

50th Kaikoura05



The Organising Committee extends a warm welcome to all delegates and visitors to Kaikoura, where it all began 50 years ago.

Please note that all information in this publication was correct at the time of going to print. However, due to factors beyond our immediate control, such as weather, road conditions and permission for land access, some unexpected late changes in field trip routes and itineraries may be required.

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Kaikoura

Field Trip Guides

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Field Trips 2 and 9

THE CONWAY FAN DELTA TERRACES AND THE UPLIFT OF THE HAWKESWOOD RANGE

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Introduction

Quaternary Gilbert-style fan deltas of the Conway Coast, New Zealand, are both formed and exposed as the result of rapid uplift and erosion of the Hawkeswood Range as part of the transpressional Marlborough Fault Zone (Pettinga and Armstrong, 1998). The Hawkeswood Range is a NE plunging growing anticline over an associated thrust fault (**Fig. 1**) (Pettinga and Armstrong, 1998; Hall, 2003) and the northeast verging Hundalee thrust Fault on the western side of the range (Pettinga and Armstrong, 1998). It is one of many anticlines forming in the hanging wall of thrust faults which are currently accommodating most of the ~30 mm/year shortening associated with the modern convergent plate boundary (Nicol, 1991). The fantastic uplift rate of the Hawkeswood anticline was first calculated as 3.1 mm/year based on correlating coastal terraces along the South Island (Ota et al., 1984), but was later revised to 2.9 mm/year for the Conway Coast (Ota et al., 1996). Recent work in the area by Hall (2003) calculated a similar ~2.9 mm/year uplift rate for the area. These uplift rates were calculated based on the assumption that the terrace features were uplifted beach surfaces.

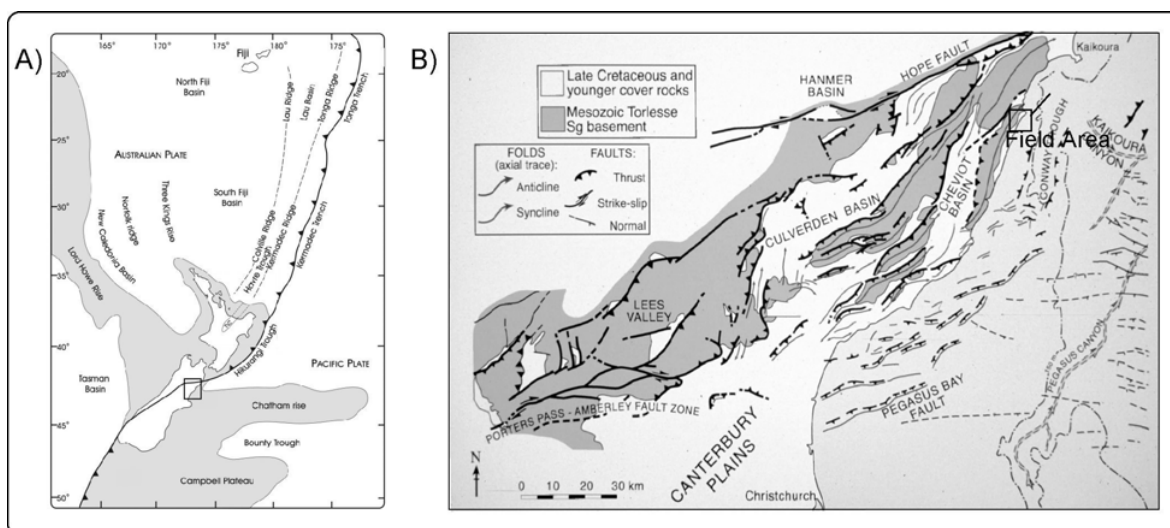


Figure 1: Map showing regional structural setting of the transpressional Marlborough Fault Zone (Pettinga and Armstrong, 1998). The Hawkeswood Range is a growing anticline formed in the hanging wall of a propagating thrust fault. The fan deltas formed on the east side of the Hawkeswood Range, marked by the rectangle.

Recent studies (McConnico and Bassett, 2003; McConnico and Bassett, 2004, McConnico et al, 2005) have found that the preserved terrace features are in fact a series of alluvial fans that have been dissected by eastward propagating thrust faults. Limited exposures make mapping difficult, but offset gravels and clast imbrication fabrics support this interpretation. The alluvial fans form Gilbert-style fan deltas where they enter the sea forming multiple terraces along the Conway Coast side of the Hawkeswood anticline. The flat-lying geomorphic expressions of the terraces have their origin in the tripartite geometry of Gilbert-style fan deltas. The rapid uplift of terraces and subsequent incision and erosion into the deposits expose complete sections with 3-dimensional exposure of Gilbert-style fan deltas in cliffs along the Coast. Cliff exposures are 50-70 meters high and expose continuous sections of Quaternary to Holocene strata. Outcrops also occur in recent slumps and in river gullies at 90° to the strike of the coastal sections thus providing 3-dimensional views of the fan deltas. The magnificent exposure of multiple Gilbert-style fan deltas provides an excellent opportunity to

observe and record the sedimentary facies architecture in terraces formed by the fan delta processes associated with rapid uplift.

Terrace Geomorphology

A series of 4 nested terraces with minor incised fluvial canyons can be identified. The Medina Terrace is the oldest and highest terrace and occurs in the southernmost portion of the field area along the coast. It is 2 km long and is 2 km wide at the widest point and has an elevation of ~10-15 m higher than the other terraces (**Fig. 2**). The terrace terminates to the west into the basement rocks of the Hawkeswood Range and to the east as a sea cliff containing fan delta deposits. The terrace surface is smooth and tilts slightly to the east and has one major west-to-east running creek dissecting the terrace.

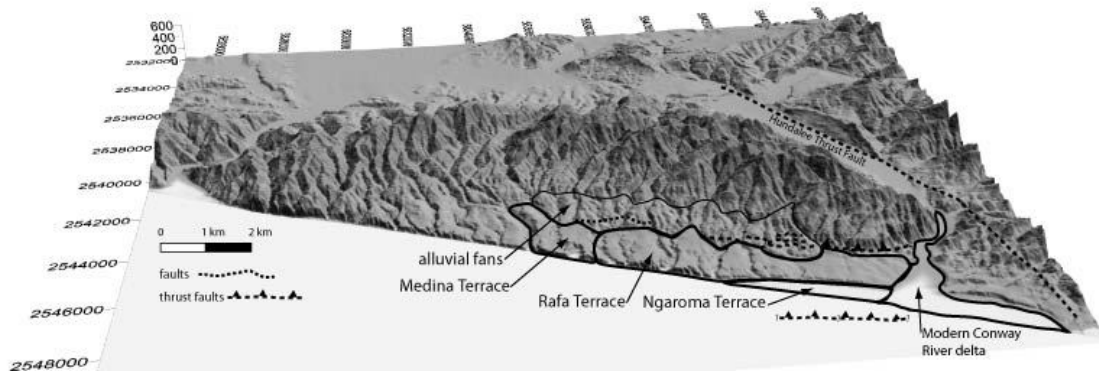


Figure 2: Map showing 4 nested terraces formed by fan deltas and the locality stops. The 4 terraces are, from north to south, the modern Conway delta, the Ngaroma Terrace, the Rafa Terrace, and the Medina Terrace. Trip 1 will focus on the Ngaroma and Rafa Terraces and Trip 2 will focus on the Medina Terrace.

The Medina Terrace is abruptly truncated to the north by incision and formation of the Rafa Terrace (**fig. 2**). The Rafa Terrace is 7 km long and up to 2.5 km wide and is ~10-15 m lower in elevation when compared to the Medina Terrace. The terrace terminates to the west into the basement rocks of the Hawkeswood Range and to the east as a sea cliff containing fan delta deposits. The surface slopes from the west to the east ~10-15° with minor undulations. There are 3 major drainages and several smaller creeks that dissect this terrace exposing associated fan delta plain topset deposits.

The Rafa Terrace is abruptly truncated to the north by incision and formation of the Ngaroma fluvial terrace (**fig. 2**). The Ngaroma Terrace is a large flat lying terrace bound to the south and west by a curvilinear contact with the Rafa Terrace and to the east by a coastal cliff containing estuary deposits. The terrace is 5 km long and up to 500 m wide. The Ngaroma Terrace has a noticeably smooth surface, is horizontal to the south near Ploughman’s Creek and is back tilted near the Conway River mouth at the coast. Several minor streams dissect the terrace.

The Ngaroma Terrace is truncated to the north by incision from the modern Conway River. The youngest terrace along the Conway coast is the currently forming delta of the Conway River (**Fig. 2**). The southern and northern boundaries are erosional scarps into the Ngaroma Terrace deposits. The fluvial gravels of the Conway River dominate the surface morphology with the delta gently dipping towards the sea.

Within the nested terraces are several remnant fluvial terraces along the edges of incised canyons. The fluvial terraces can be up to 500 m long and 50 m wide and are often very subtle, rounded and grass covered. The slope of the terrace surfaces is the same as the modern drainages in which they sit.

Sedimentary Lithofacies

The depositional environments that formed each of the terraces are exposed in beach cliffs and in the walls of deeply incised streams. These include older (Pliocene?) marine deposits, fan delta topset fluvial and estuary deposits, fan delta foreset deposits, pro-delta deposits, and interfan shallow marine deposits (fig. 3).

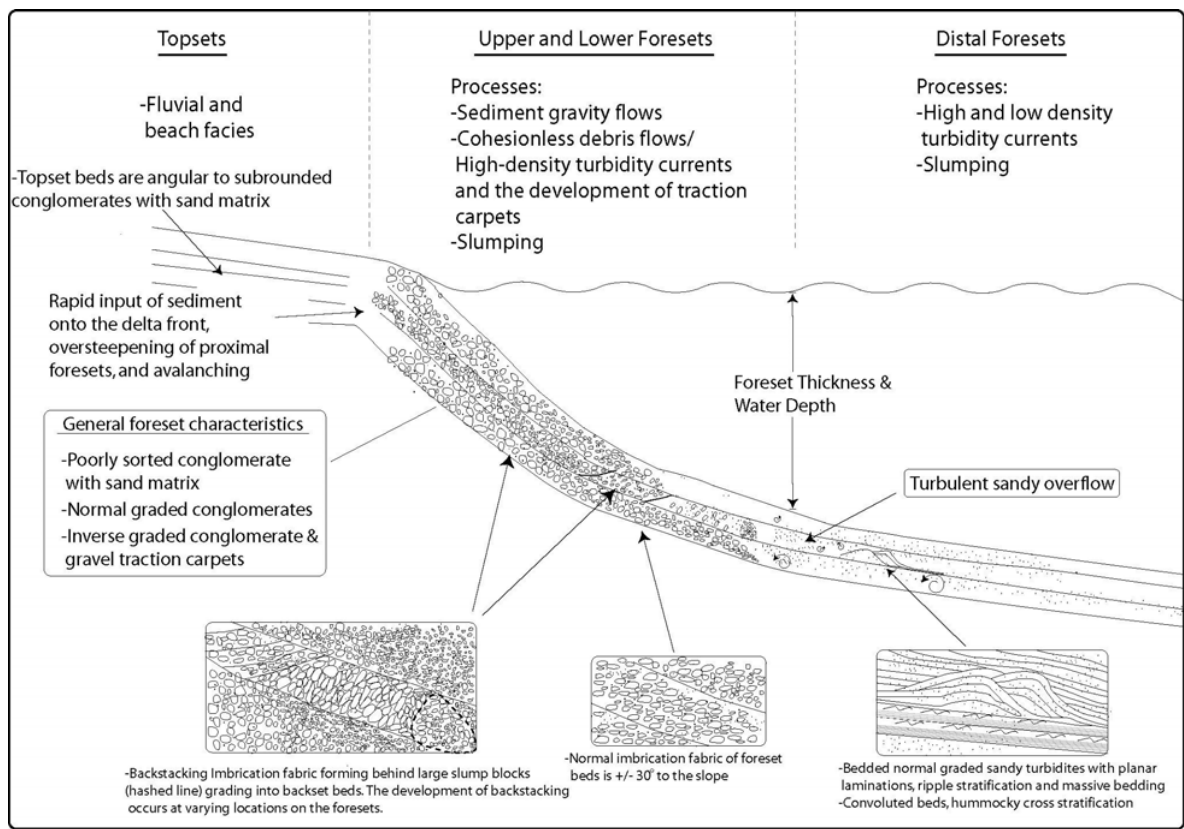


Figure 3: Schematic model of depositional processes on a Gilbert-style gravelly fan delta. Note the debris flow and fluvial bedload processes on the delta plain, the beach processes on the delta front, and slumping, debris flow, and high density turbidity currents on the delta foreset slope.

The older Marine deposits are comprised of dark muds that are occasionally interbedded with light grey, very fine silts. They contain rare laminations, are bedded, and sometimes display large scale cross bedding, slumping, and convoluted bedding. These occur beneath fan delta deposits of the Medina and Rafa Terraces and as a remnant high in the Ngaroma Terrace.

Prodelta mudstone beds typically contain diagnostic fossils, including *Zeacolpus symerricus*, and macroscopic carbonaceous material throughout (Ekdale and Lewis, 1991). The muds are comprised of matrix-supported, chaotic shell beds with random clasts indicative of debris flow deposition. They are similar to the older marine facies, however, a few diagnostic characteristic separate them easily: 1) the presence of shell material, 2) matrix supported, beds

containing shells and random clasts associated with debris flows, and 3) chaotic beds associated with slumps. Prodelta mudstones occur in the Medina and Rafa Terrace deposits.

The interfan nearshore marine facies comprises mainly yellow-grey, very fine-grained silt/mud, very fine-grained sand and rare interbedded gravels. Silt beds (2-25 cm thick) are continuous and dip $<2^\circ$ to the northeast. The beds often exhibit areas of slumping and convoluted bedding and rare hummocky cross-stratification. The interbedded sand and gravel layers are lenticular (Lewis and Ekdale, 1991). The diagnostic features of the interfan nearshore lithofacies that separate it from both the older marine and prodelta lithofacies are: 1) increased amount of silt, 2) more slumps, 3) interbedded fluvial gravels near the top of the sections, 4) lack of shell material and 5) increased carbonaceous material. The interfan marine deposits occur primarily in the Rafa Terrace along the north edge in Ploughman's Ck.

Fan delta foreset beds (**fig. 3**) are made of a series of stacked gravel beds (up to 50 cm thick) periodically parted by silt beds (up to 15 cm thick). Foreset beds dip to the northeast $\sim 10^\circ$ near the toe to $\sim 30^\circ$ near the top. Gravel beds fine towards the toe with silt beds thickening. The gravel layers are either moderately sorted and clast-supported with high percentages of sand matrix or poorly sorted and matrix supported. Clasts are well rounded to subangular and range from cobble to granule in size. In the clast supported gravel foresets, the clasts larger than 2 cm are usually horizontally imbricated. Slump features are relatively common in the fan delta foreset lithofacies. The foreset material is interpreted as deposited by sediment gravity flows, including grain flow, debris flow or high-density turbidity current, originating mainly from slumps or bottom hugging fluvial currents (Lewis, 1976; Lewis 1980; Lewis et al., 1980; McConnico and Bassett, 2003; McConnico and Bassett, 2004). Well developed foreset deposits occur in both the Medina and Rafa Terraces.

Within the fan delta complex are rare, well-preserved delta front deposits (**fig. 3**). These are comprised of discontinuous, very well sorted, very well rounded, highly stratified, and seaward imbricated gravels with interbedded sands. These are interpreted as foreshore deposits shaped by the wave activity on the beach face. These can be seen primarily in the Rafa Terrace but also rarely in the Medina Terrace.

Fan delta plain alluvial topset beds (**fig. 3**) are visibly present but are often inaccessible at the tops of cliffs. There are two distinct topset bed units: 1) well stratified, clast supported conglomerates with rounded clasts that laterally grade into foreset beds and 2) poorly sorted, matrix supported breccias with angular clasts. The well stratified, clast supported gravels are interpreted as fluvial bedload deposits whereas the poorly sorted, matrix supported gravels are interpreted as debris flow deposits. These cover the entire surface of the Medina and Rafa Terraces and occur in incised fluvial terraces forming the alluvial fan delta surfaces.

Fan delta plain estuarine topset deposits along the Conway coast comprise mainly carbonaceous-rich mud with interbedded sands and gravels. Mud layers are dark gray, contain abundant carbonaceous material, abundant rhizoliths and rootlets up to 10 cm long, and syneresis cracks (Lewis and Ekdale, 1991). Sands and silts are laminated, with sands often displaying ripple laminations. Abundant wood pieces are present ranging from <1 cm fragments to 5 cm thick pieces. Gravels are poorly sorted and matrix supported or well stratified and clast supported interpreted as debris flow and fluvial stream flow deposits respectively. Rooted in the gravels is an in situ ~ 8000 BP Podocarp forest (Ota et al, 1984; Lewis and Ekdale, 1991). These primarily occur in the Ngaroma Terrace and the modern Conway delta.

Tectonics vs. Eustatic Sealevel

The depositional/erosional patterns of the terraces exposed along the Conway Coast probably represent a complex play between active tectonics and relative rise and falls in sea level. Relative sea level rise and fall could have created the water depths needed to produce the multiple cut and fill stages recorded within the terraces. Since the beginning of the Quaternary there have been major rise and falls in sea level (Schulmeister and Kirk, 1993; Ota et al., 1996). Most notably, rises around at 130 Ka and 12 Ka and major falls beginning around 120 Ka and 30 Ka with many other minor falls occurring also. These major rises and falls in sea level throughout the Quaternary could each account for periods of cut and fill, superimposed on the gradual uplift of the Hawkeswood Range.

Alternatively, each incision episode could represent episodic uplift along the thrust faults associated with earthquakes. Such events could have triggered large scale slumping in the shallow marine deposits to the sides of the fan deltas. If the uplift and incision of the fan deltas corresponds to tectonic motions then the timing of the fan delta deposition and incision would not correspond with eustatic sea level rises and falls.

The key to connecting the regional and local tectonics with the periods of erosion and deposition is age control. Samples have been collected for Optically Stimulated Luminescence dating from the fan deltas and marine muds in hope of determining the exact relationship of sea level rise and fall to tectonics. 14C samples from the in situ podocarp forest in the Ngaroma Terrace have already returned a date of ~8,000 BP agreeing with previous dates (Ota et al., 1984).

Field Trip 2 (Pre-conference) - fan delta sedimentary processes

From Christchurch drive north on Hwy. 1 to the Conway River (~2 hrs.)
turn right (east) to coast
at fork turn right across bridge
drive to coast

Stops 1, 3, 4, 5, 6 and 7

Field Trip 9 (Post-conf.) - tectonic setting of multiple nested fan delta terraces

From Kaikoura drive south on Hwy. 1 to the Conway River (~1 hr.)
turn left (east) to coast
at fork turn right across bridge
drive to coast and south along coast

Stops 1, 2, 3, 7, 8 and 9

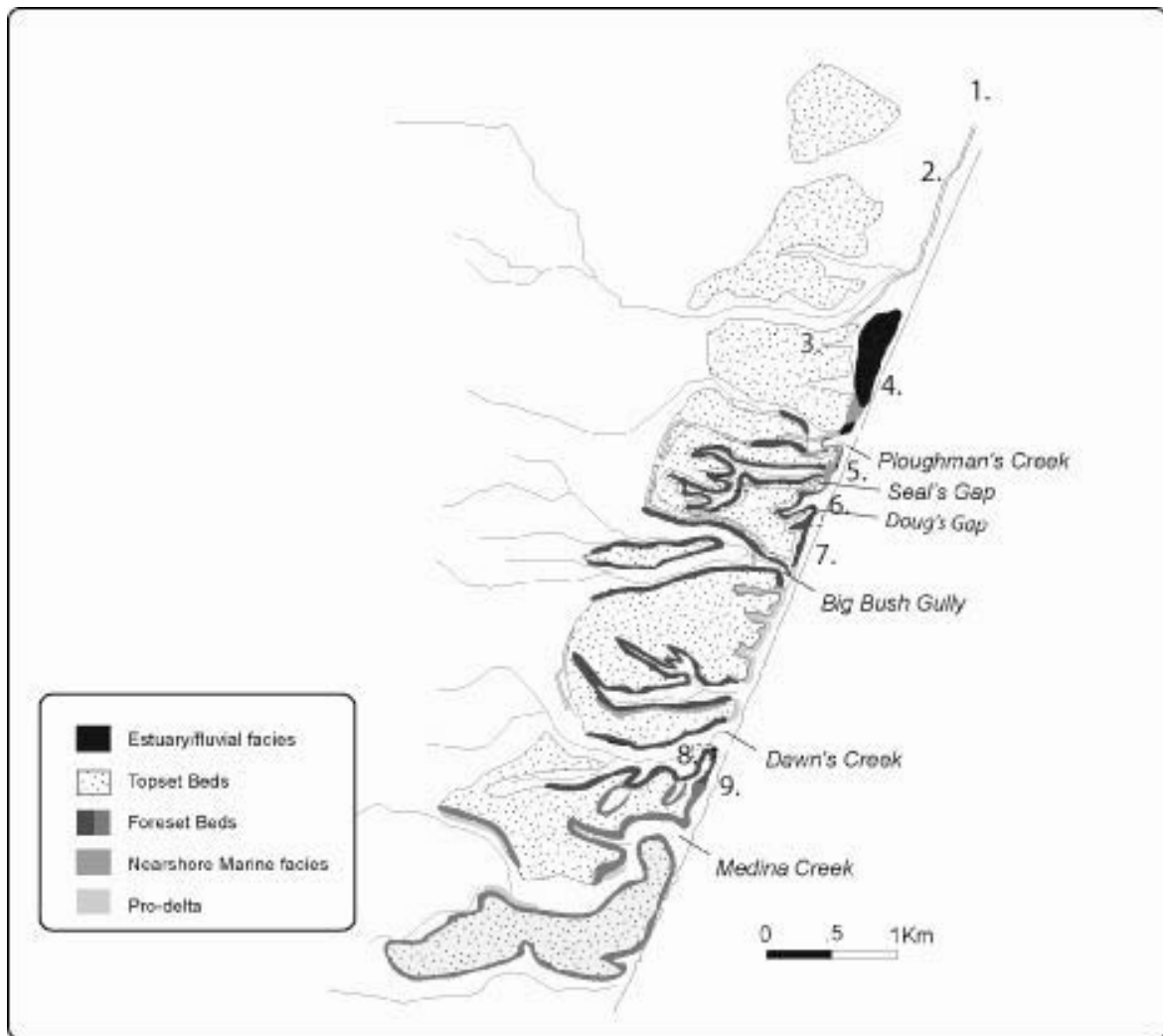


Figure 4: Map of both lithofacies and localities.

Stop 1 (On road near the mouth of the Conway River)

The youngest terrace along the Conway coast is the currently forming delta of the Conway River (**Fig. 2**). The modern Conway River is actively being deflected around the growing Hawkeswood anticline. The deflection of the river has created one of the numerous sets of inset terraces. The stacking of these terraces is probably a result of the play between tectonics and relative rise and falls in sea level. Note the delta surface morphology and depositional facies; delta front beach deposits for a thin strip with minor estuary deposits formed behind the beach barrier. The majority of the depositional facies is the fluvial delta plain topset beds.

Stop 2 (Ngaroma Terrace by the Ngaroma Shearing quarters)

The uplifted terraces preserved on the east side of the Hawkeswood range dip eastward with the exception of the Ngaroma Terrace (**Fig. 2**). The Ngaroma Terrace is also seaward dipping over most of its surface but the region near the Conway River is back tilted to the west. The back tilted section of the Ngaroma Terrace most likely overlies the active, deforming hanging wall of an eastward propagating thrust fault that roots in the Hawkeswood range.

Stop 3 (Top of the Rafa Terrace overlooking the Ngaroma Terrace)

The first example of the multiple stacking of terraces is evident by looking northwards from the contact between the Rafa and Ngaroma Terraces (*fig. 2*). The erosion of the Rafa Terrace, probably by the deflected ancient Conway River, was followed by deposition of the Ngaroma Terrace below. The terrace formed as an estuarine environment trapped behind a barrier beach similar to the modern system but on a larger scale. Unfortunately, due to its young age, there are only the coastal cliff exposures of the deposits (Stop 3).

Stop 4 (walking south along beach cliffs from road access to Ploughman's Gap)

The first outcrop scale connection of the nested terraces can be seen from the beach access southward along the beach cliffs to Ploughman's Creek (*Fig. 2*). Note the relatively low cliff height; this forms the Ngaroma Terrace. The exposed deposits are all of estuarine carbonaceous-rich mud beds with rhyzoliths and rootlets. These overlie rippled sands with abundant wood pieces (<1 cm - 5 cm) overlying gravel lenses that are either poorly sorted and matrix supported debris flow or clast supported fluvial bedload deposits. The ~8000 BP Podocarp forest (Ota et al, 1984) is rooted in the gravels of the estuary (Lewis and Ekdale, 1991). These probably formed slightly higher ground with better drainage for the trees to grow in than the surrounding estuary muds/grasslands.

Walking south along the beach to nearly at Ploughman's Creek, there is an increase in cliff height associated with an abrupt change in lithofacies to the older (Pliocene?) marine deposits. These formed a remnant high in the Ngaroma Terrace surrounded by the estuary deposits. Large scale slumps can be seen on the edges of this remnant high. On the south side of the remnant high, an incised fluvial terrace deposit can be seen with a log sticking out horizontally; this log has been dated at ~3,000 BP (Ota et al., 1984).

Just to the south of the incised fluvial deposit we return to the interbedded fluvial/estuary deposits of the Ngaroma Terrace on the north side of Ploughman's Creek. This is a fluvial gravel deposit within estuary muds with syneresis cracks. Rooted in the gravel is a podocarp tree. Ploughman's Creek itself incises the Rafa Terrace and forms the southern boundary of the Ngaroma Terrace; note the difference in both cliff height and lithofacies on the southern and northern banks of Ploughman's Creek.

Stop 5 (walking south along beach cliffs from Ploughman's Gap to Doug's Gap)

On the south side of Ploughman's Creek are the interfan marine nearshore sands and silts of the Rafa Terrace (*Fig. 2*). Walking up Ploughman's Creek we can see an example of slumping and convoluted bedding. Walking south along the beach we can see more slumping and rare- hummocky cross-stratification.

Walking southward along the beach cliffs, the nearshore marine sands become interbedded with more and more gravel lenses off the nearby fan delta foresets. Slumps become more evident as we approach the fan delta.

Stop 6 (Doug's Gap fan delta foresets of the Rafa Terrace)

Doug's Gap cuts through the middle of the fan delta providing a clear 3-dimensional view of the facies architecture (*Fig. 2*). On the north side of Doug's Gap are interesting ?levee? or hummocky cross-stratification deposits. On the south side are steeply dipping fan delta foresets overlain by well-developed beach deposits and then topset beds of a prograding fan delta. The beach deposits are extremely well rounded and well sorted gravels and contain abundant trace fossils. Doug's Gap preserves some the more interesting features from

depositional processes that occur on steep, gravelly foresets. Field evidence of traction carpets and flow transformations are well documented and support field observations of Falk and Dorsey (1998). This study also provides new information on the formation of unique clast imbrication fabrics in foreset deposits and descriptions of rarely preserved backset beds (e.g. Colella et al., 1987).

Horizontal imbrication fabrics commonly occur in the clast supported gravels of the foreset deposits in the Conway fan deltas (**fig. 5**). The clasts are strongly imbricated at $\sim 30^\circ$ in the upslope direction relative to the foreset slope dip. This creates a strong horizontal fabric developed from intergranular dispersive pressures in the traction carpet in a high density turbidity current. This contrasts with previous studies that show clast fabrics parallel to foreset bedding planes (e.g. Sohn et al., 1999).

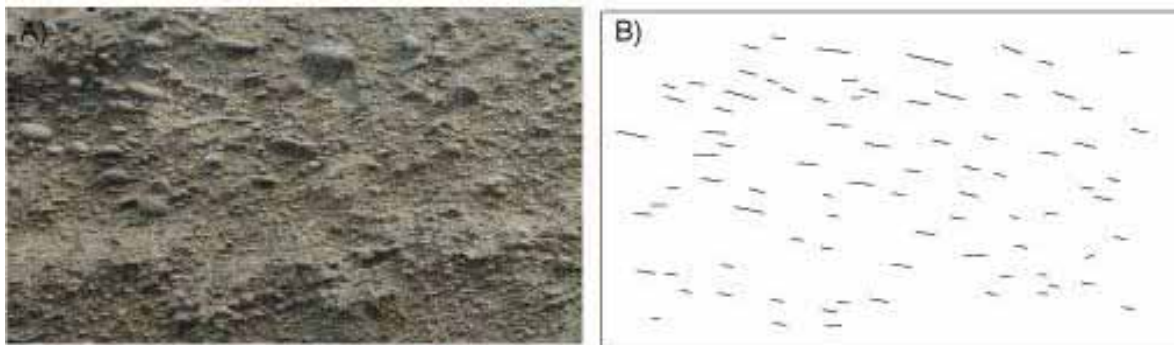


Figure 5: An example of horizontal imbrication fabric in the fan delta foresets.

Steep imbrication fabrics, referred to as ‘back stacking’, are also preserved in the fan delta foreset beds. The strong near vertical imbrication pattern visible near the mouth of Doug’s Gap has developed behind a slump feature. The clasts range from cobble to pebble with the orientation of the clasts creating a deformed fabric around the slump block. The clasts then ‘back stack’ up the slope with imbrication $\sim 75^\circ$ to the foreset slope gradually becoming less steep at the top.

Beds dipping upslope, opposite to the dip of the foreset beds, overlie and are in sharp contact with the back stacking clasts. Clasts in these beds are rounded, moderately to poorly sorted and oriented parallel to backset bedding planes. The grain size of the backset beds decreases in the down slope direction and individual beds decrease in length from >6 m to < 2 m as the depression on the foreset created by the slump is gradually infilled with each backset bed. These deposits are the result of down slope sediment transport infilling the depressions left by older slumps on the delta foresets (Colella, 1988) and are similar to the backset beds of Colella et al. (1987) in the Crati Basin (Postma, 1984).

Stop 7 (along the beach cliffs from Doug’s Gap to Big Bush Gully)

The fan delta foreset gravels continue in the beach cliffs as we walk south (**Fig. 2**). The steep dip of the foresets is not evident since we view the beds along strike thus providing an interesting view of the lateral evolution of the fan delta facies. We see the entire fan delta from just north of Doug’s Gap where gravels are interbedded with shallow marine nearshore sands to just north of Big Bush Gully where gravels incise into older marine muds and prodelta deposits in a spectacular sharp contact marked by large scale soft sediment load casting. Huge flame structures in the sands separate gravel pockets forming ball and pillow structures.

The foreset gravels incise pro-delta dark muds interbedded with occasional light grey, very fine silts. Mud/silt beds below the foreset beds of the fan deltas are massive and contain beds up to 1 m thick. Lamination in the muds is rare, but areas of soft sediment deformation are visible. The mud beds typically contain fossils, including *Zeacolpus symerricus* (Ekdale and Lewis 1991), and macroscopic carbonaceous material throughout. Interbedded with the mud are occasional sand and pebble layers. The shells in these beds are randomly oriented and on occasion exist as densely packed shell beds. The densely packed shell beds are interpreted to represent storm events. The appearance of periodic *Zeacolpus symerricus* shell horizons up to 7 cm thick that dip towards the shore favor formation by storm events. Other beds with isolated floating pebbles or shells within the muds can be explained by deposition of distal fine-grained debris flows. Deformation and cross-beds in the mud layers are due to failure of over steepened muddy slopes possibly triggered by seismic or storm events.

Stop 8 (Medina House-Dawn Creek)

The largest of the Gilbert-style fan deltas along the Conway Coast is the Rafa fan delta forming the Rafa Terrace (**Fig. 2**). The exposures in Dawn Creek have provided an excellent opportunity to describe rarely published processes that occur on steep gravelly Gilbert-style fan deltas.

The Quaternary fan delta deposits of the Conway Coast contain a large number of slump structures. These features are located in both upper and lower foresets and in the marine interfan facies (**fig. 3**). The inherently steep slope of the depositional system leads to slope failures and resedimentation by gravitational processes. These include sediment slides and slumps and debris flows. Slope failures are common within fan delta complexes with high rates of sedimentation. The failures along these slopes create down slope movement of sediments that can severely alter the morphology of the slope (Postma, 1984; Postma and Roep, 1985; Colella et al., 1987; Lonne, 1995). Reasons for foreset failure include over steepening combined with instigators such as earthquakes and storms. Within the foresets and nearshore marine facies of the Conway Coast the sizes of the slumps range from less than a meter to greater than 15 m.

Figure 6 is a photo of a large-scale slump in the upper foresets of the southern fan delta outcrops. In this location, decimeter bedded material dipping against the foreset bedding overlies large rip-up mud clasts and blocks of material. Clasts in the beds are rounded, moderately to well sorted, and parallel to bedding planes. Grain size gradually decreases on the down slope (but up foreset) side of these features. The gravels are interbedded with thin beds (< 10 cm) of fine-grained silt and sand. Upslope, the dip of the beds decreases relative to the foreset bed.

Bedding against the foreset slope and clasts parallel to bedding planes help distinguish these as backset beds. These deposits are the result of down slope sediment transport infilling the depressions left by older slumps on the delta foresets (Colella, 1988). Large rip-up clasts and blocks of material indicate that the material was deposited in proximity to a slump. Interbedded sands and silts are evidence of periods of sedimentation between subsequent flow deposits. These bedding features are similar to the backset beds of Postma (1984) and Colella et al. (1987) in the Crati Basin.

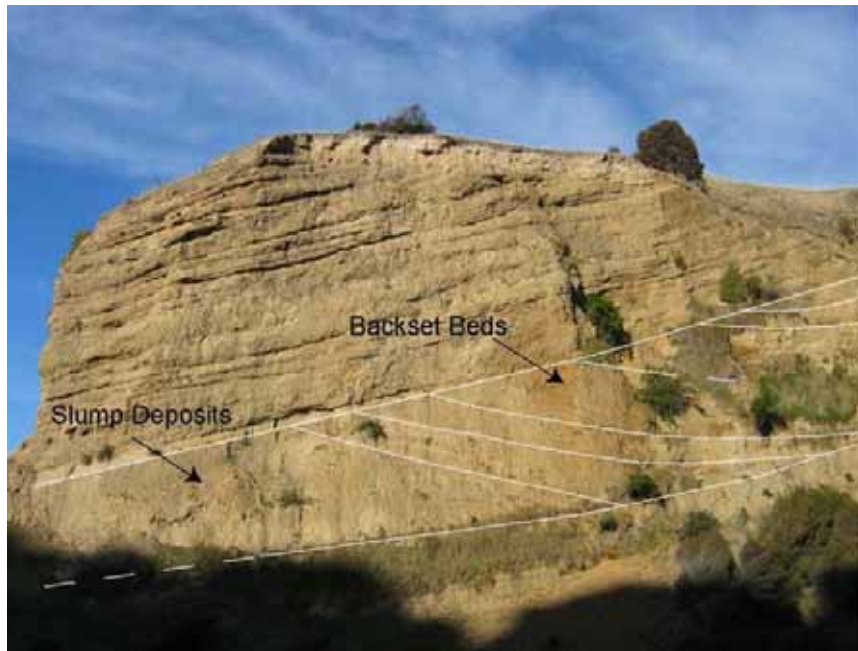


Figure 6: An example from the Rafa Terrace fan delta of backset beds forming behind a slump on the delta foresets. Slumps create depressions in the foreset slope that get progressively infilled first by gravel beds with back stacking clast imbrication followed by backset beds of alternating sands and gravels from intermittent flows.

Stop 9 (walking south along beach cliffs from Medina House)

The key to deciphering the series of nested terraces lies within the stratigraphy of the fan deltas. The Medina Terrace was formed by the progradation of the Medina fan delta (**Fig. 2**). The deposition of the Medina fan delta was followed by incision into the fan and removal of the fan deltas rounded topset beds (all other areas are a complete package of foresets and topsets). The Medina fan foreset beds are deeply eroded and then infilled by the younger Rafa fan delta foresets. This period of incision was followed by the deposition of the Rafa fan delta. The incised contact can be seen in the coastal transect. The formation of an inset terrace is also supported by the geomorphic expression of the Medina Terrace delta plain topset surface being ~15 m higher with respect to the Rafa Terrace. A similar contact between the two fan deltas is also seen up the Medina Creek.

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