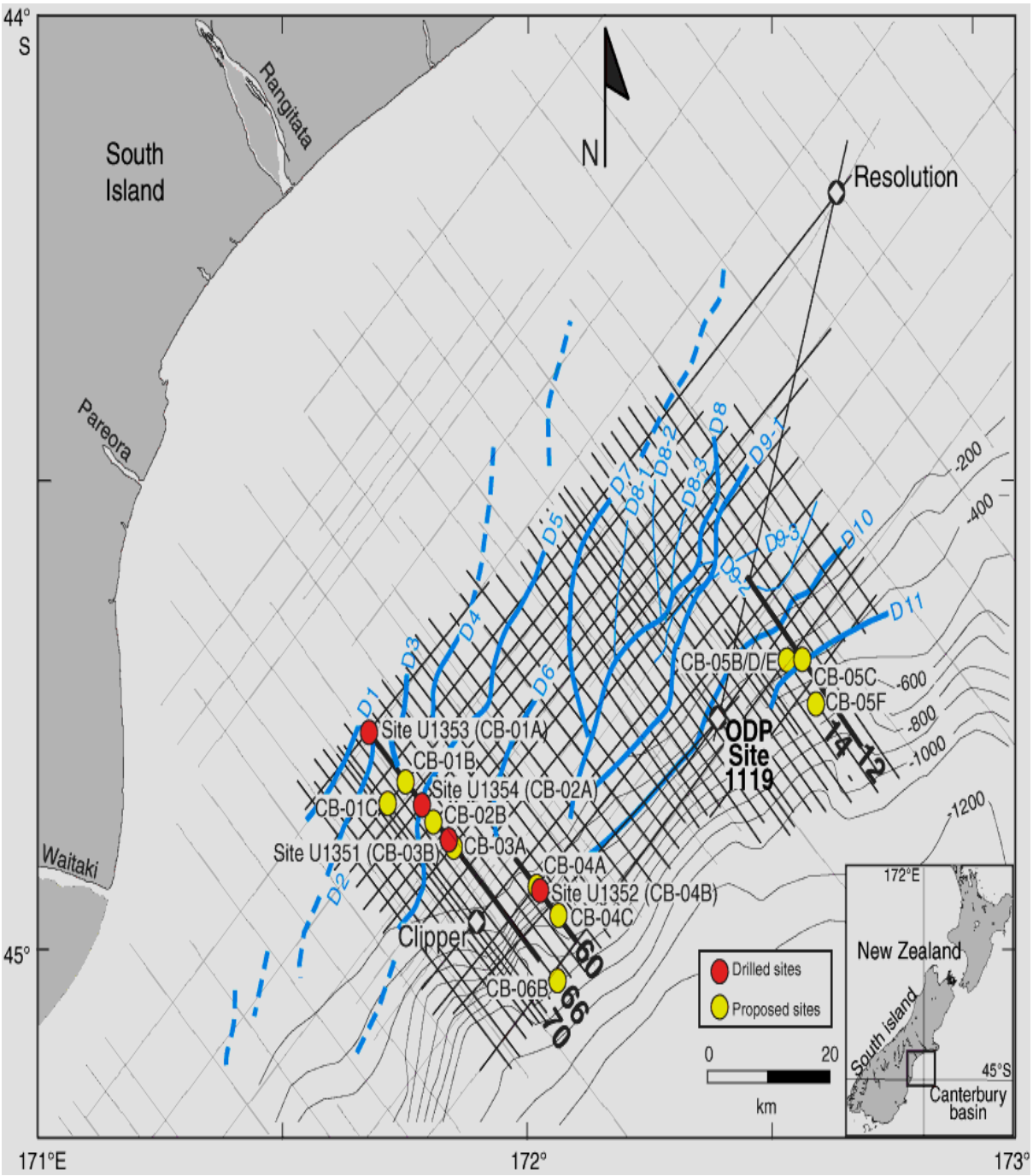

Fig. 3: Seismic Survey Grid (Expedition 317 Scientists, 2011).

b) Well Data

Well data available for this project came from four different sites all within the seismic survey grid EW00-01 (Fig. 3). Sites designated for drilling were planned before the expedition targeting most appropriate trajectories transecting sequence boundaries earlier interpreted from seismic lines. Variable successes were attained in most holes drilled. Site U1351, U1354 and U1353 can be seen on EW00-01-66 seismic profile (Fig. 4B), while site U1352 can only be seen on the seismic profile EW00-01-60 (Fig. 4A). U1351 as well as the other two sites on seismic profile EW00-01-66 are located on continental shelf; U1352 is on the upper slope. Site U1351 is in a water depth of 122 m, three wells were drilled at the site namely; U1351A, 1351B and U1351C, hole U1351B attained maximum penetration depth of 1030.6 m DSF, hole U1351A and U1351C have penetration depths of 28.0 m DSF and 967.3 m DSF respectively. Well U1351C was not cored, it was drilled purposely for wireline logging, 27.3 m and 304.5 m of core were successfully recovered from hole U1351A and U1351B respectively. Four holes were drilled in site U1352. In site U1353, three holes were drilled, two holes cored (U1353A and U1353B).

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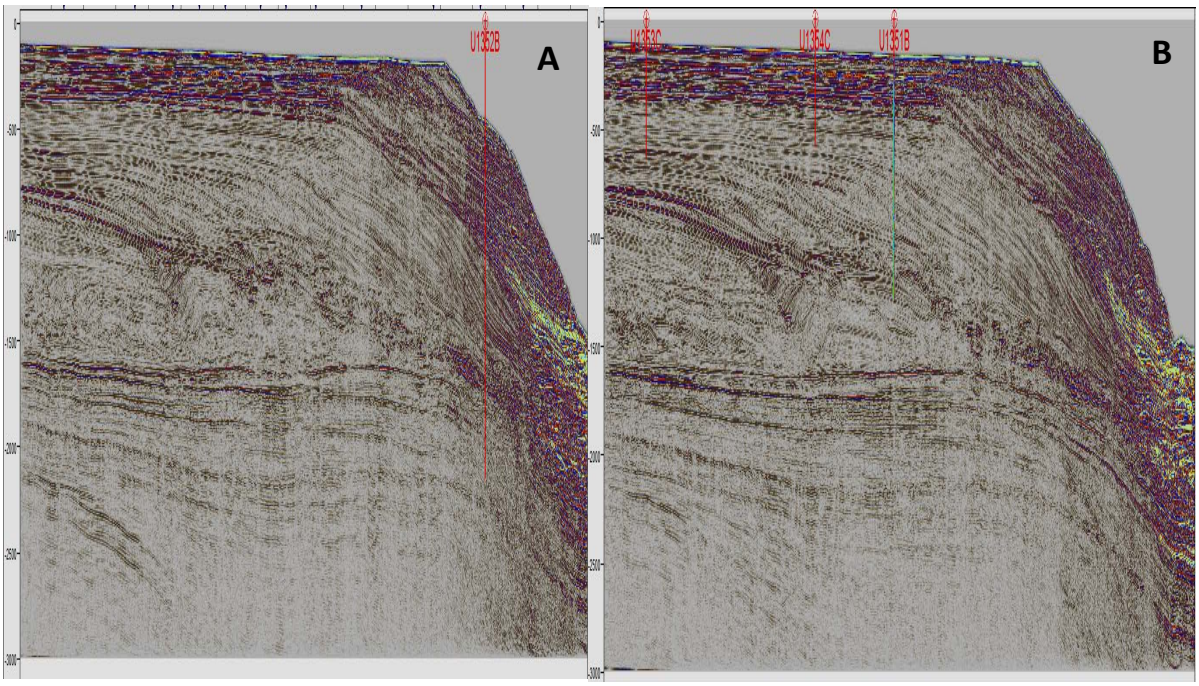

Fig. 4: Uninterpreted seismic profiles, A. showing the position of site U1352B on line 60 and B. showing sites U1351B, U1353C and U1354C wells drilled along the same profile on line 66 from petrel.

III. Methods

a) Two-Way Travel Time / Depth Conversion

The seismic data was taken in time, whereas, cores measurement is in meters, hence the need for two-way travel time to depth conservation. Conversion is required to enable correlation of sequences boundaries on actual core surfaces with sequence boundaries interpreted from seismic section. In this project two-way travel time to depth conversion was carried out using complete sonic and density logs available from Clipper-1 well (Fig. 5) which is within the survey area using Schlumberger petrel software 2013 version. This was done by creating a synthetic seismogram; the synthetic seismogram generated was compared with precruise synthetic seismogram from Lu and Fulthorpe (2004).

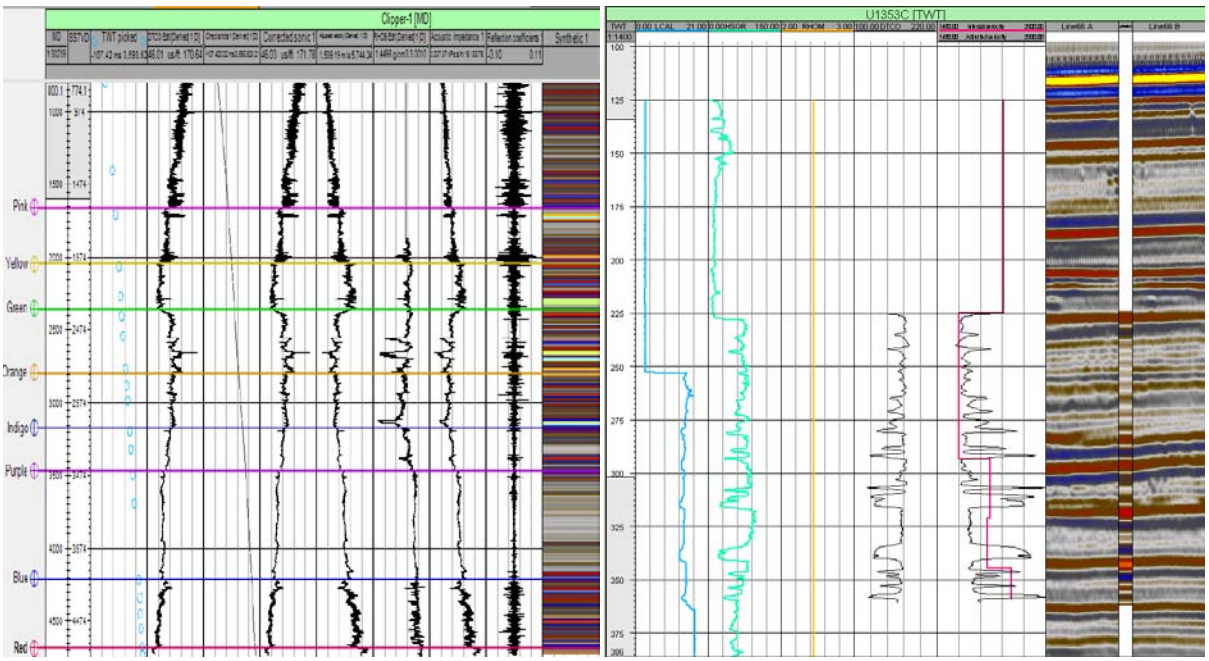

Fig. 5: Synthetic seismogram from clipper-1 well, from sonic and density logs covering the entire well interval for clipper-1, about 200 m for site U1353C.

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b) Identification of Sequence Boundaries in Cores (Core-Seismic Correlation)

From seismic data (EW00-01) earlier interpreted by Lu and Fulthorpe (2004), nineteen sequence boundaries were identified and interpreted (U1-U19), these boundaries were confirmed to be unconformities surfaces using fossils and carbon dating (Fig. 6). This interpretation was verified and further correlated with their actual depth in the cores provided. The actual sediment lithologic expression of the interpreted sequence boundaries in the cores were studied to determine the facie variation, sedimentary packages and lithologic discontinuity across the boundaries using the provided detailed core descriptions and high resolution core images. Identifying the boundaries based on rock type or lithology, with more emphasis on grain size contrast, nature of contacts, sedimentary packages and variability across the contacts. Emphasis was on the shallow boundaries considering the depth of penetration in the holes which provided the only gateway to the actual nature of sediments seen in cores.

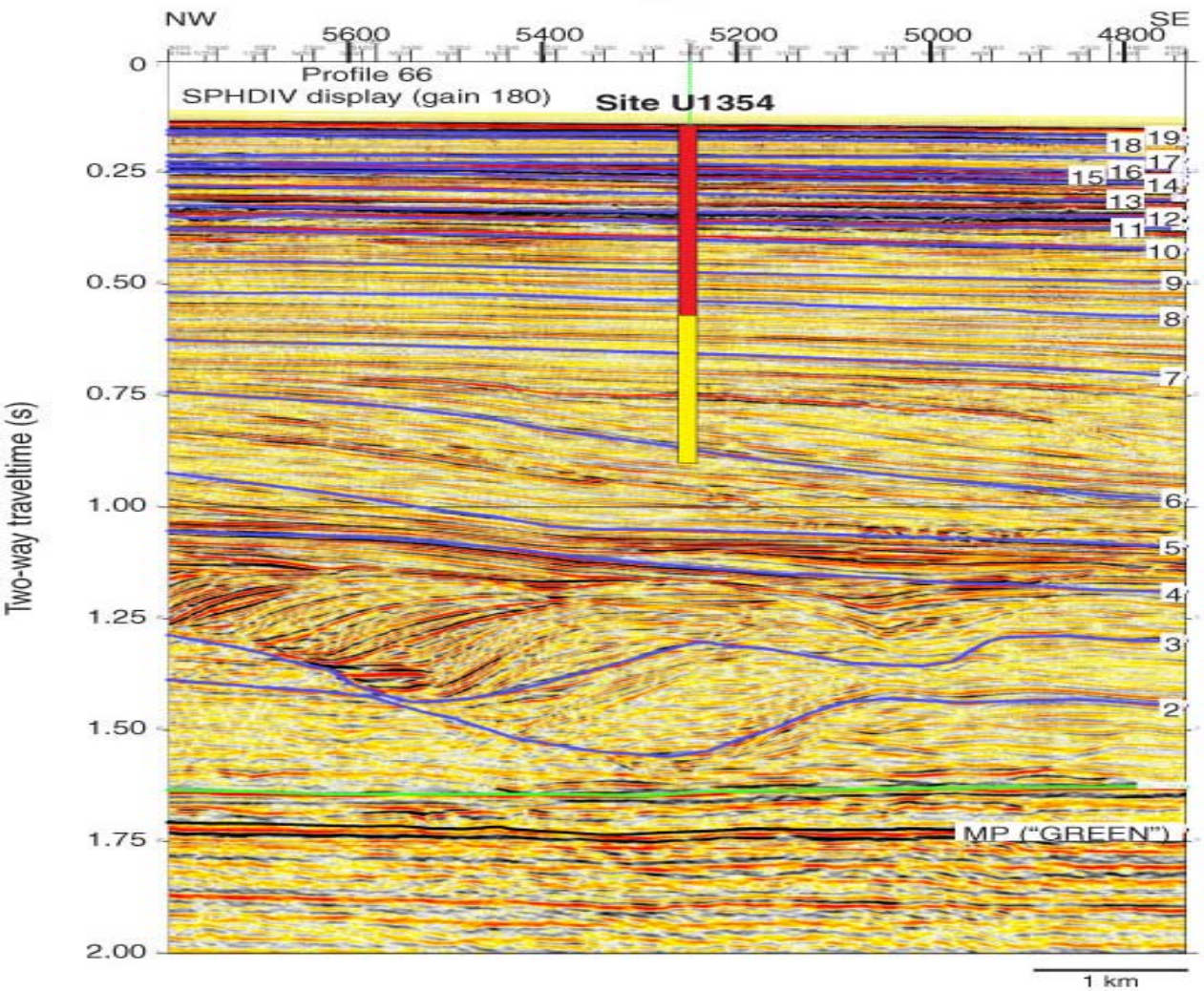

Fig. 6: Interpreted Seismic Section Profile EW00-01-66 Site U1354 (Expedition 317 Scientists, 2010).

IV. Results

Correlation of seismic interpreted sequences boundaries with the actual lithologic expression in cores were possible using seismic interpretation from Lu and Fulthorpe (2004). From the interpretation, nineteen boundaries were identified (U1-U19), these boundaries can be broadly divided into two large units. From U19-U11 (the upper units), it's dominated by downlapped seismic termination pattern along the paleoshelve and truncation surfaces across the shelve edge around site U1351B (Fig. 6), a number of channel incisions were observed in this profile. The lower units (from U10-U5) consist of less truncation but more common onlap on paleoshelves (Fig. 6), it features more drift deposits with sigmoidal reflection pattern.

Only sites U1351B and U1352B have both sonic and density logs hence 7 boundaries (U14-U8) in site U1351B and 7 boundaries (U19-U13) in site U1352B fall within the interval of the created synthetic seismogram. Other sites without synthetic seismogram cannot be correlated with much certainty due to lack of both sonic

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and density logs. However, for sites U1353 and U1354 two-way travel time picked at such boundaries were used in a function (equation 3) to determine the depth. The function was derived from check-shot data obtained from Clipper-1 well used by expedition 317 scientists (2011). The same classification and names for the different boundaries as Expedition 317 Scientists (2011) is adopted for this project with S(no) denoting a lithologic surface and U(no) representing a seismic sequence boundaries.

a) *Lithologic Expression of Sequence Boundaries at Site U1351*

Table 1: Sequence boundaries nature, of facies interpreted from core at the boundaries and between boundaries as observed from cores obtained from site U1351

Lithologic Surface	Overlying Lithology	Sediment Expression at Contacts	Sequence Boundaries
S1	Clayey Mud	Sharp Contact Between Silty and Clayey Mud	U19
S2	Very Fine Sand	Sharp Contact, Intercalated in Mud	U18
S3	Mud	Sharp Contact, Thin Sand with Mud	U17
S4	Sandy Mud	Gradational Contact in Shelly Sand	U16
S5	Medium	Incomplete Core Recovery	U15
S6	Very Fine Shelly Sand	Sharp Contact with Mud	U13
S7	Muddy Sand	Sharp Contact with Clay Beneath	U12
S8	Very Fine Muddy Sand	Sharp Contact with Basal Silty Mud	U10

b) *Lithologic Expression of Sequence Boundaries at Site* U1352

Table 2: Sequence boundaries nature, of facies interpreted from core at the boundaries and between boundaries as observed from cores obtained from site U1352

Lithologic Surface	Overlying Lithology	Sediment Expression at Contacts	Sequence Boundaries
S1	Mud	Sharp Contact with Muddy Sand Beneath	U19
S2	Muddy Sand	Sharp Bioturbated Basal Contact	U18
S3	Muddy Sand	Sharp Highly Bioturbated Basal Contact with Mud Beneath	U17
S4	Muddy Sand	Sharp Bioturbated Basal Contact with Underlying Mud	U16
S5	Sandy Mud	Sharp Basal Contact Slightly Bioturbated	U15
S6	Sandy Mud	Sharp Bioturbated Basal Contact	U13
U1352C-S9	Limestone	Sharp Basal Contact With Marlstone Beneath	U9

V. Discussion / Conclusion

Cores recovered from four sites at different parts of the shelf to slope (site U1351, U1353 and U1354 at shelf to site U1352 at slope) had further consolidated previous seismic interpretation. Facie assemblages observed across the shelf were divided into units and sub units based on facie variability to facilitate depositional environment interpretation and facies successions during different stages of sea level. At site U1351, upper to middle part of lithostratigraphic unit I (50-150 m CSF) facie assemblages consist of upward fining shelly sandy mud which coarsens upward into sandy mud. The presence of lag deposits above an erosional contact with upward-fining intervals suggests a transgressive system tract which passes into highstand mud deposit above it. Coarsening-upward sandy mud sequences suggests prograding shoreline at low accommodation space (Expedition Scientists, 2011).

At site 1352, which is strategically located on the slope slightly different facie assemblages were observed. Divided into three units, unit I which represent series of downlapping reflection termination pattern as interpreted from seismic data, it's consists of few sedimentary structures and is being interpreted as lowstand delta front deposits. Slump deposits observed in the upper part of the unit may suggest deposition during high rate of sediment supply as part of a pro-delta environment. Sharp contacts associated with dark gray sand are interpreted as gravity flow deposits part of delta along the slope as mass flow deposit. The calcareous dominated unit II with sandy marlstone and minor sandy mudstone suggest pelagic to hemipelagic deposit. The marlstone is interpreted as drift deposit, calcareous nature of these units suggest condensed section formed during sediment starvation period (Expedition Scientists, 2011). Alternating nature of light-colored marlstone with dark mudstone and thin sand

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interval indicates fluctuation in sea level and change in water condition from quiescence period with deposition in deepwater setting with little terrigenous supply, mainly pelagic sediments to more turbulent period of current activities with deposition of mass flow deposit, drift; and increase in sediment supply with deposition of sand. Unit III is correlated with the regionally extensive Amuri limestone believed to be deposited in an outer shelf to slope setting (Field and Brown, 1989).

Multiple lithologic units can be seen in cores which can be easily identified as sequence boundaries existing near the predicted depth, making it difficult to identify the actual sequence boundaries from lithostratigraphic data alone in site U1352. These lithologic units have potentials to provide strong seismic impedance contrast, however, only a single reflector is visible on seismic section and is expected at the predicted depth. Possible explanation to this scenario is that this could be related to the vertical resolution of seismic data from acquisition. The ability of seismic to recognize individual closely spaced events or reflectors is limited to the pulse length; maximum resolution of seismic is from 1/4 to 1/8 of the dominant wavelength of the pulse. Typical vertical resolution for a reflection seismic survey with a dominant frequency of 50 HZ and average sedimentary velocity of 2.0 km/s is 10 m (Sheriff and Geldart, 1983). Hence, most of the reflectors seen and interpreted on seismic are believed to be an order of magnitude larger and stronger than the actual lithologic expression seen in cores.

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