21

The archaic and puzzling record of Lake Xere Wapo, New Caledonia

Janelle Stevenson

Archaeology and Natural History, ANU College of Asia and the Pacific, Australian National University, Canberra

Janelle.Stevenson@anu.edu.au

Richard Gillespie

Archaeology and Natural History, ANU College of Asia and the Pacific, Australian National University, Canberra; School of Earth and Environmental Sciences, University of Wollongong, Wollongong

Geoff Hope

Archaeology and Natural History, ANU College of Asia and the Pacific, Australian National University, Canberra

Geraldine Jacobsen

Institute for Environmental Research, Australian Nuclear Science and Technology Organisation, Menai

Stewart Fallon

Research School of Earth Sciences, ANU College of Physical Sciences, Australian National University, Canberra

Vladimir Levchenko

Institute for Environmental Research, Australian Nuclear Science and Technology Organisation, Menai

Introduction

Research into the palaeoenvironmental history of New Caledonia was begun independently by Hope and Stevenson in the early 1990s. While the original work of Hope and colleagues was centred around questions of the long-term vegetation dynamics of maquis and rainforest within the ultramafic terrain of New Caledonia (Hope and Pask 1998; Read et al. 2000), Stevenson and colleagues were exploring questions of human impact and the detection of initial human settlement (Stevenson and Dodson 1995; Stevenson 1998; Stevenson et al. 2001; Stevenson 2004). Hope and Stevenson later came together to work on the longest record so far recovered from the tropical southwest Pacific, Lake Xere Wapo in southwest New Caledonia.

Having published the initial findings from this site (Stevenson and Hope 2005), a major problem remained, that of a robust chronology. The 12 m core XW-B reached radiocarbon background shortly after 300 cm, had several significant age inversions and had what appeared to be a very shallow Holocene sequence of fewer than 20 cm. Stevenson and Hope revisited Lake Xere Wapo in 2005, collecting new material for further dating aimed at untangling the chronology. Results from this new dating program are reported here, with a summary of previous radiocarbon determinations.

Environmental setting

New Caledonia (20-23° S and 164-167° E; Figure 1) has a tropical to subtropical climate influenced by the prevailing southeast trade winds. The average annual rainfall for the region is around 3000 mm yr^{-1}, with the warmest and wettest months being from December to April and the driest from August to November. Annual rainfall is also highly variable and years of rainfall shortage are linked to the El Niño – Southern Oscillation (ENSO) phenomenon (Morliere and Rebert 1986).

The archipelago is probably best known for its rich and distinctive flora, with the high rate of endemism (80% of an estimated 3000 species) thought to occur as a result of its Gondwanan origins and the unusual ultramafic terrain that covers approximately one third of the main island (Morat et al. 1984). Within this terrain at the southeast end of the island is the Plaine des Lacs, an old plateau around 180-250 m in altitude and crossed by a series of low ridges separated by gently sloping areas with numerous lakes. Within this terrain lies Lake Xere Wapo (22° 17.5′ S, 166° 58.5′ E) at an altitude of 220 m (Figures 1 and 2). The lake is roughly triangular in plan, is approximately 0.85 km^2 in area and has a catchment consisting of the area within ~100 m of the lake. The lake is usually shallow, only 1-2 m in depth, with shelves of laterite on the northern shoreline flooded on occasion. There are no feeder streams and it is thought that the basin formed by solution, possibly influenced by some fault control, with the lake rising after heavy rain and draining underground to the Wajana River.

The gentle slopes that surround Lake Xere Wapo are an ultramafic complex of hartzbergite and serpentinite mostly covered in a ferritic soil mantle, although in places characterised by an iron pan crust known as 'sols cuirasse'. These soils are high in iron, magnesium, manganese and nickel, and plant growth is challenged by a lack of phosphorous, potassium and nitrogen. Vegetation on ultramafic substrates therefore tends to have a distinct species composition, rich in local endemics and lacking species from adjacent substrates. In many parts of the world, the ultramafic floras are species-poor (Brooks 1987), but in New Caledonia the species diversity of the ultramafic terrain is high and the vegetation ranges from stunted maquis (heath-shrubland) to structurally complex rainforest, with many of the rainforest species not confined to the ultramafic substrate.

The vegetation surrounding Lake Xere Wapo is characterised by a bushy maquis dominated by either *Gymnostoma deplancheanum* or *Dacrydium araucarioides*, with various Myrtaceae forming a denser, closed scrub down to the water's edge (examples: *Austromyrtus altemifolius*, *Babingtonia lerattii*, *Melaleuca gnidioides*, *Syzygium ngoyensis*, *Tristaniopsis glauca*, *T. guillaimii*, *Uromyrtus myrtoides*, *U. emarginata*). Two sedges (*Costularia xyridioides* and *Schoenus brevifolius*) grow in the shallow water margins. The low nutrient status for all lakes and streams within this landscape is evident from the sparseness of aquatic flora and fauna.

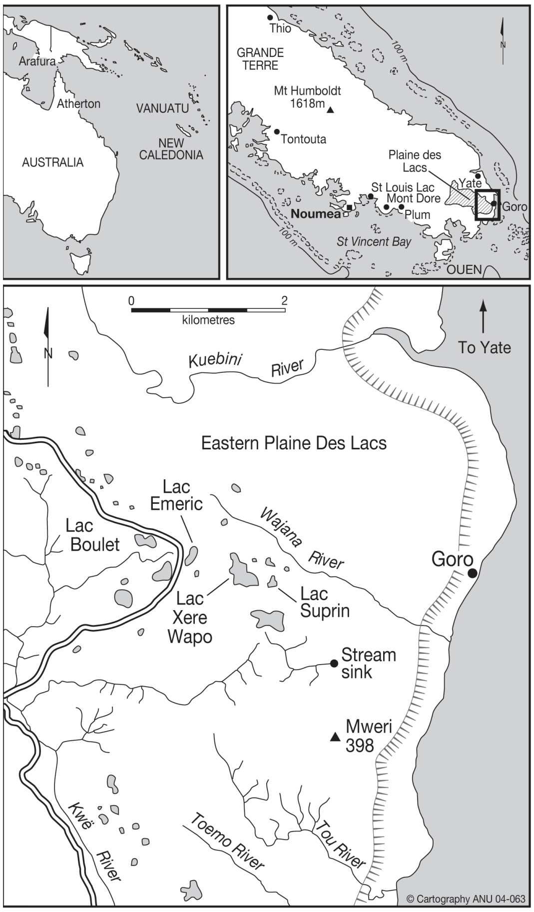

Figure 1. Location map of Lake Xere Wapo within the Plaine des Lacs region of New Caledonia

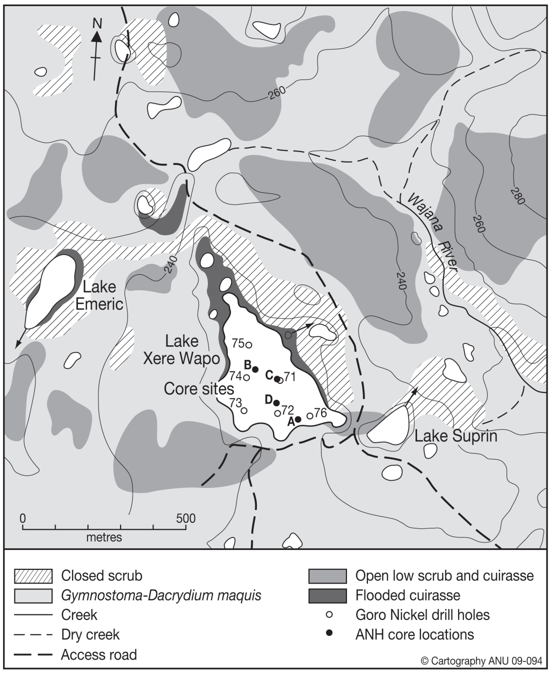

Figure 2. Site map of Lake Xere Wapo showing coring locations

Of note is that, while the diversity of the dicotyledonous flora of the Plaines des Lacs region is high, grasses are absent.

Methods and materials

Lake sediment coring

Sediment core locations for Lake Xere Wapo are shown in Figure 2. A 50 cm core, XW-A, was taken in June 1992, about 25 m from the southern edge of the lake, and a 1280 cm core, XW-B, was taken in December 1994 from the centre of the lake in a water depth of ~60 cm. In both cases, sediment was collected with a D-section corer, except for the interval 1000 cm to 1280 cm in XW-B, where a Livingston piston corer was used. Core XW-B was chosen for the pollen and charcoal analyses, published in Stevenson and Hope (2005), given the greater depth of sediment recovered. Some difficulty was encountered in collecting material from the upper 3 m, however, as several quite fluid horizons were encountered.

At location XW-C in 2005, a 60 cm mud-water interface core was collected and extruded in the field into 0.5 cm slices. Lake sediments were also sampled from 30-230 cm at this location with a D-Section corer as the upper sediments were too loose for collection with a Livingstone corer. An attempt was made to collect sediments from 200 cm onwards (giving a 30 cm overlap with the D-Section cores) with a Livingston corer. However, two major woody layers at 290 cm and 340 cm prevented further collection using either coring system. Operations were therefore moved to site XW-D (see Figure 2), where sediments from 150-850 cm were recovered using a combination of D-Section and Livingstone corers.

In 2001, the company Vale Inco Nouvelle Calédonie drilled Lake Xere Wapo as part of a mining survey for the Goro Nickel plant (Figure 2). This drilling survey reinforced how difficult the sediments are to collect, as all five drill locations had extremely poor recovery down to 7-9 m. Below this, however, the drillers were able to recover more compact lake muds to a maximum depth of 25 m. Drill hole 01RG-76 from the Goro Nickel drilling program had the best and deepest recovery, at 25.2 m, with this and the other cores held in cool storage at the Grand Lac mining camp. Because an aim of the 2005 field season was to extend the record of XW-B, 01RG-76 was sampled at 10 cm intervals from 6.3 m to 20.35 m.

At the time of the 2005 field season, the layout of the mining survey was not known. That information became available at a later date, revealing that core location XW-C is in close proximity to drill hole 01RG-71, with the drilling notes revealing that three attempts were made to collect material from the site and only on the third attempt was there reasonable recovery.

Radiocarbon dating

So far, 31 samples from five Xere Wapo cores have been analysed by four radiocarbon laboratories, one using radiometric techniques (ANU) and three using AMS (OZ, SANU and Wk codes), along with a variety of physical and chemical pre-treatments. Radiocarbon and stable-isotope measurements were made using standard procedures at the respective laboratories (e.g. Fink et al. 2004; Hogg et al. 2006)

For the bulk sediment sample from 115-123 cm in core XW-A, the <500 μm fraction was solvent extracted, then given standard hot acid-base-acid (ABA) chemistry. Samples from core XW-B comprised three wood and three 250-600 μm bulk sediment fractions, all treated with hot HCl only. For later sediment samples from core XW-B, the 10-250 μm pollen size fractions were treated with cold HCl, cold HF, warm KOH and cold HCl. Similar pre-treatment was applied to samples from XW-C and XW-D, but on the 10-125 μm fraction.

Four paired sediment and wood samples from cores XW-C and 01RG-76 were processed in 2009. Sediment samples were treated with cold NaOCl, HCl, warm NaOH and HCl (OxABA), then sieved to produce a pollen-rich size fraction of 38-50 μm; the dominant pollen type was *Dacrydium*, which varied from 30% to 70% of the total fraction. Wood samples were treated with two cycles of cold NaOCl, hot HCl, hot pH3 $NaClO_2$, hot NaOH, HCl (OxAOxBA). Because these waterlogged wood samples were cut into matchstick-size slices with a scalpel, complete decontamination may not have been achieved; reference standard New Zealand kauri wood samples, ground to <1 mm and treated with two cycles of cold NaOCl, hot pH3 $NaClO_2$ and HCl (OxAOxA), produced clean white cellulose which yielded consistent results (OZL-485 and 486). The hypochlorite and chlorite oxidation (bleaching) steps are based on chemistry discussed in Gillespie et al. (2008).

Results

Stratigraphy

The Goro Nickel drilling program provides an overview of the depth of organic sediment within the lake (Figure 3). That drilling program and the hand coring carried out by Stevenson and Hope reveal that the surface sediments of Lake Xere Wapo are firm and the lake bed appears to have no discernable topography. Underlying this, however, are many fluid horizons, possibly resulting from voids within and around tree debris (Figure 4). Wood fragments have been

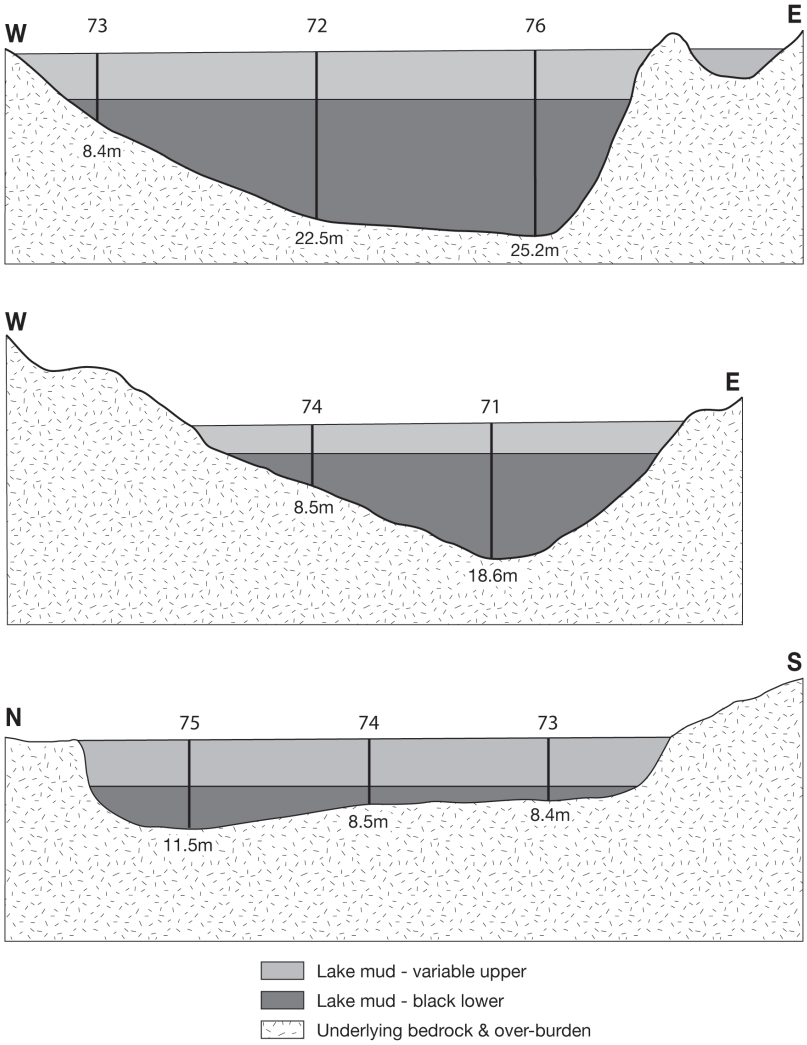

Figure 3. Goro Nickel survey sections

noted at various depths in the Lake Xere Wapo sediments. Wood from a similar context in Lake Suprin (see Figure 1), but with better preservation, has been identified as the freshwater mangrove conifer *Retrophyllum minor* (Hope and Pask 1998). The wood from Lake Xere Wapo is from several taxa, including *R. minor*, and is indicative of considerable fluctuations in water level.

Sediment descriptions of XW-A to XW-D as well as 01RG-76 are set out in Table 1 and a stratigraphic diagram illustrating the major changes in sediment type is shown in Figure 5. Across the cores there are several correlating units. Prominent among these are the black organic mud layers at 150 -175 cm in XW-B, 101-172 cm in XW-C, 150 -160 cm in XW-D, 35-100 cm in XW-A and from 60-70 cm in 01RG-76. In all cases this unit is underlain by dark yellowish brown clay (10YR 4/3-4/6) and, depending on location within the lake, this unit can be extremely fluid. In the original cores collected by Hope, this layer was described (without a Munsell chart description) as an orange clay. The next stratigraphic unit common to all the cores is another dark yellowish brown clay unit, which like the unit above, is also very fluid. However, the major sedimentary unit common to all of the deeper cores is the black organic mud that commences at 300 cm in XW-B, 356 cm in XW-D, and 275 cm in 01RG-76. From 660-2030 cm in the 01RG-76 core, the sediment is predominantly this very dark grey mud, with punctuations of lighter coloured sediment from 1530-1580 cm (dark grey), 1660-1720 cm (dark olive brown), and 1945-2030 (dark grey brown-dark olive brown). These black/grey muds and clays comprise the bulk of the sediment in the lake and

Table 1. Sediment core descriptions (see Figure 2 for locations) (Table 1 continues on page 389)

Depth (cm)	**XW-A**
0-15	Sloppy-brown organic mud with wood fragments
15-35	Orange-brown mud
35-100	Black organic mud
100-138	Orange-brown mud
138-290	Brown organic mud with thin white clay band at 160 cm
290-302	Brown-orange mud
302-455	Brown-organic mud with wood at 310-330, 430-440
455->500	Grey silty clay and coarser mineral particles
	XW-B
0-25	Yellow-brown organic clay
25-40	Dark-brown clayey organic mud – fine yellow band 32 cm
40-45	Brown organic clay
45-125	Black organic mud – fine yellow clay band at 90 cm, wood from 90-125 cm
125-140	Brown organic mud
140-150	Wood – in matrix of black mud
150-165	**Black organic mud**
162-175	Wood – in matrix of black mud
175-180	Orange clay
180-200	Brown organic mud
200-240	Dark-brown organic mud, wood and roots at 222 and 238
240-265	Light-brown/orange clay with wood fragments
265-300	Dark-brown organic mud – lighter colour + wood 275-280
300-610	Black org. mud – coarse, grading into fine from 460-480 (grey clay 410-415; wood @ 470-480, 600)
610-650	Grey mud
650-1100	Black organic mud
0-14	Dark yellowish-brown mud
Depth (cm)	**XW-C**
14-18	Transition to very dark-brown mud
18-26	Very dark-brown mud
26-28	Transition to very dark grey-brown mud
28-30	Very dark grey-brown mud
30-50	Very dark-brown organic mud – wood 31-36 cm, rootlets at 42 cm, wood 50-53 cm
50-53	Dark yellowish-brown clay – loose and watery with lots of wood
53-60	Very dark-brown mud – voids filled with dark yellowish-brown mud
60-101	Dark yellowish-brown mud with rootlets
101-172	Black organic mud – lots of wood and other organic debris – yellow bands at 149 and 156
172-185	Wood in a matrix of dark yellowish-brown clay – very fluid
185-187	Dark yellowish-brown clay – no wood
187 -230	Grades into very dark grey-brown organic clay – wood at 190, 193-196, 199-205, 214-223
	XW-D
150-159	Black organic mud
159-173	Dark yellowish-brown clay – gravels at 163-167
173-280	Dark-brown organic clay – very fluid
280-335	Dark yellowish-brown clay
335-356	Dark greyish-brown mud

356-850	Black organic mud – wood at 358-362 and 635-650
	01RG-76
0-58	Dark yellowish-brown clay
58-63	Black organic mud
63-265	Very dark-brown mud – wood and roots at 180-185
265-275	Dark yellowish-brown mud – wood throughout – very fluid
275-670	Black – wood throughout from 295
670-1660	V. dark grey mud – fine roots and wood throughout – olive-brown mud with roots and small wood fragments from 710-740
1660-1720	Dark olive-brown slightly organic clay
1720-1835	Changes gradually to very dark grey clay – wood and roots from 1825-1835 – less consolidated
1835-1950	Black organic mud – unconsolidated at time of collection
1950-1990	Very dark grey-brown – wood from 1980-1990
1990-2035	Dark olive-brown, changing to very dark grey clay

Note: 01RG-76 description from Goro Nickel core logs. Colours descriptions are based on the Munsell colour chart.

are seen in the other Goro Nickel drill holes (Figure 3). Many of the cores have extremely poor recovery for the upper 2-4 m due to the highly fluid nature of the sediments, resulting in the uppermost black unit missing from many of these locations.

Wood layers are noted throughout the cores, but the greatest concentration is in cores closer to the current shoreline. XW-D contains the least woody debris, suggesting that this may be the location where greater water depth has been most consistent over time.

Chronology

All ^{14}C determinations for Lake Xere Wapo are listed in Table 2, and are shown against depth in the schematic core stratigraphy for XW-A to D and 01RG-76 (Figure 5).

Results for cores XW-A and XW-B were discussed by Stevenson and Hope (2005). The sample from 96-107 cm, originally reported as a bulk sediment sample, was in fact the >600 µm

Figure 4. Composite showing the fluid layers within the upper sediments of Lake Xere Wapo. A) XW-D 300-358 cm. B) Zero recovery or voids in drill core 01RG74

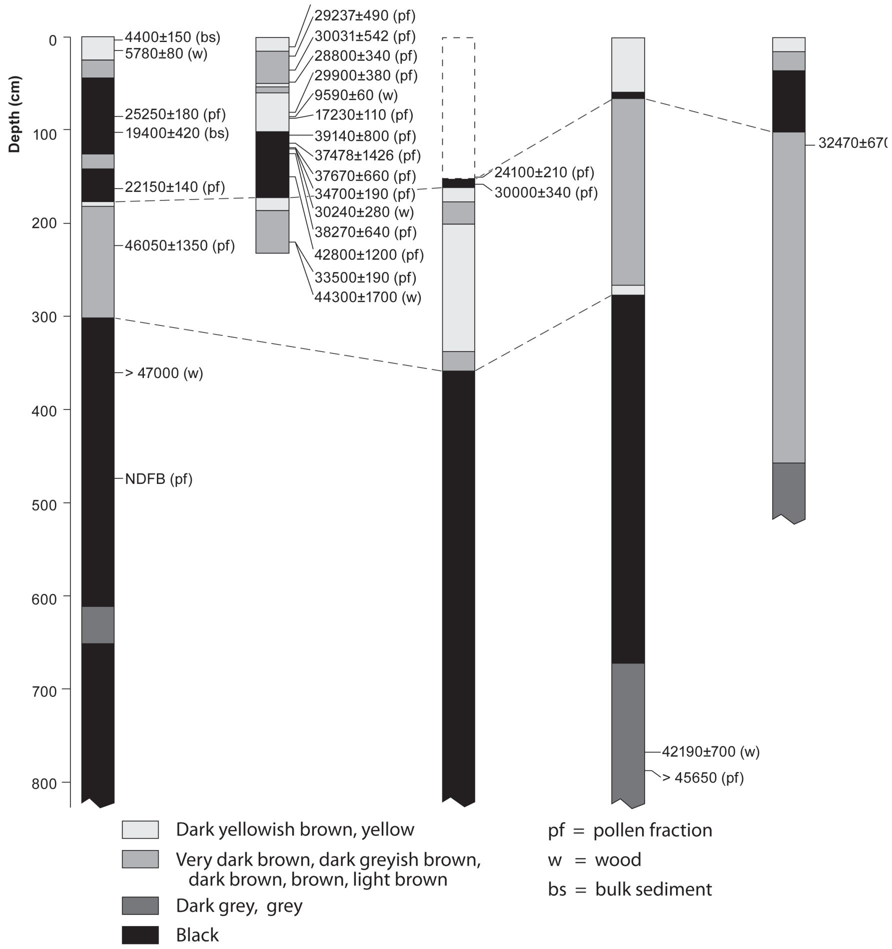

Figure 5. Schematic of core stratigraphy for XW-A to XW-D and 01RG-76, with age determinations

fraction, composed largely of small twigs; it is therefore now viewed as a wood sample. Extreme age inversions were also noted at 250-270 cm and 290-300 cm, and laboratory records indicate these two samples were unusually small for a conventional radiocarbon date; they were dropped from any discussion concerning the chronology. Further results from pollen-size fractions produced another age inversion, with background reached at 360 cm in the core XW-B.

Because the fluid yellow-brown layers have always been considered to stem from disturbance within the catchment, the focus for fresh material collected in 2005 was on the black, highly organic layers, as they were likely to be indicative of greater stability. Four samples were dated from field-extruded 5 mm slices of the XW-C mud-water interface section in an attempt to construct a better Holocene chronology. The sample from 10 cm returned an age of 8792 ± 53 (Wk-18065), but four samples covering 20 cm to 81 cm depth are surprisingly old and statistically indistinguishable at 1σ, with an error-weighted mean age of 29,540 ± 220 BP. Four pollen size fractions from the black organic mud layer spanning 101 cm to 126 cm in XW-C are also statistically indistinguishable at 1σ, with an error-weighted mean age of 37,450 ± 380 BP, and the sample from 150-151 cm at the base of this black organic mud unit in XW-C returned an age of 42,800 ± 1200 (OZJ-298). Two samples from the bottom 9 cm of the corresponding unit in core XW-D returned ages in stratigraphic order at 24,100 ± 210 (OZJ-293) and 30,000 ± 340 (OZJ-294).

The latest round of dating on the Lake Xere Wapo sediments, using paired wood cellulose and pollen-rich preparations, adds further disarray to an already confusing set of radiocarbon ages. For the three sample pairs from core XW-C, each pair has significantly different ages and both the 85-87 cm and 119-121 cm pairs are out of sequence with the two pooled means noted above. The much deeper pair from drill core 01RG-76 also returned significantly different ages, with the wood cellulose at 42,190 ± 700 BP (OZL-484) and the pollen-rich fraction (SANU-8320) not distinguishable from background.

The graph in Figure 6 plots ^{14}C age against $\delta^{13}C$, showing the expected difference between wood cellulose at $\delta^{13}C$ = -20 to -22‰ and the pollen-rich organics, most of which have $\delta^{13}C$ = -27 to -30‰. The four samples at $\delta^{13}C$ = -23 to -25‰ appear anomalous, less negative than other pollen-rich samples, but the oldest three of these were given hypochlorite oxidation plus ABA chemistry, which is expected to significantly reduce humic acids and other lignin-derived organics, thus moving $\delta^{13}C$ of residual non-pollen plant debris towards the cellulose values.

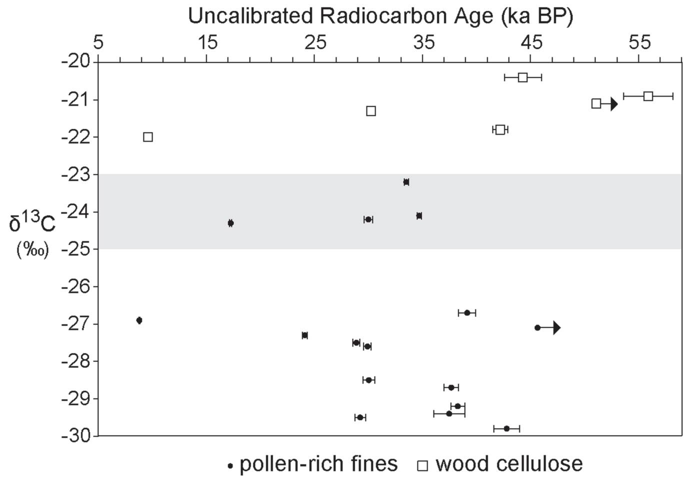

Figure 6. Radiocarbon age against $\delta^{13}C$ (‰)

Discussion

The most consistent unit dated between cores is the yellow-brown lake surface sediment that has a varying depth of 15-58 cm across the basin. In XW-B, this unit is 25 cm thick and returned two mid-Holocene dates. In XW-C, this surface layer is 14 cm thick and a sample from 10 cm returned an early Holocene age. These Holocene dates suggest that this most recent sedimentary unit may have started accumulating around 10,000-12,000 BP, and be indicative of (1) how slowly these sediments accumulate, and (2) the potential age of all underlying sediments. The next most consistent unit within the lake sediment is the upper black organic mud unit in cores XW-B, XW-C and XW-D. However, samples dated from the base of this unit in the three different cores (163 cm, 150 cm, 158 cm) returned ages of 22,150 BP, 42,800 BP and 29,910 BP respectively, suggesting no horizontal correlation in age. Another curiosity in the dating of Xere Wapo is that by 20 cm, the XW-C ages have already reached 29,540 BP, although there is no discernable stratigraphic hiatus in the sediments to explain this sudden shift in age.

The paired dating of wood and pollen-rich samples from these layers was carried out to resolve this issue. Vandergoes and Prior (2003) and a follow up study Newnham et al. (2007) highlighted the difficulties of dating the organic fraction in old sediments from several lakes and swamps in a high rainfall area of southern New Zealand. They concluded that it was the accompanying fine organic fraction in some pollen concentrates that caused young carbon contamination, or in some cases, the incomplete removal of humic acids that may have entered the older sediments through root penetration. The paired dating exercise in this study produced mixed results, with three out of the four pollen-rich dates being older than

Table 2. Carbon isotope analyses. Radiocarbon determinations by Australian National University (ANU radiometric, SANU accelerator), University of Waikato (Wk accelerator (in collaboration with UC Irvine)), Australian Nuclear Science and Technology Organisation (OZ accelerator). Pre-treatment chemistry: A = acid only; ABA = acid, base, acid; OxABA = hypochlorite, acid, base, acid; OxAOxBA = hypochlorite, acid, chlorite, base, acid; OxAOxA = hypochlorite, acid, chlorite, acid; all with distilled water washes between reagents. Reference standards are ancient NZ kauri wood samples courtesy of Alan Hogg, Waikato. NDFB = not different from background

Core	Depth (cm)	Fraction dated	Chemistry	$\delta^{13}C$ (‰)	^{14}C Age (yr BP)	Lab number
XW-A	115-123	bulk sediment <500 µm	solvent, ABA	-24.0 (est.)	32,470 ± 670	ANU-8420
XW-B	3-4	bulk sediment 250-600 µm	A	-24.0 (est.)	4400 ± 150	ANU-9797
	10-20	whole wood	A	-24.0 (est.)	5780 ± 80	ANU-9793
	83-85	pollen-rich 10-250 µm	ABA	N/A	22,150 ± 140	OZF-756
	96-107	whole wood >600 µm	A	-24.0 (est.)	19,400 ± 420	ANU-9794
	163-164	pollen-rich 10-250 µm	ABA	N/A	25,250 ± 180	OZF-755
	223-225	pollen-rich 10-250 µm	ABA	N/A	46,050 ± 1350	OZF-757
	250-270	bulk sediment 250-600 µm	A	-24.0 (est.)	8500 ± 420	ANU-9795
	290-300	bulk sediment 250-600 µm	A	-24.0 (est.)	14,660 ± 660	ANU-9796
	360	whole wood	ABA	N/A	> 47,000	OZE-449
	475	pollen-rich 10-250 µm	ABA	N/A	NDFB	OZE-448
XW-C	10-10.5	pollen-rich 10-125 µm	ABA	-26.9	8792 ± 53	Wk-18065
	20-20.5	pollen-rich 10-125 µm	ABA	-29.5	29,237 ± 490	Wk-18066
	35-35.5	pollen-rich 10-125 µm	ABA	-28.5	30,031 ± 542	Wk-18067
	48-49	pollen-rich 10-125 µm	ABA	-27.5	28,880 ± 340	OZJ-295
	80-81	pollen-rich 10-125 µm	ABA	-24.2	29,990 ± 380	OZJ-296
	85-86	wood cellulose	OxAOxBA	-22.0	9590 ± 60	OZL-481
	86-87	pollen-rich 38-50 µm	OxABA	-24.3	17,250 ± 110	SANU-8316
	105-106	pollen-rich 10-125 µm	ABA	-26.7	39,140 ± 800	OZJ-297
	110-111	pollen-rich 10-125 µm	ABA	-29.4	37,478 ± 1426	Wk-17760
	115-116	pollen-rich 10-125 µm	ABA	-28.7	37,670 ± 660	OZJ-291
	119-120	pollen-rich 38-50 µm	OxABA	-24.1	34,700 ± 190	SANU-8317
	120-121	wood cellulose	OxAOxBA	-21.3	30,240 ± 280	OZL-482
	125-126	pollen-rich 10-125 µm	ABA	-29.2	38,270 ± 640	OZJ-292
	150-151	pollen-rich 10-125 µm	ABA	-29.8	42,800 ± 1200	OZJ-298
	219-220	pollen-rich 38-50 µm	OxABA	-23.2	33,500 ± 190	SANU-8318
	220-221	wood cellulose	OxAOxBA	-20.4	44,300 ± 1700	OZL-483
XW-D	150-151	pollen-rich 10-125 µm	ABA	-27.3	24,100 ± 210	OZJ-293
	158-159	pollen-rich 10-125 µm	ABA	-27.6	29,910 ± 340	OZJ-294
01RG-76	770	wood cellulose	OxAOxBA	-21.8	42,190 ± 700	OZL-484
	790	pollen-rich 38-50 µm	OxABA	-27.1	NDFB	SANU-8320
Ref. std.	NZK-1	wood cellulose	OxAOxA	-21.1	>51,100	OZL-485(1)
		wood cellulose	OxAOxA	-20.9	55,900 ± 2300	OZL-485(2)
	NZK-2	wood cellulose	OxAOxA	-22.3	NDFB	OZL-486(1)
		wood cellulose	OxAOxA	-22.2	NDFB	OZL-486(2)

wood cellulose dates and several more age inversions, suggesting that contamination by young carbon through the fine organic fraction is not the main factor operating here.

The sediment fractions in this latest trial were treated with hypochlorite oxidation in an attempt to destroy organic contamination not removed by standard ABA chemistry (e.g. Gillespie 1990), and then concentrated to a size fraction of 38-50 µm. The paired wood samples were converted to cellulose by a combination of alkaline hypochlorite and acidic chlorite oxidations, which produced ages consistently younger than the existing dataset. The stable isotope results presented in Table 2 are another way of looking this data. One interpretation is that they verify that the latest dating exercise has removed organic contamination (most likely humic acids and other lignin degradation products) not removed by previous methods and by doing this, has increased the cellulose content derived from non-pollen plant debris. However, the results might also indicate a significant amount of non-pollen fine plant debris in the samples. The source of this may be coarse non-pollen plant debris sinking through the quite fluid muds, contributing ages that are apparently too young. However, without doing more detailed work, we can't draw any firm conclusions on the reliability of the various dated fractions.

Stevenson and Hope (2005) suggested that the upper 250 cm of Lake Xere Wapo were most likely disturbed, possibly by in-washing of catchment sediment and erosion of shallow sediments, combined with phases of aquatic woodland interrupting deposition over the past 20,000 years. It is worth noting that a number of neighbouring lakes, such as Lake Suprin and Lake Emeric, have similar sedimentation histories for the uppermost sediments, with units of dark-yellow to reddish-brown sediments alternating with darker organic units (Hope and Pask 1998). Dating of these sediments also produced age inversions and finite dates in sediments assumed to date from beyond the radiocarbon age limit.

Given the similarity in some aspects of their pollen records, Stevenson and Hope (2005) compared the Lake Xere Wapo record with that from Lynch's Crater in northern Queensland (Kershaw 1986). Radiocarbon dating of the organic-rich Lynch's Crater sediments also produced a number of age inversions, although none as severe as those encountered in the Lake Xere Wapo dating exercises, and simple ABA pre-treatment yielded more consistent results than ABOX-SC treated samples (Acid-Base-Oxidation-Step Combustion) (Turney et al. 2001a, b). The decline of *Araucaria* within the past 50 ka and increase in fire in the Australian record has been attributed variously to human impact and climate change, and remains largely unresolved. New Caledonia was not inhabited by people until c. 3000 years ago and so does not have the complicating factor of human agency, hence the importance of the record. However, a robust chronology remains elusive.

The dating of sediment cores collected by the ANU team and Goro Nickel drilling program has found that the underlying sedimentation history of the lake is more complex than first imagined, and the discussion here suggests that sediment disturbance may well be a significant factor. Fluctuations in water level and changes in sedimentary type over the past 50,000 years or more have at various times led to forest growth on the lake-bed surface. Sediments recovered in core XW-D suggest that this may be a location that had less forest incursion than other coring sites. It is this core that will now receive most attention with regard to pollen analysis and further dating. Due to the lack of free quartz in this environment, we have not been able to pursue alternative dating techniques such as optically stimulated luminescence. One avenue that may be explored is the detection of peaks in volcanic glass shards. Several peaks in volcanic glass were detected in Marine Isotope Stages 2, 3 and 4 sediments in deep-sea core Fr7/01:GC4 from the New Caledonia Basin off southern New Caledonia (Gretton 2002). If similar peaks occur in the Lake Xere Wapo sediments, then it may be possible to link and correlate the sediments with the marine stages.

Conclusion

Although some of the problems encountered in dating the Lake Xere Wapo sediments may stem from the variety of sample type and pre-treatment protocols used, later dating exercises have attempted to keep the material dated and chemistry performed more consistent. However, given the frequency of age inversions in the record – at least one in each set of radiocarbon results obtained – it is unlikely that sample contamination can explain the disparate age-depth relationships at the five core locations. Disturbance of the sediments must therefore be considered. The most recent dating programs have not resolved the problems originally reported; indeed, they add new levels of complexity and confusion to interpretations of the tempo and mode of lake-sediment formation in the Plaines des Lacs, New Caledonia.

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References

Brooks, R.R. 1987. New Caledonia. In R.R. Brooks (ed.) *Serpentine and its vegetation: a multidisciplinary approach*. pp330-353. London.

Fink, D., M. Hotchkis, Q. Hua, G. Jacobsen, A.M. Smith, U. Zoppi, D. Child, C. Mifsud, H. van der Gaast, A. Williams and M. Williams 2004. The ANTARES AMS facility at ANSTO. *Nuclear Instruments and Methods* B 223-224:109-115.

Gillespie, R. 1990. On the use of oxidation for AMS sample pretreatment: *Nuclear Instruments & Methods* B52:345-347.

Gillespie, R., L.K. Fifield, V. Levchenko and R. Wells 2008. New ^{14}C ages on cellulose from *Diprotodon* gut contents: explorations in oxidation chemistry and combustion. *Radiocarbon* 50:75-81.

Gretton, E. J. 2002. *Palaeoceanographic changes offshore New Caledonia for the past 140,000 years.* Unpublished Honours Thesis. Canberra: The Australian National University.

Hogg, A.G., L.K. Fifield, C.S.M. Turney, J.G. Palmer, R. Galbraith and M.G.K. Baillie 2006. Dating ancient wood by high sensitivity liquid scintillation counting and accelerator mass spectrometry – Pushing the boundaries. *Quaternary Geochronology* 1:241-248.

Hope, G.S. and J. Pask 1998. Tropical vegetational change in the late Pleistocene of New Caledonia. *Palaeogeography, Palaeoclimatology, Palaeoecology* 142:1-21.

Kershaw, A.P. 1986. Climatic change and Aboriginal burning in north-east Australia during the last two glacial/interglacial cycles. *Nature* 322:47-49.

Morat, Ph., J-M. Veillon and H.S. Mackee 1984. Floristic relationships of New Caledonian rainforest phanerogams. In F.J. Radovsky, P.H. Raven and S.H. Sohmer (eds) *Biogeography of the Tropical Pacific: Proceedings of a Symposium*, pp71-128. Honolulu: Bernice P. Bishop Museum.,

Morliere, A. and J.P. Rebert 1986. Rainfall shortage and El Niño-Southern Oscillation in New Caledonia, Southwestern Pacific. *Monthly Weather Review* 114:1131-1137.

Newnham, R.M., M.J. Vandergoes, M.H. Garnett, D.J. Lowe, C. Prior and P.C. Almond 2007. Test of AMS 14C dating of pollen concentrates using tephrochronology. *Journal of Quaternary Science* 22:37-51.

Read, J., T. Jaffré, E. Godrie, G.S. Hope and J-M. Veillon 2000. Structural and floristic characteristics of some monodominant and adjacent mixed rainforests in New Caledonia. *Journal of Biogeography* 27:233-250.

Stevenson, J. 2004. Late Holocene environmental change at Lac Saint Louis, New Caledonia. *The Holocene* 14(6):888-898.

Stevenson, J. 1998. *Late Quaternary Environmental Change and the Impact of Melanesian Colonisation in New Caledonia*. Unpublished PhD Thesis. Kensington: University of New South Wales.

Stevenson, J. and J.R. Dodson 1995. Palaeoenvironmental evidence for human settlement on New Caledonia. *Archaeology in Oceania.* 30:36-41.

Stevenson, J., J.R. Dodson and I.P. Prosser 2001. A late Quaternary record of environmental change and human impact from New Caledonia. Palaeogeography*, Palaeoclimatology, Palaeoecology* 168:97-123.

Stevenson, J and G.S. Hope 2005. A comparison of late Quaternary forest changes in New Caledonia and northeastern Australia. *Quaternary Research* 64(3):372-383.

Turney, C.S.M., M.I. Bird, L.K. Fifield, A.P. Kershaw, R.G. Cresswell, G.M. Santos, M.L. di Tada, P.A. Hausladen and Z. Youping 2001a. Development of a robust C-14 chronology for Lynch's Crater (North Queensland, Australia) using different pretreatment strategies. *Radiocarbon* 43:45-54.

Turney, C.S.M., A.P. Kershaw, P. Moss, M.I. Bird, L.K. Fifield, R.G. Cresswell, G.M. Santos, M.L. di Tada, P. A. Hausladen and Y. Zhou 2001b. Redating the onset of burning at Lynch's Crater (North Queensland): implications for human settlement in Australia. *Journal of Quaternary Science* 16:767-771.

Vandergoes, M.J. and C.A. Prior 2003. AMS dating of pollen concentrates: a methodological study of Late Quaternary sediments from south Westland, New Zealand. *Radiocarbon* 45:479-491.