

COMMENT ON "RESOLVING VOLCANIC ACTIVITY OF 20 MA AGO WITH  
RELATIVE ACCURACY OF 1 YR FROM TREE RINGS OF PETRIFIED WOOD"

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The 7 tree-ring series presented by Kumagai and Fukao (1992, hereafter abbreviated KF) pose a challenging test of the ability of cross-correlation (CC) analysis to detect pattern-matching among short (<80 year) time series. The difficulty of proving matching among such series is compounded by the age of KF's series: all span an interval for which a dated reference ring-width chronology, compiled from many contemporaneously-growing trees, is not available. This "blind-dating" context is intriguing because it raises statistical issues that have not been addressed. Nonetheless, we believe KF's CCs are insufficient to support their conclusion that petrified trees in the Hachiya Formation record the emplacement chronology of these Miocene volcanic deposits. Here, we clarify the statistical setting for KF's paper. We then present evidence supporting our alternative interpretation that inferred pattern-matching among the 7 series is probably not significant, and may be erroneous. Lastly, we mention several references on early-Holocene/late-Glacial dendrochronology relevant to KF's paper.

We began our analysis by tracing KF's plots on a micrometer and deriving ring widths from the Pythagorean theorem. Superposition of our reproduced data on the original plots and the similarity of our CCs (Table 1) suggest that the reproductions are within a few percent of original values. Because trend and serial persistence (large numbers tending to follow large numbers, and small numbers tending to follow small numbers) artificially inflate CCs (e.g., Fritts, 1976, p. 324; Monserud and Yamaguchi, 1989), we then removed these from the data in two steps. For series with decay trends related to increasing tree age (e and g; Fritts, 1976), detrending was accomplished by fitting decay curves to them by least squares and dividing ring widths by corresponding curve values (Fritts, 1976). The same curves were also fitted to series containing both trend and growth releases. Here, however, only pre-disturbance portions of series were used to determine curve parameters (the first 49 widths of series a and the first 67 widths of series d). This approach simultaneously scaled releases for tree age. Remaining persistence within each series, which reflects tree physiology (Fritts, 1976), was removed by time series analysis (termed "prewhitening;" Box and Jenkins, 1976). This involved using square root or ln transformations to homogenize series variances, and fitting appropriate autoregressive (AR) models to the transformed data (below).

Next, CCs were computed for all relative dating positions with at least 34 years of overlap (the length of the shortest series f) between each pair of series. Series f was central to KF's thesis because it and series b are the only 2 that contain outermost rings. Lastly, the  $\alpha$  significance level of the best  $t$  value for each pair of series was adjusted for multiplicity, the number of potential matching positions tested, using:

$$P = 1 - (1 - \alpha)^m. \quad (1)$$

Here,  $P$  is the adjusted significance, and  $m$  is the number of positions tested (Table 2). Data processing thus far has been previously reported (e.g., Orton, 1983; Wigley et al., 1987; Yamaguchi and Allen, 1992).

The above methods, however, provide little guidance relative to the blind-dating context. Two unanswered questions are: (i) What critical  $\alpha$  should one use to accept or reject the null hypothesis of no ring-width matching between one series and multiple others? (ii) Is multiplicity adjustment as described above adequate? Both questions arise because the blind setting involves computing CCs at more potential positions for individual samples than are accounted for by paired-sample multiplicity adjustment.

Table 1. Cross-correlation matrix for reproduced KF tree-ring widths at relative dating positions inferred by KF.

Series and interval spanned (relative years)		b	c	d	e	f	g
a 29-89	$r$	.762	.727	.352	.317	.022	.486
	DF	56#	44#	53#	31#	30#	40#
	$t$	8.81*	7.02*	2.74*	1.86*	.012	3.52*
b 14-88	$r$	-	.725	.418	.434	.324	.395
	DF	-	45	54#	48#	30#	40#
	$t$	-	7.06*	3.35*	3.34*	1.88	2.72*
c 40-86	$r$	-	-	.443	.209	.644	.741
	DF	-	-	44	31#	30#	31
	$t$	-	-	3.28*	1.19	4.61*	6.14*
d 9-85	$r$	-	-	-	.304	.589	.587
	DF	-	-	-	54#	32	48#
	$t$	-	-	-	2.34*	4.12*	5.02*
e 1-77	$r$	-	-	-	-	.204	.596
	DF	-	-	-	-	30#	49#
	$t$	-	-	-	-	1.14	5.20*
f 43-76	$r$	-	-	-	-	-	.372
	DF	-	-	-	-	-	28
	$t$	-	-	-	-	-	2.12*
g 18-72	$r$	-	-	-	-	-	-
	DF	-	-	-	-	-	-
	$t$	-	-	-	-	-	-

Notes: All  $r$  values within .12 of KF values (mean difference = .03). DF, degrees of freedom;  $t = r[DF/(1 - r^2)]^{0.5}$ ; #, early rings truncated from series with later starting date so that DF match those of KF. \*,  $\alpha < .05$  level used by KF.

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To approach these questions, we turned to the literature on the conventional case of cross-correlating a prewhitened undated ring series against a prewhitened reference series. Here, Wigley et al. (1987) proposed  $1/m$  as a reasonable critical  $\alpha$ . By analogy, we propose  $1/m'$  as an appropriate

critical  $\alpha$  for blind dating, where  $m'$  is the sum of pairwise  $m$

Table 2. Cross-correlation matrix for reproduced, transformed series at best relative dating positions.

Series, transformation(s), and AR model		b	c	d	e	f	g
a, dt-ln, 1	off	-1	-20	-6	-9	0	4
	r	.423	.396	.514	.294	.519	.254
	DF	58	39	53	50	32	49
	t	3.55	2.70	4.36	2.17	3.43	1.84
	$\alpha$	.0008*	.010	.0001*	.034	.0017*	.072
	m	69	41	71	71	28	49
	P	.054	-	.007	-	.047	-
P'	.231	-	.032**	-	.429	-	
b, sq, 2	off	-	-37	-37	13	-2	-3
	r	-	.362	.380	.324	.397	.270
	DF	-	36	36	62	32	53
	t	-	2.33	2.47	2.70	2.45	2.04
	$\alpha$	-	.026	.019	.009	.020	.046
c, ln, 1	off	-	-	19	29	-10	-1
	r	-	-	.365	.342	.473	.351
	DF	-	-	45	45	32	44
	t	-	-	2.63	2.44	3.03	2.48
	$\alpha$	-	-	.012	.019	.005	.017
d, dt-sq, 1	off	-	-	-	29	-33	20
	r	-	-	-	.295	.406	.385
	DF	-	-	-	46	32	33
	t	-	-	-	2.09	2.51	2.40
	$\alpha$	-	-	-	.042	.017	.022
e, dt-sq, w	off	-	-	-	-	0	17
	r	-	-	-	-	.373	.297
	DF	-	-	-	-	32	36
	t	-	-	-	-	2.27	1.87
	$\alpha$	-	-	-	-	.030	.070
f, sq, 1	off	-	-	-	-	-	0
	r	-	-	-	-	-	.491
	DF	-	-	-	-	-	32
	t	-	-	-	-	-	3.18
	$\alpha$	-	-	-	-	-	.0032*
	m	-	-	-	-	-	22
	P	-	-	-	-	-	.068
P'	-	-	-	-	-	.461	
g, dt-sq, 1	-	-	-	-	-	-	-

Notes: Dt, series detrended as described in text; ln or sq, natural log or square root transformations. An AR1 model describes serial correlation as  $X_t = aX_{t-1} + b$ , while an AR2 model describes it as  $X_t = aX_{t-1} + bX_{t-2} + c$ . Here,  $X_t$  is the detrended/transformed ring-width at time  $t$ , and  $a$ - $c$  are constants. W, transformed series adequately prewhitened. "Off," number of years the outermost ring of upper series lags outermost ring of lefthand series at best-matching position.  $M$ ,  $P$ , and  $P'$  terms described in text; for brevity, these are shown mainly for CCs with  $\alpha$  values  $< 1/m'$  (\*, see text), \*\*,  $P' < 0.05$ .

terms computed for each sample. For example,  $m'$  terms in Table 2 range from 193 (for series f) to 410 (for series e). Thus, critical  $\alpha$  values range from about 0.005 to 0.002, respectively. Similarly, we propose that blind multiplicity adjustment should follow (1), but use  $m'$  instead of  $m$ . Both uses of the  $m'$  term are logical extensions of prior methods.

The above procedures show that of the many "significant" CCs KF reported, only 4 appear to pass critical  $\alpha$  levels. Of these, only 1 appears to pass blind multiplicity-adjustment (Table 2).

Other features of our analysis provide supporting evidence that the relative positions proposed by KF may be spurious: (i) Of the 4 potential positions that pass critical  $\alpha$  levels, only 1 (Table 2, a vs. b) matches that of KF. (ii) Dates for the 2 most-significant positions (a vs. b, and a vs. d) lack consistency (note lack of corresponding relative matching at b vs. d). (iii) Examinations of histograms of  $r$  and  $t$  values generated during CC runs, with 1 possible exception (a vs. d), lack single positive outliers suggestive of ring-width matching (e.g., Orton, 1983; Yamaguchi and Allen, 1992).

In summary, the statistical data that support KFs' inferred dating positions appear weak. Their series are too short to accept or reject relative dating principally on the basis of CC analysis. Thus, KFs' interpretations of past volcanic behavior, which rest on these data, are also suspect.

A final comment is that KFs' statement (p. 1859), that dendrochronology has been limited to late-Holocene dating, was mistaken. We refer readers to Kaiser (1989), Becker et al. (1991), Barbetti et al. (1992), Leavitt and Kalin (1992), and references therein.

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