Deely thesis analysis
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In the late 70s I completed a PhD at the University of Canterbury, New Zealand called The Environmental Geology of the Avon-Heathcote estuary.

I came to some surprising, counter-intuitive, conclusions, and published a couple of papers based on my research in the mainstream earth science peer-reviewed literature.

It was an innovative, richly ideated piece of work. Reviewing it, all these years later, it still deserves to be taken seriously … but some of my conclusions have been contested, notably by the geochemist J M Deely, also a Canterbury PhD.

Why have I done this analysis?

Because Deely dismissed the central discoveries of my 1978 PhD, and my key conclusions published in the journal Environmental Geology, stating unequivocally that I was wrong. I didn't realise this at the time, and in any case didn't – still don't – have the institutional resources to contest her conclusions.

Does this matter?

Perhaps it doesn't. That was then, this is now, and we've all moved on.

Or maybe it didn't matter much before the 2011 Christchurch earthquakes, which have changed bed levels and caused extensive liquefaction in the estuary, motivating a new interest in its physical environment, oceanography and biology.

Perhaps my late 70s observations have a fresh relevance.

A lot of what I recorded no longer exists.

So this is a hard look at Deely's 1991 thesis, now available on line, courtesy of the University of Canterbury library. Eventually I'll do a more systematic deconstruction of this thesis, and try to synthesise the key elements to make it easier to understand where it fails, and what that means. For now, here's a first draft run-through.

Here we go

She begins, 32 pages into her thesis, with a critique of reconstruction of historical changes in the tidal compartment and at the entrance to the estuary.

This was the central theme of my Journal of Environmental Geology paper (and I'll put a scanned copy of this paper here soon – it doesn't appear to be available free on line).

Deely said, about changes in the tidal compartment, that there had been: "… much debate regarding changes in tidal compartment, bed levels, and sedimentation …".

She then inaccurately summarised and trivialised my analysis of early survey data, for example stating at one point that "Macpherson felt that this was a more accurate …". I didn't 'feel', I investigated, observed, and drew balanced conclusions.

She wrote that "An anomaly in Findlay and Kirk's curve is the decelerating tidal compartment growth after 1920, which coincides with rapid urban growth and changes recorded at the inlet in the 1920s and 30s (Findlay and Kirk, 1988; Knox and Kilner, 1973; Macpherson, 1978; Penney, 1982)."

She doesn't say why she believes this is anomalous, and in any case my synoptic maps and accompanying explanation make these observations explicable and logical. Deely is exhibiting here the first evidence of a fundamental misunderstanding of cause and effect, and she does so consistently hereafter.

Deely wrote "Macpherson observed a … mud layer (labelled unit C), averaging over 25 cm in depth, in over 40 … cores from the estuary … . Unit C mud covers the whole estuary and occurs in areas where mud does not normally accumulate. Macpherson concluded that unit C deposited quickly, between 1850 and 1875, under conditions of unnaturally rapid sedimentation, which caused the decrease in tidal compartment … . During this period there was considerable land clearing as the population of Christchurch increased from 100 to 11,000."

No argument with that, but she continued, "However, the population of Christchurch increased to 22,000 by 1878 and 75,000 by 1906 (Scott, 1963), which is a more rapid growth than between 1850 and 1875. These figures suggest that runoff should have increased significantly between 1875 and 1906, resulting in a further decrease in the tidal compartment."

Those figures emphatically do that suggest that. Although it's not clear from what she has written here, Deely seems to be suggesting that there is a direct relationship between population number and runoff, and between runoff and tidal compartment.

Deely then goes on to write: "Macpherson (1978 and 1979) suggested that since the establishment of the Christchurch Drainage Board in 1875 drain laying has led to an ever increasing water flux to the estuary, which is eroding unit C sediment."

I did not suggest that.

"Findlay and Kirk agreed with Macpherson", she continues, "in that water flows have increased since early times, but point out that most sewers were connected after 1950 and the growth of the urban area did not accelerate until after 1925 … This information suggests that major erosion of Christchurch area may have

occurred after 1925 and not in the early period (1850 to 1875) as concluded by Macpherson."

Again, it's not clear what she is saying, but she seems to misunderstand cause and effect again and the relevance of population growth and the laying of sewers. The earliest stages of the development of organised, underground, sewage reticulation is a proxy for a probable decrease in sediment yield, not a cause of more.

That "… most sewers were connected after 1950 …", and that "… growth of the urban area did not accelerate until after 1925 …" emphatically do not "suggest" that "major erosion … may have occurred after 1925 and not in the early period (1850 to 1875) as concluded by Macpherson." More nonsense.

Using the historical evidence then available to me, and calling on previously described and well-established natural histories of the impact of new urban areas on previously undisturbed waterways, I modeled a likely reaction in the estuary, linked to the early days of Christchurch settlement. Normally earliest habitation causes the greatest impact, and quite quickly land surface stabilisation and organised drainage reverses or overwhelms the early impact. My companion paper on anthropogenic mud in the estuary develops this line of reasoning in more detail.

Now, with the ability to interrogate the media of the day by key word and phrase (*via* Papers Past, see my clipping collection and analysis: Voices from the past Avon Heathcote Estuary.pdf), it is clear that my model reflects the historical reality. Earliest settlement and the digging of surface drains that emptied directly into the estuary adversely affected both the rivers and the estuary in the 3 to 5 decades after first settlement, to an extent which would have been a national scandal had it occurred in the 20th century.

Writing about changes at the estuary mouth, Deely goes on to discuss the Furkert-Heath relationship, dismissing it because:

1. Some of the harbours and estuaries that it applies to are much larger
2. The entrance is mobile, adjusts to weather events on short time frames
3. The early data are unreliable

None of these factors are relevant. The Furkert-Heath relationship assumes a cause and affect link between the amount of water that flows through an estuary inlet and the cross-sectional area of the inlet. Data recently collected by NIWA apparently shows that in this estuary, where earthquake activity has reduced the tidal compartment by 10%, the relationship does apply.

Deely concludes: "All the discrepancies discussed above indicate that tidal compartment changes may not have had as significant an influence on the estuary bed and inlet as previously thought and perhaps changes in sedimentation rates may have had some effect."

Apart from getting cause and effect wrong yet again (the tidal compartment does not drive change in bed levels, it is an effect of change; and changes in outlet geometry are driven by changes in tidal compartment), she has not demonstrated 'discrepancies'.

Deely then goes on to discuss changes in bed levels, saying that I had attributed measured patterns of erosion and deposition between 1920 and 1962 "to the increasing tidal compartment."

I did not. Changes in the volume of the tidal compartment (the difference between volume and low tide and volume at high tide) in this estuary are primarily a consequence of erosion and deposition (adjusted for sea level rise), not the cause of it.

She also said that "Macpherson suggested that slight adjustment in subtidal channels is responsible for erosion and deposition after 1962" and she dismisses a 1920 survey (the limitations of which are carefully explained in my thesis) as "too inaccurate to compare with the later surveys." Both statements are wrong.

A key to understanding the history of this estuary is the unusual, originally estuary-wide layer of olive coloured, plastic, smelly mud (unit C in my stratigraphy) mentioned above. My conclusion was that this layer was deposited throughout the estuary in the period 1850 to about 1900, as clay and silt flooded the estuary in the early years of settlement, and that a 30% decrease in the tidal compartment resulted. My field observations and extensive coring programme showed that deposition of this mud layer would have caused a reduction in the tidal compartment of that scale.

My data also show that erosion of the estuary, which began in about 1900, continued until the time of my project in the late 70s, but at a declining rate, and that the tidal compartment was asymptotically approaching a post European volume of just under 11 million cubic metres. NIWA's much more accurate immediately pre-earthquake volume (about 30 years later) is 11 million cubic metres. I was on the button.

Deely set out to test these conclusions, writing (p38) that "Accurate dating of this layer [my unit C mud] is required to determine whether or not 1) anthropogenic activity influenced the deposition of unit C, and 2) a major period of erosion followed unit C deposition."

She began her alternative history by assembling a multi-page table of drainage-related events, and writes that "By referring to [this] Table …, the timing of drainage and sedimentation changes on land, in the rivers, and in the estuary can be compared and the order of events leading to "silting" (deposition of unit C) in the estuary will be disclosed. In addition, the timing of silting can be compared with periods of industrial activity which most likely caused heavy metal contamination of the estuary sediments."

However, she does not present any analysis to support this view, and referring to the table is no help. Her history of the development of drainage contains more information than did mine, but does not contradict it. It is clear from her, and from contemporary accounts, that surface watercourses and drains in and around the growing city were chronically blocked with sediment from the earliest days, and that keeping them flowing was a continuing task. Twenty five to 35 years of this activity, to sometime around 1900, would easily have contributed the volumes of mud and silt needed to form the 19th century layer in the estuary. In a period of rapid growth, with the estuary some distance from the new settlement, and with no prior observations to benchmark from, this would have attracted relatively little attention.

There are however some newspaper accounts which support this timeline, and even one assessment of the rate of sediment supply to the Avon River, published in the Star, Weds March 17, 1897, where a "Mr E Smith said that the work of improving the river must be done by someone, and he thought the Drainage Board the proper body to do it. He attributed the present state of the river to two causes, viz., diminution of flow of water and the accumulation of silt from the side channels and drains. This silting process amounted to about one ton per day, and had been going on for 20 years. He favoured the mud being thoroughly cleaned out …".

Anecdotal, of course, but this report does show that for an extended period, the Avon at least had been accumulating (and presumably transporting some to the estuary) large volumes of sediment. The Heathcote is known to be a far larger contributor. From this observation, a figure of 20,000 to 30,000 tons carried into the estuary is feasible. However, the numbers don't matter, the timing (1877 to 1897) does.

Deely makes much of a process of river 'sweeping' used in the Avon from the mid 1920s to sometime in the 30s, and for a longer period in the Heathcote River. Murray Hicks – a later reviewer – doubts that this process would have contributed much mud to the estuary. In my view, had it done so the event would not have gone unremarked.

And in any case, river clearing began shortly after first settlement in 1850, and continued, sometimes annually, until the 1960s. 'Sweeping' was a different approach, but not exceptional.

My search of the Star and The Press for the period from their first publication to around 1920 has found a number of contemporary accounts which contradict Deely's statement (p53) that "An extensive survey of the historical literature has revealed no record of sedimentation or water level changes in the Avon-Heathcote Estuary prior to 1920."

The opposite is true, and in any case the 'water level' would not have changed, regardless of what was happening on the intertidal flats and in the sub-tidal channels.

Deely's photographic 'evidence' and her anecdotes provided by local residents do not contradict a period of rapid sedimentation in the period 1850 to 1900. They may support a significant contribution of mud to the estuary since then, some due to river 'sweeping', but mud has been deposited in the Heathcote Basin and along the upper east side intertidal flats continuously since settlement began, and probably before.

Where anecdotal evidence contradicts her thesis, Deely dismisses it. For example, she quotes local resident George Andrews, who sailed in the estuary between 1895 and 1952.

"In page 2 of his notes … he writes that "The greatest change that has come over the upper part of the estuary has been the disappearance of the seagrass, the lowering of the mud flats, and silting up of the channels. I estimate the lowering of the mud flats has been from 1-2 feet over the greater part. The old channels have almost entirely silted up and shallow new ones acting as drains and taking a more direct course to the outlet, have in part taken their place."

Deely comments that "This statement mentions lowering of the mud flats, which indicates major erosion as alleged by Macpherson (my emphasis – alleged by!). She goes on to write "However, Anderson clarifies this point on page 3 of his notes: "Without going into figures, it can be concluded that [1.5 feet] more water over the whole estuary would a tremendous increase in the volume of water going in and out each side of high water. Changes with a sandy outlet were bound to happen."

Andrews' evidence supports my field observations, my analysis of historical survey data, and my estimates of consequent change in the tidal compartment – his numbers were about right, and he even deduces that change at the outlet "were bound to happen."

Deely however, seems to invoke a rise in sea level to explain away Andrews' observations, writing, incredibly "Hence, Andrews is more likely referring to an increase in the tidal compartment, than erosion of the estuary bed." From this, I understand Deely to be claiming that Andrews' deeper water was not due to lowering of the bed, but to a 1.5 foot rise in sea level!

There is no evidence of an extended period of early 20th century mud deposition, at a scale which would have been noticed, and commented on. There are however well-substantiated contemporary comments about erosion since the turn of the 20th century.

However, Deely was sufficiently confident, from her scanty and contradictory information to conclude that: "The observations of changes in 1) sedimentation and 2) channel positions strongly suggest that the estuary was filled with a blanket of mud between 1925 and about 1952. This blanket of mud is probably unit C sediment of Macpherson (1978). The disappearance of the loops in the Avon and Heathcote channels and the straightening and widening of their courses corresponds with 1) the increasing tidal compartment and 2) the

gradual build up of silt on the eastern and western shores, and Avon and Heathcote depositories. Somewhere between 1952 and 1962 the mud deposition slowed and estuary conditions stabilised, as indicated by the uniform pattern of the channels between 1962 and 1978. Recently, further stabilisation of the estuary is suggested by the gradual formation of meanders near the former channel loop positions."

Frankly, as itemised above, this is nonsense.

Historical changes in eel grass (Zostera nana) in the estuary are interesting. Unit C mud commonly contains Zostera leaves and organic hash that may be mostly Zostera detritus, and on the higher intertidal flats, unit C is often rich in organic material, including Zostera leaves, which presumably existed in the estuary at the time unit C accumulated. George Andrews' notes suggest that erosion and the disappearance of Zostera were contemporaneous, implying that Zostera was not happy in an eroding estuary, and Knox's observations support this conclusion. Its reappearance in recent decades may indicate that it is re-inhabiting the estuary as the rate of erosion slows down, and perhaps as surface muddiness increases.

In her extended synthesis of historical data (from p 72) Deely builds a deeply flawed picture of the natural history of the estuary. Some low-lights:

Page 73: "The events that lead to the major "silting" phase in the estuary started during the early urbanisation of Christchurch. Between 1875 and 1880 7 major storm water drains were built all leading to the Avon and Heathcote Rivers, except the City Outfall drain which emptied directly into the estuary. These drains successfully lowered the water table of Christchurch. However, during heavy rain and floods large quantities of surface soils were carried … into the rivers. As a result, the rivers shallowed rapidly. The construction of the City Outfall Drain in 1874 may have initiated "silting" in the Heathcote Basin area of the estuary; however there is no supporting evidence in the given review."

So what's wrong with this? She seems to be building a case that sediment "carried into the rivers" during early settlement stayed there – but this is a period of about 50 years, and we know that regular, sometimes annual, river clearing began in the 1860s or 70s. Sediment entering the surface drains and rivers was moved on or drag-lined out, in large volumes. At least some of it – the finer, muddy material – ended up in, or passing through, the estuary. Unit C mud is the evidence.

"The rapid sedimentation of the rivers continued until 1925 when the Christchurch Drainage Board purchased a river sweeper. Between 1900 and 1925 silting of both rivers increased markedly. The causes were 1) tripling of the area drained by storm sewers, which followed the amalgamation of Christchurch suburbs (1914-1931), and 2) soil erosion in the Heathcote Valley (1912-1914), where market gardens were being developed."

There's no evidence for a marked increase in sedimentation linked to increases in storm water drainage (the opposite is a more likely outcome) or local

government reorganisation, and the role of land use change in the Heathcote Valley is not clear cut, as Hicks' later work showed.

"The period of the river sweeping as well as the photographic, historical, and scientific records (including the disappearance of Zostera) strongly suggest that the Avon-Heathcote Estuary filled with mud rapidly from 1925 to the early 1950's. The evidence suggests that the thickest silt deposits accumulated in the channels."

On the contrary, the observations of George Andrews and Knox and Kilner, and my own detailed analysis of survey data, directly contradicts this statement.

But just think about what "filled with sediment" implies. A major environmental event, over two or more decades, in an estuary which was sailed on, walked over at low tide, fished in, and closely observed by a growing sea-side community in New Brighton and on the south shore and hillsides. Could such an event have gone unremarked?

In the 1870s, when the new Christchurch Drainage Board proposed emptying raw sewage into the estuary near Heathcote, there was a very vigorous public debate, and a number of observations about the state of the rivers and the estuary.

Had river sweeping deposited up to a metre of mud in the estuary, over an extended period in the early to mid 20th century, it would have been a national scandal.

"All historical and scientific evidence of erosion presented here relates to bioturbation and erosion of either the channels or the periphery of the estuary … Considerable erosion has been reported during the period of rapid sedimentation between 1925 and 1950. The erosion of the channels seems to be related to 1) intense bioturbation, 2) infilling of old channels, and 3) the disappearance of the zostera beds."

Hard to know where to begin with this paragraph. It's not clear, for a start, what Deely is saying, but just take the central statement, that "Considerable erosion has been reported during the period of rapid sedimentation between 1925 and 1950." What does that mean? Can erosion and sedimentation occur at the same time? Erosion in some places, but not in others? Recall that she is proposing widespread deposition of mud during this period.

"Erosion around the circumference of the estuary clearly relates to increasing water levels throughout the history of Christchurch. Rising water levels were caused by 1) increasing tidal compartment, and 2) rapid infilling of channels with sediment."

This is absolute nonsense. Where was her PhD supervisor or reviewer? It's clear from my observations, and others, that the estuary deepened from about 1900 to the late 1970s. The amount of water in the estuary at high tide increased as

erosion occurred. It got deeper, not higher! How can deeper water (or even rising water levels, were that possible) be caused by an increasing tidal compartment?

The serious point here is that Deely clearly did not understand what she was saying. She didn't understand what 'tidal compartment' meant. Her understanding of sedimentary processes is sketchy at best. Her core reasoning was deeply flawed. Her following paragraph makes this very clear.

"The growing tidal compartment is a direct result of drain laying in the Christchurch area after 1875, which has accelerated stormwater runoff. To a lesser extent, discharge of sewage and industrial effluent would have enhanced the water volume prior to 1950. However, after 1950 the massive increase in effluent discharging on the western slopes probably had a greater affect on tidal compartment volumes. The higher volume of sewage effluent discharged to the estuary after 1950 was due to 1) the rapid growth of Christchurch, 2) extensions of the CDB treatment plant, and 3) the diversion of all industrial effluents to the treatment plant. The findings of this analysis suggest that the tidal compartment increased fairly rapidly from the time the early settlers arrived, which agrees with the tidal compartment curve of Findlay and Kirk (1988)."

Wrong, wrong, wrong.

And then this! Breathtakingly wrong: "While rapid sediment deposition may slightly decrease the volume of water entering and leaving an estuary during a tidal cycle, it would also lead to elevated water levels. Water would be expected to spread upwards and outwards in a small shallow estuary … The erosion reported around the perimeter of the estuary supports such water movement."

My underlining. I take this to mean that Deely thought that her mud layer was pushing up the level of the overlying water! Some basic physical laws being denied – like gravity.

Chapter 3, beginning at page 77
"Sediment studies of the Avon-Heathcote Estuary have been undertaken by Knox and Kilner (1973), Millward (1975), Harrison (1976), Macpherson (1978), and Christchurch Drainage Board (1988). All these studies show uniform sediment accumulation over the last 20 years, with most areas of the estuary showing coherent patterns of sediment deposition."

Wrong, the opposite was the case. I certainly demonstrated a net loss in the period 1962 to 75, and probable quite large losses between 1920 and 1962, using the best available data, not since contradicted.

"… no evidence was found for widespread erosion from the bed of the estuary."
Wrong, I found such evidence, and carefully documented it. Later work, summarised by Hicks, supported my observations.

Stratigraphy

Deely's observations of the subsurface sediment of the estuary begin at p 79. She acknowledged my previously published stratigraphy, and her descriptions of the properties of sedimentary units are largely taken from my work.

My unit B was the estuarine sequence, deposited after the estuary was separated from the open ocean, sometime between 450 and 2,000 years ago. Deely described a 1-2 cm black zone at the top of unit B cores, especially in those from the Heathcote basin. Her core AHE/5 from the southern edge of the Heathcote Basin contained black streaky layers near the top of unit B, and she reported coal particles at top of unit B in AHE/2a, and in unit C in core AHE/1a. We'll come back to this later.

My unit C was a distinctive layer of massive, plastic, often malodourous mud and very fine sandy mud. Deely reported Zostera leaves and clumps of partly decayed organic matter in unit C. She deduces mass mortality of Zostera at the time of deposition of unit C. Zostera is a mud-loving intertidal perennial, but does not tolerate "excessive sedimentation" (Davison and Hughes, 1998). It does seem plausible that the conditions prevailing during deposition of unit C would have inhibited Zostera growth. Zostera may also have tolerated the muddiness of the water column during deposition of unit C, and then could not tolerate the erosion and increasingly sandy intertidal zone that followed.

However it is evident from my review of Deely's core logs, and by comparisons to my nearby equivalents (her location map is so large scale as to be useless except in a very general sense, so direct comparison to my core logs is difficult) that in some cases she misidentified unit B sediment as unit C. The significance of this will become clear below – it means that her 'dated' anthropogenic layer was almost certainly pre-European.

Dating of sediments and estimations of sedimentation rates
"Knowledge of marker beds and other historical data are often incorporated into radiometric dating calculations (such as ^{210} Pb) to obtain accurate age profiles and sedimentation rates.

"In the following section all sediment units of the Avon-Heathcote Estuary are accurately dated using a combination of ^{210} Pb profiles, 14C ages, pollen profiles, and the historical records of Chapter 2."

Carbon 14
Deely dated a couple of shell samples, one from a layer she identified as "near the base of" unit C in her cores AHE/2a-d, and another from an exposed bed of Mactra ovata shells on the side of the tidal channel near Pleasant Point.

The age of the shells in core AHE/2a was 350 plus/minus 60 years.

Deely's flawed "historical evidence" told her these shells should be younger than 1927. She observed that the sediment was slightly blackened at the top of unit B and base of unit C in most cores. Charcoal and ash occurred in this layer. In fact, a charcoal particle is visible in Fig. 3.19. Such material is most likely derived from

burning of fossil fuels during the early period of industrialization (Chapter 2, section 2.8)", she wrote. The date didn't fit her theory, so she rejected it.

The evidence of blackening, and charcoal and ash, near the top of unit B and at the bottom of unit C is consistent with evidence from later cores adjacent to the estuary, collected by NIWA's tsunami hunters, and is probably evidence of Maori deforestation. That fits with my stratigraphy, and supports the C14 date, but not Deely's 1920s date.

The M ovata shells were dated at "post bomb". They seem to have died sometime in the 1960s. The layer of dead shells (in their life position) dips under the modern sediment surface in their locality (Deely found it in her core AHE/6 at a depth of 45-50 mm, upslope nearby). These animals may have been killed by effluent from the nearby CBD outfall in the 60s. Their age tells us nothing about the age of the sediments around or above them.
My sediment budget maps show accumulation in this zone. The dip of the beds reflects a shallower estuary, just as the dip of unit C does.

^{210} Pb dating
"Sediment in the Avon-Heathcote Estuary varies from almost pure sand to > 80% mud, and the most recent sediment layer, unit D, is intensely bioturbated in many places. Thus it was difficult to find a core that contained a thick and undisturbed sediment sequence. Core AHE/1a: from near Sandy Point was chosen; the sediment is almost un-bioturbated except for a small section across the contact between Unit C and Unit D."

There are some issues with this approach:

1. The stratigraphy. Photos in my thesis show that the mud layer is only present off Sandy Point in a narrow zone along the HW mark. Further off-shore, the layer has been eroded away as the estuary has deepened. It's not possible to reconstruct where Deely's core was collected, with reference to the outer edge of the eroding mud.

   She describes sediment deeper than 130 cm in this core as unit A. Between the top of unit A, up to a visible bioturbation interface at about 35 cm below the surface, she describes a sequence of olive grey fine sandy mud containing black streaks of carbonaceous matter, pieces of wood, lumps of charcoal (coal), sandy laminations, and muddy zones. Sand content increases with depth below 72 cm. She identified this zone as unit C, the anthropogenic mud layer. Her descriptions do not match my descriptions of unit C, and I would not have called this sequence unit C.

   At 84 cm Deely noted a gradational contact (with a sharp colour change) between this sediment, and a lower zone of black slightly muddy fine sand, massive dark grey fine sand, alternating laminations of mud, muddy fine sand, and fine sandy mud, with laminations grading up and down. She identified this 46 cm zone as layer B, the estuarine sequence. It matches my unit B descriptions, as does her unit C above.

Given what my photographs show of unit C at the surface at this approximate location, and the core log, Deely did not have unit C in this core. She sampled unit B estuarine sand, the upper zones of which have been bioturbated.

My core logs support this conclusion. Core log 47, collected on line 10 just north of sandy Point at an inshore location recorded 10 cm of unit C mud at depths of 33 to 45 cm. At this location, the unit C mud had not been eroded away. However core log 42, offshore from 47 on line 10, shows no Unit C mud. At this location, it had been eroded away. Contemporary photographic evidence supports this observation. My nearest core to the south, on line 12, number 43, also shows no unit C in situ, but with remnants mixed into unit B. Here it had also been eroded away and bioturbated downwards as the estuary deepened. In several cores in this part of the estuary, unit C was either absent, or mixed into older sandy sediment.

To summarise: my photographic evidence, my adjacent core logs, and her own descriptions of her core AHE/1a prove that it did not contain any in situ unit C mud.

2. The bioturbation assumption. Mottling which highlights bioturbation in subsurface sediments only shows when there are variations in grain size, muddiness or sediment colour/chemistry. In the low-mud, well sorted, uniform sand typical of Sandy Point, bioturbation will not be visible. In fact, it's highly likely, given the dense populations of contemporary bioturbating animals at this location, that Deely's entire core was intensely bioturbated.

3. Tsunami hunter James Goff and Catherine Chagué-Goff (2007) described three cores from supratidal successions from Estuary Park and Charlesworth Reserve, immediately adjacent to Sandy Point. They wrote: "European and Maori arrivals were recorded in … three cores from Estuary Park. European arrival was associated with a marked charcoal layer that appears to record a period of burning in the area. This was not noted in the cores from other sites. European and Maori arrivals were … picked up in … cores using microfossil data. Core 1 contained a distinct charcoal layer, which … appears to be linked to a period of Maori occupation well before European arrival. The point in the core where Maori arrival is first noted however underlies a branch that has been radiocarbon dated to around 1550-1890 years BP …".

The two Goffs provide evidence not available to me or to Deely, and their work reinforces my conclusion that the material in Deely's AHE/1a core predates the deposition of unit C. Her carbonaceous material probably has the same Maori or early European burning origins as the analogous material in the Goff cores.

The most plausible explanation for Deely's dates of 1920 to 1924 for her AHE/1a core (between 33 cm and 81 cm from the top of the core), 1924 to 1948 for the interval from 16 to 28 cm, and 1958 to 1979 for the top 12 cm is that they reflect erosion and deposition of sediment, and intense bioturbation. They have no connection to the deposition if unit C mud, which is not present at this location.

She notes a number of problems with her methodology, including variable sedimentation rates, organic material, and so on. However the most problematic is bioturbation, which will almost certainly have been intense right through the depositional history of this estuary. She relies on her historical analysis to support her dates, and that is flawed. She has not sampled unit C, and the conditions for meaningful ^{210} Pb dating have not been met. To the extent that the remainder of her thesis depends on dating of core AHE/1a , it will be equally wrong.

Pollen analysis

Deely had pollen counting done for her core AHE/3a, which was collected apparently from an upper intertidal location at about CBD lines 7 and 8, in the upper east area of the estuary. She calls a zone of "olive grey slightly sandy mud" between 20 and 35 cm Unit C, and she has it grading down to olive grey massive slightly muddy very fine sand, with 3 cm of olive grey mud at the base, then a sharp contact underlain by typical Unit A sand.

The top of Unit A in this core and throughout the estuary, represents the transition from open ocean to estuary enclosure, and is typically sharp, reflecting the major discontinuity between the two depositional regimes. There may have been significant erosion of open ocean sediment as the spit grew south and progressively enclosed the estuary, and the Avon River migrated south.

Native podocarp and wetland plant pollen in upper unit A indicate a pre-Maori, native forested hinterland. A sudden change to bracken and grass pollen, and a decrease in native forest and wetland species that corresponds to the thin layer of mud at 90 cm reflects ground cover changes that occurred at the time of Maori deforestation by burning (as recorded by the Goffs). This evidence shows that at this time, the estuary accumulated a thin layer of mud, a small scale anthropogenic response that was to be repeated on a much larger scale when the first European settlers arrived, and radically altered the ground cover and drainage patterns.

Re-examination of my core logs shows that I often recorded a thin, 2 – 10 cm, olive very fine sand and sandy mud zone at the base of unit B, and in the light of Deely's pollen data, this may be estuary-wide evidence of a response to Maori deforestation at about AD1250 (from the Goff's cores).

The first evidence of European habitation – introduced plants – occurs at about 50 cm below the surface, just below Deely's unit C, which implies that this is indeed unit C, first deposited just after the arrival of European settlers, and that

it may be more sandy here than elsewhere in the estuary. If it is unit C, it is undergoing erosion by bioturbation at the top, and was at least 35 cm thick at this location. Deely's interpretation – "Hence, the early settlement of Christchurch (1850 to 1925) did not have a significant affect on sedimentation in this area of the estuary" is by her evidence plainly wrong. Her pollen data adds some detail to my interpretation, and supports it. It contradicts her conclusions.

So to repeat – and without analysing the remainder of her thesis – to the extent that Deely's analysis and conclusions depend on a 20th century date for the anthropogenic mud layer in this estuary, they are wrong.