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Carbon-13 Nuclear Magnetic Resonance Spectra of Some Podocarpane Derivatives

INGER WAHLBERG, SVEN-OLOF ALMQVIST, TOSHIAKI NISHIDA and CURT R. ENZELL *

Research Department, Swedish Tobacco Co., P. O. Box 17007, S-104 62 Stockholm, Sweden

^{13}C NMR studies of a series of ring C substituted podocarpane and podocarpene derivatives using proton-noise and single frequency off resonance decoupling, partially relaxed Fourier transform techniques, shift reagents and specifically deuterium labelled derivatives have permitted unequivocal assignment of nearly all signals. The shielding effects caused by introduction of hydroxyl and carbonyl groups are discussed as is the pronounced deshielding of the δ-carbon caused by hydroxyl and methyl groups in close steric proximity to this carbon. Some effects of deuterium substitution on the carbon resonances are presented.

^{13}C NMR has become a very useful analytical technique in natural product chemistry and has been applied in structural and stereochemical studies of various terpenoids.[1–10]

The common occurrence of diterpenoids and nor-terpenoids in tobacco [11] and the utility of ^{13}C NMR in the structural determination of these compounds have encouraged further studies.[12] The present paper is devoted to a systematic investigation of ring C oxygenated podocarpanes and podocarpenes, which are relatively rigid and conformationally well defined and therefore suitable models for the evaluation of substituent shielding effects.

RESULTS

The compounds examined in this study comprise besides the parent hydrocarbon podocarpane (*1*), ring C oxygenated podocarpanes (*2* – *12*) and podocarpenes (*13* – *23*), as well as deuterated analogues (*24* – *43*; Table 1). The methyl carbon signals were assigned using single frequency off resonance (SFOR) decoupling, while the partially relaxed Fourier transform (PRFT) technique was employed to facilitate recognition of methylene, methine, and quaternary carbon signals, thereby making use of the well-known difference in spin lattice relaxation rates, $1/T_1$, between such carbons.[9,13,14] The PRFT technique was found particularly useful in this work because of the proximity of some of the sp^3 carbon signals, which prevented unambiguous assignment by SFOR decoupling. Further assistance in the assignment of the non-trivial resonances was obtained by comparison of published data for

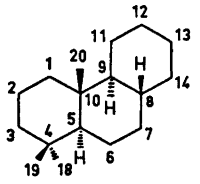
Table 1. Deuterium labelled compounds examined.

No.	Compound
24	8β,13,13,14,14-d_5-Podocarpane
25	8β-d_1-Podocarpan-12α-ol
26	8β-d_1-Podocarpan-12β-ol
27	9α-d_1-Podocarpan-12α-ol
28	9α-d_1-Podocarpan-12β-ol
29	11,11,13,13-d_4-Podocarpan-12α-ol
30	11,11,13,13-d_4-Podocarpan-12β-ol
31	9α-d_1-Podocarpan-14α-ol
32	9α-d_1-Podocarpan-14β-ol
33	8β,13,13-d_3-Podocarpan-14α-ol
34	8β,13,13-d_3-Podocarpan-14β-ol
35	8β-d_1-Podocarpan-12-one
36	9α-d_1-Podocarpan-12-one
37	11,11,13,13-d_4-Podocarpan-12-one
38	8β,13,13-d_3-Podocarpan-14-one
39	8β,11,13,13-d_4-Podocarp-9(11)-en-12-one
40	8β-d_1-Podocarp-13-en-12β-ol
41	9α-d_1-Podocarp-13-en-12β-ol
42	8β-d_1-Podocarp-13-en-12-one
43	9α-d_1-Podocarp-13-en-12-one

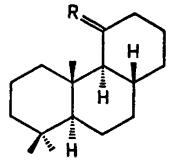
structurally related compounds and especially by examination of the selectively deuterated analogues (*24*–*43*), since deuterium labelling, as has been pointed out previously,[15–18] allows unambiguous identification of the signals due to the labelled carbons and frequently also of those due to adjacent carbons. The assignments made on these bases are given in Tables 2 and 3.

Podocarpane (*1*). The shift analysis of the spectrum of podocarpane (*1*) was made possible by comparison with published ^{13}C NMR data for pimaradienes and with the spectrum of 8β,13,13,14,14-d_5-podocarpane (*24*). Thus, nine peaks in the spectrum of podocarpane, having chemical shift values virtually identical to those found for the C-1 to C-6 and C-18 to C-20 signals in the spectrum of pimara-8(14),-15-diene [6] and being of appropriate multiplicity, were assigned on this basis alone. The remaining singlet at δ 36.9 in the off-resonance decoupled spectrum of *1* was then ascribed to C-10.

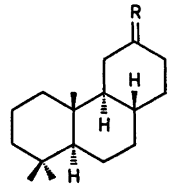
The two methine carbon signals at δ 36.8 and 56.3 were attributed to C-8 and C-9, respectively, since the former signal was virtually absent and the latter experienced an upfield shift of 0.08 ppm in the spectrum of 8β, 13, 13, 14, 14-d_5-podocarpane (*24*). Similarly, isotope induced upfield shifts of 0.15, 0.24, and 0.08 ppm for the signals at δ 35.9, 25.1, and 27.1 are only compatible with their assignments as C-7, C-11, and C-12, respectively. The remaining two signals at δ 26.4 and 35.5, hardly visible in the spectrum of the labelled derivative, were ascribed to C-13 and C-14, respectively; the differentiation was based on the fact that C-14 being adjacent to a branched center should be deshielded. Hence we consider the assignment of the spectrum of podocarpane



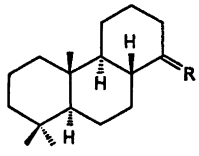
1



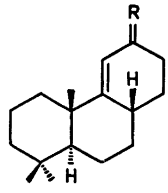
2 R = H, α-OH
3 R = H, β-OH
10 R = O



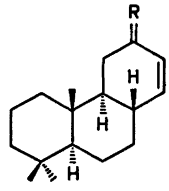
4 R = H, α-OH
5 R = H, β-OH
8 R = H, α-OAc
9 R = H, β-OAc
11 R = O



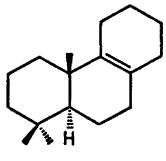
6 R = H, α-OH
7 R = H, β-OH
12 R = O



13 R = H_2
14 R = H, α-OH
15 R = H, β-OH
16 R = H, α-OAc
17 R = H, β-OAc
18 R = O



19 R = H, α-OH
20 R = H, β-OH
21 R = H, β-OAc
22 R = O



23

Table 2. Carbon-13 chemical shifts and assignments for the podocarpane derivatives *1*–*12*[a]

Compound	Carbon																
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	18	19	20
Podocarpane (*1*)	39.1	19.0	42.4	33.3	55.5	21.8	35.9	36.8	56.3	36.9	25.1	27.1	26.4	35.5	33.6	22.0	14.3
Podocarpan-11α-ol (*2*)	41.7	19.1	42.0	33.6	55.3	21.9	35.7	36.4	62.0	39.0	71.9	38.4	23.9	34.9	33.9	22.1	15.0
Podocarpan-11β-ol (*3*)	39.6	18.7	42.2	33.2	55.7	21.7	36.0	30.1	58.9	37.5	66.4	35.4	19.1	35.6	34.0	22.1	16.7
Podocarpan-12α-ol (*4*)	38.8	18.9	42.2	33.3	55.4	21.7	35.4	36.4	48.5	36.4	31.5	67.0	32.3	28.6	33.6	21.7	14.1
Podocarpan-12β-ol (*5*)	39.0	18.9	42.2	33.2	55.2	21.6	34.9	35.6	53.9	36.7	34.6	71.4	35.2	32.9	33.6	21.9	14.3
Podocarpan-14α-ol (*6*)	39.3	18.9	42.2	33.3	54.9	21.5	30.6	40.7	48.2	36.7	24.8	20.0	33.6	71.0	33.6	22.0	14.1
Podocarpan-14β-ol (*7*)	39.4	19.0	42.2	33.2	55.1	21.1	31.0	44.1	53.9	36.7	24.4	24.0	35.4	76.8	33.6	21.9	14.3
Podocarpan-12α-yl acetate (*8*)[c]	38.9	18.8	42.2	33.3	55.4	21.6	35.3	36.1	49.4	36.4	29.2[b]	70.7	29.6[b]	28.8	33.6	21.9	14.0
Podocarpan-12β-yl acetate (*9*)[d]	39.0	18.8	42.1	33.2	55.1	21.6	34.7	35.7	53.6	36.8	30.9[b]	74.4	31.5[b]	32.4	33.6	21.9	14.2
Podocarpan-11-one (*10*)	38.4	18.7	42.3	33.3	54.9	21.2	35.8	40.0	67.4	36.7	211.8	44.3	26.7	34.5	33.7	22.0	14.6
Podocarpan-12-one (*11*)	38.7	18.7	42.0	33.2	54.8	21.4	34.3[b]	35.6	56.1	37.3	41.0	213.4	41.1	34.2[b]	33.6	21.9	13.8
Podocarpan-14-one (*12*)	39.4	19.0	42.0	33.3	54.6	20.6	26.3[b]	49.7	57.3	37.6	24.4	26.5[b]	41.8	213.7	33.5	21.9	13.9

[a] δ-values relative to TMS. [b] Assignment may be reversed. [c] $-\overset{\overset{O}{\|}}{C}-CH_3$ 170.7 and 21.7. [d] $-\overset{\overset{O}{\|}}{C}-CH_3$ 170.6 and 21.6.

Table 3. Carbon-13 chemical shifts and assignments for the podocarpene derivatives *13*–*23*[a]

Compound	Carbon																
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	18	19	20
Podocarp-9(11)-ene (*13*)	37.6	19.2	42.5	33.8	54.0	21.2	36.4	33.4	151.5	39.6	114.3	26.0	22.2	32.0	33.4	21.9	21.1
Podocarp-9(11)-en-12α-ol(*14*)	37.3	19.0	42.3	33.8	53.5	22.0	35.7	33.3	155.2	39.6	117.4	66.2	29.7	26.6	33.3	21.9	21.0
Podocarp-9(11)-en-12β-ol (*15*)	37.4	19.0	42.3	33.7	53.8	21.9	36.2	33.4	153.1	39.3	119.3	67.4	31.1	28.6	33.3	21.9	19.0
Podocarp-9(11)-en-12α-yl acetate (*16*)[c]	37.3	19.0	42.2	33.8	53.3	21.9	35.5	33.4	157.4	39.8	113.4	69.5	26.8[b]	26.6[b]	33.3	21.9	21.1
Podocarp-9(11)-en-12β-yl acetate (*17*)[d]	37.3	19.0	42.2	33.8	53.8	21.9	35.9	33.3	155.7	39.7	114.8	70.8	27.0	27.9	33.3	21.9	20.9
Podocarp-9(11)-en-12-one (*18*)	36.7	18.7	41.7	33.9	53.1	21.4	35.2	34.2	175.9	40.9	119.5	200.4	35.8	29.4	33.3	22.0	21.1
Podocarp-13-en-12α-ol (*19*)	38.4	18.8	42.3	33.3	55.7	21.9	33.7	36.5	47.4	36.2	30.6	65.0	126.7	137.8	33.5	21.7	14.6
Podocarp-13-en-12β-ol (*20*)	38.4	18.8	42.3	33.3	55.4	21.9	33.9	36.3	52.6	36.4	32.3	69.6	129.9	135.0	33.4	21.6	14.3
Podocarp-13-en-12β-yl acetate (*21*)[e]	38.4	18.8	42.2	33.3	55.3	21.9	33.8	36.2	52.3	36.5	28.1	72.5	125.6	137.0	33.4	21.6	14.2
Podocarp-13-en-12-one (*22*)	38.0	18.6	42.0	33.2	54.8	21.7	32.9	36.6	54.0	36.6	37.8	201.1	128.1	155.9	33.4	21.7	14.4
Podocarp-8-ene (*23*)	36.5	19.0[b]	42.0	33.3	51.9	19.1[b]	32.6	138.4	125.9	37.8	23.0[b]	23.9[b]	23.6[b]	30.8	33.3	21.7	19.3

[a] δ-values relative to TMS. [b] Assignment may be reversed. [c] $-\overset{\overset{O}{\|}}{C}-CH_3$ 171.0 and 21.6. [d] $-\overset{\overset{O}{\|}}{C}-CH_3$ 170.9 and 21.5. [e] $-\overset{\overset{O}{\|}}{C}-CH_3$ 170.8 and 21.4.

(*1*) the parent hydrocarbon of the compounds included in the present study, firmly established and reliable for extraction of substituent effects when compared with the spectra of the substituted podocarpane derivatives.

Podocarpanols (*2*–*7*). Previous studies have demonstrated that a hydroxyl substituent incorporated in rigid molecules such as steroids influences only the chemical shifts of the α-, β-, γ-, and δ-carbons.[17] Consonant with this, the signals due to the three methyl groups, ring A carbons – except for the C-1 resonance derived from podocarpan-11α-ol (*2*) – and the methylene carbons of ring B – except for the C-7 signals in the spectra of the two podocarpan-14-ols (*6*–*7*) – were found at fields almost identical to those observed for the parent hydrocarbon (*1*). The resonances associated with the hydroxyl substituted carbon atoms (α-carbons) were readily identified, since they invariably appeared in the lowest field regions of the spectra (δ 66.4–76.8), while the remaining shift assignment were delineated as follows.

Selective deuterium labelling of C-8 (*25*–*26*), C-9 (*27*–*28*), and C-11, C-13 (*29*–*30*) of the podocarpan-12-ols (*4*–*5*) served to identify not only the resonances due to the carbon atoms carrying the label but also those due to the adjacent carbon atoms, *i.e.* C-7, C-10, and C-14.

Similarly, incorporation of deuterium at C-9 (*31*–*32*) and C-8, C-13 (*33*–*34*) solved the shift assignments of C-7 to C-13 for the two podocarpan-14-ols (*6*–*7*).

Use of the shift reagent Eu(dpm)$_3$ facilitated the identification of the remaining carbon signals in the spectra of the podocarpan-11-ols (*2*–*3*), *e.g.* differentiation between the C-7, C-12, and C-14 signals, which in the case of the β-epimer (*3*) are positioned at δ 36.0, 35.4, and 35.6, respectively (Table 4).

Table 4. Lanthanide-induced shifts (LIS) for podocarpan-11α- and -11β-ol (*2*–*3*).

Carbon	Compound			
	2		*3*	
	δ	LIS[a]	δ	LIS
7	35.7	0.08	36.0	0.13
11	71.9	1.00	66.4	1.00
12	38.4	0.49	35.4	0.45
14	34.9	0.14	35.6	0.17

[a] Relative shifts using Eu(dpm)$_3$.

Podocarpan-12-yl acetates (*8*–*9*). Acetylation of podocarpan-12α- and -12β-ol (*4*–*5*) caused virtually no shift of the C-1 to C-10 and C-18 to C-20 signals, while the signal due to C-12 showed an expected downfield shift.[18] A clear differentiation between the β-carbon (C-11, C-13) resonances, shifted upfield on account of acetylation,[18] was not possible since these peaks were too closely spaced in the spectra of both acetates (*8*–*9*). The remaining peaks present at δ 28.8 and 32.4 in the spectra of podocarpan-12α-yl acetate (*8*) and -12β-yl acetate (*9*), respectively, whose positions are only slightly altered relative to the positions of the C-14 resonances for the corresponding alcohols (*4*–*5*), were ascribed to C-14.

Podocarpanones (*10*–*12*). In agreement with previous findings for keto steroids,[16] introduction of an oxo group at C-11 (*10*), C-12 (*11*) or C-14 (*12*) in podocarpane (*1*) affects only the shieldings of the α-, β-, γ-, and δ-carbons and leaves the signals due to C-1 to C-6 and the three methyl groups at invariant positions. The carbonyl carbon singlets (α-carbons), located above δ 200, were readely recognised, whereas the identification of the remaining resonances for podocarpan-12-one (*11*) and -14-one (*12*) was aided by deuterium labelling. Thus, examination of the spectra of 8β-d_1-, 9α-d_1-, and 11,11,13,13-d_4-podocarpan-12-one (*35*–*37*) enabled the assignments of the C-8 to C-11 and C-13 signals, but did not allow a distinction between the C-7 and C-14 resonances, which are positioned at δ 34.2 and 34.3. Similarly, the peaks corresponding to C-7, C-8, C-12, and C-13 were unequivocally identified from the spectrum of 8β, 13, 13-d_3-podocarpan-14-one (*38*).

The assignments of the remaining signals in the spectrum of podocarpan-11-one (*10*) were guided by the substituent parameters extracted from the results for podocarpan-12- and -14-one (*11,12*).

Podocarp-9(11)-enes (*13*–*18*). Comparison of the spectra of the podocarp-9(11)-enes (*13*–*18*) with that of podocarpane (*1*) and application of simple chemical shift theory, allowed ready recognition of the signals corresponding to the functionalised carbons and

also assignment of the other signals, except those due to C-1, C-7, C-13, and C-14 – and in the case of podocarp-9(11)-ene (*13*) also that due to C-12.

The shift analysis for podocarp-9(11)-en-12-one (*18*) was completed with the aid of deuterium labelling. Hence, observations of appropriate geminal and vicinal isotope effects for the corresponding 8β,11,13,13-d_4 derivative (*39*), confirmed the shift assignments of C-8 and C-11 and identified the signals due to C-7, C-13, and C-14. The remaining signal at δ 36.7, being about 1.5 ppm downfield of the C-7 resonance, must then be ascribed to C-1. Since the chemical environments of C-1 and C-7 of podocarp-9(11)-en-12-one (*18*) are relatively similar to those of C-1 and C-7 of the other podocarp-9(11)-enes (*13*–*17*), this result was applied to differentiate the C-1 and C-7 signals in the spectra of the latter compounds, *i.e.* of the two possible signals that at lower field was attributed to C-1.

Distinction between the C-13 and C-14 signals for the podocarp-9(11)-en-12-ols (*14*, *15*) was achieved by spectral comparison with their corresponding acetates (*16*, *17*). The signal at δ 29.7 in the spectrum of the 12α-alcohol (*14*) and the signal at δ 31.1 in that of the 12β-alcohol (*15*) displayed considerable upfield shifts (3–4 ppm) as a result of acetylation.[18] These signals were therefore identified as being due to C-13, while the peaks at δ 26.6 and 28.6 for *14* and *15*, respectively, undergoing expected small upfield shifts on acetylation, were ascribed to C-14.

Having established the peak assignment of C-14 for the two allylic acetates (*16*, *17*), the identification of the corresponding signal for podocarp-9(11)-ene (*13*) follows from a spectral comparison. Thus, since previous studies have demonstrated that the introduction of an allylic acetoxy group leads to shielding of the γ-sp^3 carbon,[19,20] it is evident that the signal at δ 32.0 in the spectrum of *13*, which is downfield of the C-14 resonances for the acetates *16* and *17*, must be ascribed to C-14. Introduction of an allylic acetoxy group has also been found to cause deshielding of the γ-olefinic carbon, a result which accords with our findings for the C-9 resonances.[19,20]

Of the remaining two peaks in the spectrum of podocarp-9(11)-ene (*13*), that at δ 26.0, having a chemical shift value close to the value observed for the C-3 signal for cyclohexene (δ 25.5),[21] was ascribed to C-12, thereby leaving C-13 to account for the signal at δ 22.2.

Podocarp-13-enes (19–22). Comparison of the spectra of the podocarp-13-enes (*19*–*22*) with that of podocarpane (*1*) left the resonances due to C-1, C-7, C-11 to C-14 to be accounted for. Of these, the signals due to C-12, the carbon atom carrying the hydroxyl (*19*, *20*), acetoxyl (*21*) or the oxo (*22*) substituents were readily recognized, while some of the remaining assignments were aided by deuterium labelling. Hence, the C-7 and C-11 signals for podocarp-13-en-12β-ol (*20*) and -12-one (*22*) were identified and the peak assignments of C-8, C-9, and C-10 confirmed by an examination of the ^{13}C NMR data of the corresponding derivatives labelled at C-8 (*40*, *42*) and C-9 (*41*, *43*). The signals at δ 38.4 and 38.0 for the 12β-alcohol (*20*) and the 12-ketone (*22*), respectively, were then ascribed to C-1.

With these results for podocarp-13-en-12β-ol (*20*) in hand, the assignments of C-1, C-7, and C-11 for the corresponding acetate (*21*) followed from a spectral comparison. While the shift values of the C-1 and C-7 signals were virtually unaffected, the signal due to C-11 showed an expected upfield shift of 4 ppm as a result of acetylation.[18]

Moreover, comparison of the ^{13}C NMR data of podocarp-13-en-12β-ol (*20*) and the corresponding acetate (*21*) distinguished the C-13 and C-14 resonances. Thus, in accordance with the allyl acetate effect [19] the peak at δ 129.9 in the spectrum of the allylic alcohol (*20*), undergoing an upfield shift of 4 ppm on acetylation, was attributed to C-13, whereas the peak at 135.0, shifted downfield (2 ppm) in the spectrum of the acetate (*21*), must be due to C-14.

Similarly, the peak assignments for podocarp-13-en-12α-ol (*19*) were facilitated by a spectral comparison with the corresponding 12β-alcohol (*20*). Hence, four peaks in the spectrum of *19*, which had chemical shift values close to those found for the C-1, C-7, C-13, and C-14 resonances of the 12β-alcohol (*20*), were assigned on this basis. The remaining peak at 30.6 ppm in the spectrum of the 12α-alcohol (*19*) was then attributed to C-11.

The C-13 and C-14 resonances for podocarp-13-en-12-one (*22*), positioned at δ 128.1 and

155.9, respectively, were differentiated using the ^{13}C NMR data of cyclohex-2-enone as a guide line.[22] Thus, the chemical shift value of the C-13 resonance was almost identical to that of the C-2 resonance for cyclohexenone, while the C-14 resonance was 6.1 ppm downfield of that due to C-3 in the model compound, a result which is in harmony with the fact that C-14 is adjacent to a methine carbon.

Podocarp-8-ene (*23*). Comparison of the spectrum of podocarp-8-ene (*23*) with ^{13}C NMR data for pimara-8,15-diene [6] allowed assignment of all peaks except for a differentiation of the C-2 and C-6 signals, positioned at δ 19.0 and 19.1, and of the C-11, C-12 and C-13 signals, having chemical shift values of δ 23.0, 23.6 and 23.9.

DISCUSSION

Previous studies on ^{13}C NMR spectra of various alicyclic alcohols such as cyclohexanols,[23] *trans*-decalols,[24] and sterols [17,18] have established that a hydroxyl substituent deshields both the α- and β-carbons, whereas the effect on the γ-carbon is shielding. The α- and β-effects produced by an equatorial hydroxyl group are usually larger than those observed for an axial substituent. The γ-effect, on the other hand, is usually more pronounced for compounds incorporating an axial hydroxyl group as this orientation generally leads to a *gauche* arrangement of the substituent and the γ-carbon, while an equatorial orientation normally corresponds to an *anti* arrangement and generates less steric interaction with and less polarization of proximate hydrogen atoms. In the case of δ-effects this theoretical model seems to fail since the *syn*axial arrangement, which involves interactions between non-bonded atoms similar to those of the *γ-gauche* configurations, causes downfield shifts of 2.0 to 3.5 ppm.[24]

Our results for the podocarpan-11-, -12-, and -14-ols (*2*–*3*, *4*–*5*, *6*–*7*), summarized in Table 5, conform to these findings. Thus the α-carbon signals for podocarpan-12β-ol (*5*) and -14β-ol (*7*) are found 4.4 and 5.8 ppm downfield of the α-carbon signals displayed by their axial counterparts (*4*, *6*). The difference between the α-carbon chemical shifts for the two podocarpan-11-ols (*2*, *3*) is also of the usual magnitude (5.5 ppm) which is in agreement with the fact that the hydroxyl group in each isomer experiences roughly the same steric interaction. In this context it may be noted that the difference in chemical shift between the α-carbon signals for 11α- and 11β-hydroxyprogesterone,[17] where the hydroxyl group of the axial epimer is subjected to a further δ-interaction from the 19-methyl group, is much smaller (0.9 ppm). This is also the case when the hydroxyl group in the axial, but not in the equatorial isomer, is subjected to a δ-interaction as exemplified by the chemical shift differences for the two epimeric pairs 10β-methyl-5α-decal-2α- and -2β-ol (−0.7 ppm) and 10β-methyl-5α-decal-4α-and-4β-ol (−1.8 ppm.[24]

The β-effects are consistently larger for podocarpan-11α-ol (*2*), -12β-ol (*5*) and -14β-ol (*7*) than for the corresponding axial epimers (*3*, *4*, *6*). In agreement with earlier observations,[25] the methylene β-carbons are affected to a higher degree than the methine β-carbons, *e.g.* the C-12 signal undergoes a downfield shift of 11.3 ppm, while the C-9 signal is shifted 5.7 ppm downfield on introduction of an equatorial hydroxyl group at C-11 in podocarpane.

The shielding effects on the γ-carbon atoms are in all but one case considerably larger for the axial epimers (*3*, *4*, *6*) than for their equatorial counterparts (*2*, *5*, *7*; *i.e.* 6.7–8.1 ppm *versus* 0.4–3.1 ppm); the exception being the γ-(*peri*-) effects on C-7 produced by the axial and equatorial hydroxyl groups in the two podocarpan-14-ols (*6*–*7*). These *peri*-effects are of approximately the same magnitude for the two epimers, 5.3 (14α-OH) and 4.9 (14β-OH) ppm, a result which may be rationalized by the fact that the 1,3 non-bonded proton-hydroxyl interactions are almost the same in the two cases.

In contrast to these shielding effects, the hydroxyl substituents in the podocarpan-11-ols (*2*, *3*) cause deshielding on the quaternary C-10. Although the reason for this is not fully understood, it is worth mentioning that similar results have been obtained for the C-10 signals in the spectra of 11α- and 11β-hydroxyprogesterone [17] and 10β-methyl-5α-decal-2α- and 4α-ol.[24]

The δ-effects caused by introduction of a hydroxyl substituent at C-12 or C-14 in podo-

carpane are all small and directed towards higher fields. In contrast, introduction of an equatorial hydroxyl group at C-11 leads to a substantial deshielding of C-1 (2.6 ppm) and insertion of an axial hydroxyl group at C-11 moves the signal due to C-20, the methyl substituent at C-10, 2.4 ppm downfield. These downfield shifts are in agreement with recent findings for other compounds comprising *syn*axial hydroxyl-methyl interactions such as 11α- and 11β-hydroxyprogesterone [17] and 10β-methyl-5α-decal-2β-ol and -4β-ol.[24]

Since the general equivalence of hydroxyl and methyl groups has been recognised and *syn*axial methyl-methyl interactions are of common occurrence in terpenoids, it was of interest to estimate the influence of the C-19 methyl group on the shielding of the C-20 methyl group in podocarpane (*1*; 14.3 ppm). Starting from the chemical shift value of the methyl group in 10β-methyl-5α-decalin (δ 15.8) and accounting for the *γ-gauche* interaction from C-11 on introduction of ring C [26] gives a value of δ 11.8, which differs from that observed by 2.5 ppm. This differential value, taken as the δ *syn*axial effect from the C-19 methyl group, is in good agreement with the values found for corresponding hydroxyl group interactions and emphasizes the importance of the δ-effect on methyl groups in terpenoids.

Introduction of an equatorial or axial hydroxyl group at C-12 in podocarp-9(11)-ene, *14*, *15*, results in deshielding of the α- and β-carbon atoms (Table 5). In comparison with

Table 5. Substituent effects [a] of the hydroxyl group in the spectra of the podocarpanols *2*–*7* and the podocarp-9(11)-en-12-ols *14*–*15*.

Compound		α		β		γ		δ	
2	(eq.-OH)	C-11	46.8	C-9	5.7	C-8	−0.4	C-1	2.6
				C-12	11.3	C-10	2.1	C-5	−0.2
						C-13	−2.5	C-7	−0.2
								C-14	−0.6
								C-20	0.7
3	(ax.-OH)	C-11	41.3	C-9	2.6	C-8	−6.7	C-1	0.5
				C-12	8.3	C-10	0.6	C-5	0.2
						C-13	−7.3	C-7	0.1
								C-14	0.1
								C-20	2.4
4	(ax.-OH)	C-12	39.9	C-11	6.4	C-9	−7.8	C-8	−0.4
				C-13	5.9	C-14	−6.9	C-10	−0.5
5	(eq.-OH)	C-12	44.3	C-11	9.5	C-9	−2.4	C-8	−1.2
				C-13	8.8	C-14	−2.6	C-10	−0.2
6	(ax.-OH)	C-14	35.5	C-8	3.9	C-7	−5.3	C-6	−0.3
				C-13	7.2	C-9	−8.1	C-10	−0.2
						C-12	−7.1	C-11	−0.3
7	(eq.-OH)	C-14	41.3	C-8	7.3	C-7	−4.9	C-6	−0.7
				C-13	9.0	C-9	−2.4	C-10	−0.2
						C-12	−3.1	C-11	−0.7
14	(ax.-OH)	C-12	40.2	C-11	3.1	C-9	3.7	C-8	−0.1
				C-13	7.5	C-14	−5.4	C-10	0
15	(eq.-OH)	C-12	41.4	C-11	5.0	C-9	1.6	C-8	0
				C-13	8.9	C-14	−3.4	C-10	−0.3

[a] Values represent $\delta_C(ROH) - \delta_C(RH)$ for corresponding carbon signals in each case. A negative sign designates an upfield shift on substitution.

the situation for the saturated alcohols the shifts are somewhat less dependent on the orientation of the hydroxyl group and the magnitudes of the β-effects on the sp^2 carbon atoms, C-11, are only half of those found on the sp^3 carbon atoms, C-13. The γ-sp^3 carbons, C-14, suffer expected upfield shifts, whereas the γ-sp^2 carbons, C-9, carrying no hydrogens behave like quaternary carbons and undergo downfield shifts. In both cases the effects are more pronounced for podocarp-9(11)-en-12α-ol (*14*) than for the equatorial epimer (*15*).

The carbonyl carbon signals for the saturated oxo derivatives podocarpan-11-, 12-, and 14-one (*10* – *12*) appear at δ 211.8 – 213.7 (Table 1), while, as expected, the corresponding signals for the α,β-unsaturated oxo derivatives podocarp-9(11)-en-12-one (*18*) and podocarp-13-en-12-one (*22*) occur at somewhat higher fields, δ 200.4 and 201.1, respectively (Table 2).

The observed downfield shifts of the β-methylene (14.7 – 17.2 ppm) and β-methine carbon signals (11.1 – 12.9 ppm) for the podocarpanones *10* – *12* (Table 6) are consistent with the known deshielding effect of an oxo group on β-sp^3 carbon atoms and its dependence on the branching at this carbon.[16,25,27]

According to previous studies, γ-carbons are either shielded or deshielded by an oxo group. The effect is normally fairly small except for cases involving eclipsing of the carbonyl group and the γ-carbon or involving a bridgehead γ-carbon, when appreciable shifts are found.[16,25,27] The shifts observed for the γ-carbons in the podocarpanones *10* – *12* conform well to these results, and range within $\pm$1.3 ppm in all but two cases. Thus, the signal due to the bridgehead carbon C-8 of podocarpan-11-one (*10*) is shifted downfield by 3.2 ppm, and that due to the eclipsed carbon C-7 of podocarpan-14-one (*12*) is shifted upfield by 9.6 ppm. In contrast, C-10 in podocarpan-11-one (*10*), also eclipsed with the carbonyl group, is only slightly affected, which might be due to the fact that C-10 is quaternary and accordingly lacks a distortable carbon hydrogen bond.

The effects at the δ-carbon atoms produced by the oxo substituents in the podocarpanones *10* – *12* are found to be small and range within $\pm$1.2 ppm.

Introduction of an oxo group at C-12 in podocarp-9(11)-ene (*13*) causes deshielding of the β-sp^3, β-sp^2, and γ-sp^2 carbon atoms, whereas the γ-sp^3 carbon, C-14, undergoes an upfield shift. The effect on C-11 is of reduced magnitude compared with the influence of the oxo group on the β-carbon in the saturated analogues *10* – *12*. On the other hand, the downfield shift at the γ-sp^2 carbon, C-9, is substantial, observations which are readily rationalised in terms of the

Table 6. Effects[a] of the carbonyl group in the spectra of the podocarpanones *10* – *12* and podocarp-9(11)-en-12-one (*18*).

Compound	β		γ		δ	
10	C-9	11.1	C-8	3.2	C-1	−0.7
	C-12	17.2	C-10	−0.2	C-5	−0.6
			C-13	0.3	C-7	−0.1
					C-14	−1.0
					C-20	0.3
11	C-11	15.9	C-9	−0.2	C-8	−1.2
	C-13	14.7	C-14	−1.3	C-10	0.4
12	C-8	12.9	C-7	−9.6	C-6	−1.2
	C-13	15.4	C-9	1.0	C-10	0.7
			C-12	−0.6	C-11	−0.7
18	C-11	5.2	C-9	24.4	C-8	0.8
	C-13	13.6	C-14	−2.6	C-10	1.3

[a] Values represent $\delta_C(R{=}O) - \delta_C(RH_2)$ for corresponding carbon signals in each case. A negative sign designates an upfield shift on substitution.

electron withdrawing power of the carbonyl group.

Deuterium isotope effects. In agreement with previous results,[15–18] replacement of a hydrogen by a deuterium atom at various positions in the podocarpane derivatives (*24–43*, Table 1) was found to cause a drastic reduction of the intensity of the signal due to the labelled carbon atom. This reduction, which has been ascribed to a combination of quadrupolar broadening, spin-spin splitting and a decreased nuclear Overhauser enhancement,[18] made a direct measurement of the geminal isotope shift possible in only a few cases. Thus, the spectrum of 9α-d_1-podocarp-13-en12-one (*43*) displayed a triplet at δ 53.5 (J 19.5 Hz), shifted 0.5 ppm upfield of the C-9 signal for the corresponding non-labelled compound (*22*).

The resonances due to the carbon atoms adjacent to the labelled carbon atoms showed isotope shifts, whose magnitudes were proportional to the number of deuterium atoms. Thus, a single deuterium atom was found to cause an upfield shift of 0.1 ppm at a vicinal sp^3 carbon, whereas two deuterium atoms gave rise to a vicinal shift of 0.2 ppm. Very small isotope shifts, 0.05 ppm, were detected at carbons three bonds distant from the deuterium atom. Resonances due to carbonyl carbons and quarternary carbons proved to undergo a considerable reduction of intensity when the neighbouring carbon atom was labelled, an observation which conforms with previous results for labelled keto steroids.[16]

EXPERIMENTAL

The Fourier transform ^{13}C NMR spectra were obtained on a Varian XL-100-12 WG spectrometer operating at 25.16 MHz and equipped with an S-124 XL FT accessory. The instrument was controlled *via* a Varian 620 L 16 K computer.

The samples were examined as 0.1–0.5 M solutions in $CDCl_3$ using TMS as internal standard. To examine the influence of concentration on chemical shifts the ^{13}C NMR spectra of 1.0 and 0.1 M solutions of the podocarpan-11- and -12-ols (*2–3*, *4–5*) were recorded. All signals, except those due to the α- and β-carbon atoms of the two podocarpan-12-ols (*4–5*), which exhibited downfield shifts of 0.4 and 0.2 ppm, respectively, in the more dilute solutions, remained at virtually invariant positions. The observed dilution shifts are best interpreted by molecular association through hydrogen bonding. The proximity of the equatorial hydroxyl group to C-1 in podocarpan-11α-ol (*2*) and the 1,3-diaxial interaction between the hydroxyl group and the methyl group at C-10 in podocarpan-11β-ol (*3*) probably diminish the importance of the hydrogen bonding for these compounds thus explaining the absence of dilution shifts.

An RF flip-angle (45°, 21 μs) was usually used to achieve optimum sensitivity enhancements in survey spectra. Attempts were made to separate all peaks by the use of 8 K data points for 2.5 or 2.0 kHz spectrum widths. The precision of the peak positions in the proton noise decoupled (PND) spectra was ±0.03 for sp^3 and ±0.05 ppm for sp^2 carbon signals.

Single frequency off-resonance (SFOR) decoupled spectra were obtained by irradiation 300 Hz upfield from TMS in the proton spectrum. Partially relaxed Fourier transform (PRFT) spectra were obtained by the inversion-recovery method in which a pulse sequence of (180°-t-90°-T) was employed.

^1H NMR spectra were recorded at 100 MHz in $CDCl_3$ solutions. Melting points were determined on a Leitz Wetzlar instrument and are uncorrected. Infrared spectra were recorded on a Perkin-Elmer 257 spectrometer and low resolution mass spectra on an LKB 2091 instrument at 70 eV with an ion source temperature at 200 °C. The high resolution mass measurements were performed on an Atlas SM 1 instrument. Microanalyses were performed by A. Bernhardt, Elbach über Engelskirchen, West Germany.

Podocarpane (*1*). To a solution of 0.45 g of KOH in 5 ml of diethylene glycol was added 0.2 ml of hydrazine hydrate and 100 mg of podocarpan-12-one (*11*). The reaction mixture was refluxed under nitrogen for 2 h. Water was distilled off, and the reaction mixture was refluxed for an additional 3 h, now at a slightly higher temperature. Acidification, dilution with water, extraction with ether and chromatography over silica gel gave 45 mg of podocarpane (*1*) as a gum. (Found: C 87.31; H 12.75; M^+ 234. Calc for $C_{17}H_{30}$: C 87.10; H 12.90; mol. wt 234); ^1H NMR peaks at δ 0.82 (6 H, s) and 0.85 (3 H, s).

Podocarp-9(11)-en-12α-ol (*14*) *and podocarp-9(11)-en-12β-ol* (*15*). To a solution of 1.4 g of podocarp-9(11)-en-12-one (*18*) in 30 ml of methanol was added 1.0 g of $NaBH_4$. The reaction mixture was stirred at 0 °C for 0.5 h. Acidification, dilution with water and extraction with ether afforded a mixture of alcohols. Part of this mixture (0.4 g) was separated by chromatography over silica gel into 80 mg of podocarp-9(11)-en-12α-ol (*14*) as a gum (Found: M^+ 248. Calc for $C_{17}H_{28}O$: mol. wt. 248); IR bands at 3340 and 1655 cm^{-1}, ^1H NMR peaks at δ 0.87 (6 H, s), 1.03 (3 H, s), 4.17 (1 H, m, $W_{\frac{1}{2}} \sim 14$), and 5.49 (1 H, m, $W_{\frac{1}{2}} \sim 10$) and 230 mg of podocarp-9(11)-en-12β-ol (*15*), m.p. 105–107 °C. (Found: C 82.02; H 11.49; M^+

248.2136. Calc. for $C_{17}H_{28}O$: C 82.20; H 11.36; mol. wt. 248.2140); IR bands at 3330 and 1645 cm^{-1}; ^{1}H NMR peaks at δ 0.87 (6 H, s), 1.04 (3 H, s), 4.17 (1 H, m, $W_{\frac{1}{2}} \sim 14$) and 5.35 (1 H, m, $W_{\frac{1}{2}} \sim 12$).

Podocarp-9(11)-ene (13). A solution of 0.9 g of a mixture consisting of (*14*) and (*15*) in 10 ml of pyridine and 10 ml of acetic anhydride was kept at room temperature for 6 h. Work up in the usual manner gave a mixture of acetates. Without further purification this mixture and 0.7 g of lithium were added to 30 ml of ethylamine kept in a flask fitted with a dry ice-acetone condenser.[28] The reaction mixture was stirred for 1.5 h, then 60 ml of 2-methylbutan-2-ol was added. When all lithium had been consumed the ethyl amine was driven off with the aid of a stream of nitrogen. The residue was dissolved in water, acidified with ammonium chloride and 10 % acetic acid, and extracted with ether. Evaporation afforded a crude product which was purified by chromatography over silica gel to give 0.45 g of podocarp-9(11)-ene (*13*) as a gum (Found: C 87.88; H 12.12; M$^+$ 232. Calc. for $C_{17}H_{28}$: C 87.86; H 12.14; mol.wt. 232); IR band at 1645 cm^{-1}, ^{1}H NMR peaks at δ 0.84 (6 H, s), 1.03 (3 H, s) and 5.32 (1 H, m, $W_{\frac{1}{2}} \sim 9$).

Podocarpan-11-one (10). To a solution of 0.4 g of podocarp-9(11)-ene (*13*) in 10 ml of ether was added 1.8 g of BF_3-etherate and 0.38 g of LAH in 20 ml of ether. The reaction mixture was stirred for 1 h at room temperature. A saturated aqueous solution of Na_2SO_4 was then added followed by solid Na_2SO_4. The mixture was stirred for 1 h, filtered and evaporated. The residue was dissolved in 80 ml of ethanol containing 0.4 g of NaOH and stirred with 4 ml of 30 % H_2O_2 for 30 min.[28] Work up gave a gum, which was dissolved in 15 ml of acetone and stirred with 7 ml of Jones' reagent for 30 min. Work up in the usual manner afforded a mixture of podocarpan-9α-H-11-one (*10*) and podocarpan-9β-H-11-one. A solution of this mixture in 8 ml of methanol and 1 ml of 40 % NaOH was subsequently refluxed under nitrogen for 1 h. Acidification, dilution with water, extraction with ether and chromatography over silica gel furnished 0.12 g of podocarpan-9α-H-11-one (*10*), m.p. 48 – 51 °C. (Found: M$^+$ 248.2132. Calc. for $C_{17}H_{28}O$; mol. wt. 248.2140); IR band at 1710 cm^{-1}, ^{1}H NMR peaks at δ 0.86 (6 H, s) and 1.11 (3 H, s).

Podocarpan-11α-ol (2) and podocarpan-11β-ol (3). To a solution of 90 mg of podocarpan-11-one (*10*) in 10 ml of tetrahydrofuran and 0.8 ml of 5 % NaOH was added 190 mg of $NaBH_4$. The reaction mixture was refluxed for 17 h. Acidification, dilution with water and extraction with ether afforded a mixture, which was separated by chromatography over silica gel into 41 mg of podocarpan-11β-ol (*3*) as a gum. (Found: M$^+$ 250. Calc. for $C_{17}H_{30}O$: mol. wt. 250). IR band at 3450 cm^{-1}, ^{1}H NMR peaks at δ 0.85 (6 H, s), 1.11 (3 H, s) and 4.26 (1 H, m, $W_{\frac{1}{2}} \sim 10$); and 33 mg of podocarpan-11α-ol (*2*); m.p. 86 – 88 °C. (Found: M$^+$ 250. Calc. for $C_{17}H_{30}O$: mol. wt. 250); IR band at 3380 cm^{-1}, ^{1}H NMR peaks at δ 0.83 (6 H, s), 0.97 (3 H, s) and 3.61 (1 H, m, $W_{\frac{1}{2}} \sim 22$).

Podocarpan-12α-yl acetate (8), podocarpan-12β-yl acetate (9) podocarp-9(11)-en-12α-yl acetate (16), podocarp-9(11)-en-12β-yl acetate (17) and podocarp-13-en-12β-yl acetate (21). A solution of 30 mg of podocarpan-12α-ol (*4*) in 5 ml of pyridine and 5 ml of acetic anhydride was refluxed for 5 h. Work up in the usual manner gave 32 mg of podocarpan-12α-yl acetate (*8*), m.p. 62 – 65 °C. (Found: M$^+$ 292. Calc. for $C_{19}H_{32}O_2$: mol. wt. 292); IR bands at 1740, 1240, and 1255 cm^{-1}, ^{1}H NMR peaks at δ 0.81 (3 H, s), 0.84 (3 H, s), 0.86 (3 H, s), 2.05 (3 H, s) and 5.12 (1 H, m, $W_{\frac{1}{2}} \sim 7$).

Podocarpan-12β-yl acetate (*9*) m.p. 104 – 107 °C. (Found: M$^+$ 292. Calc. for $C_{19}H_{32}O_2$; mol. wt. 292), podocarp-9(11)-en12α-yl acetate (*16*) gum. (Found: M$^+$ 290. Calc. for $C_{19}H_{30}O_2$: mol. wt. 290), podocarp-9(11)-en-12β-yl acetate (*17*) gum (Found: M$^+$ 290. Calc. for $C_{19}H_{30}O_2$; mol. wt. 290) and podocarp-13-en-12β-yl acetate (*21*), m.p. 139 – 140 °C. (Found: M$^+$ 290. Calc. for $C_{19}H_{30}O_2$; mol. wt. 290) were prepared by treatment of podocarpan-12β-ol (*5*), podocarp-9(11)-en-12α-ol (*14*), podocarp-9(11)-en-12β-ol (*15*), and podocarp-13-en-12β-ol (*20*), respectively, with a mixture of pyridine and acetic anhydride (1:1) at 0 °C for 12 h. *9* had IR bands at 1740 and 1250 cm^{-1}, ^{1}H NMR peaks at δ 0.85 (9 H, s), 2.02 (3 H, s) and 4.66 (1 H, m, $W_{\frac{1}{2}} \sim 21$). *16* had IR bands at 1730 and 1645 cm^{-1}, ^{1}H NMR peaks at δ 0.86 (6 H, s), 1.03 (3 H, s), 2.04 (3 H, s), 5.14 (1 H, m, $W_{\frac{1}{2}} \sim 9$) and 5.21 (1 H, dd, *J* 1.5 and 4.5). *17* had IR bands at 1745 and 1650 cm^{-1}, ^{1}H NMR peaks at δ 0.85 (6 H, s), 1.05 (3 H, s), 2.03 (3 H, s), and 5.27 (2 H, m). *21* had IR bands at 1735 and 1650 cm^{-1}, ^{1}H NMR peaks at δ 0.84 (3 H, s), 0.86 (6 H, s), 2.05 (3 H, s), and 5.5 (3, H, m).

Podocarp-8-ene (23). Reduction of 12-methoxypodocarpa-8,11,13-triene using lithium in ammonia[29] afforded as a minor component podocarp-8-ene *(23)* m.p. 24 – 26 °C. (Found: C 87.95; H 12.10; M$^+$ 232; Calc. for $C_{17}H_{28}$: C 87.86; H 12.14; mol. wt. 232); ^{1}H NMR peaks at δ 0.93 (3 H, s), 0.95 (3 H, s) and 0.98 (3 H, s).

8β,13,13,14,14-d_5*-Podocarpane (24).* To a solution of 20 mg of podocarpan-14-one (*12*) in 0.5 ml deuterioacetic acid was added dry amalgamated zinc filings and a mixture obtained by treating 1 ml of acetyl chloride with 0.5 ml of deuterium oxide. The reaction mixture was refluxed for 4 h. Work up and chromatography over silica gel afforded 5 mg of *8β*,13,13,-14,14-d_5-podocarpane (*24*), whose retention time on GLC was identical to that of the corresponding nondeuterated derivative and whose ^{1}H NMR spectrum displayed the three methyl resonances at unaltered positions.

Isotopic composition according to MS: 7 % d_3, 29 % d_4, 62 % d_5, and 2 % d_6.

The syntheses of the other compounds examined here have been or will be described elsewhere.[29,30]

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REFERENCES

1. Abraham, R. J., Holden, C. M., Loftus, P. and Whittaker, D. *Org. Magn. Resonance 6* (1974) 184.
2. Nakanishi, K., Crouch, R., Miura, I., Dominguez, X., Zamudio, A. and Villarreal, R. *J. Amer. Chem. Soc. 96* (1974) 609.
3. Pregosin, P. S., Randall, E. W. and McMurry, T. B. H. *J. Chem. Soc. Perkin Trans. 1* (1972) 299.
4. Moss, G. P., Pregosin, P. S. and Randall, E. W. *J. Chem. Soc. Perkin Trans. 1* (1974) 1525.
5. Mussini, P., Orsini, F., Pelizzoni, F., Buckwalter, B. L. and Wenkert, E. *Tetrahedron Lett.* (1973) 4849.
6. Wenkert, E., and Buckwalter, B. L. *J. Amer. Chem. Soc. 94* (1972) 4367.
7. Hanson, J. R., Savona, G. and Siverns, M. *J. Chem. Soc. Perkin Trans. 1* (1974) 2001.
8. Taylor, D. A. H. *J. Chem. Soc. Perkin Trans. 1* (1974) 437.
9. Nakanishi, K., Gullo, V. P., Miura, I., Govindachari, T. R. and Viswanathan, N. *J. Amer. Chem. Soc. 95* (1973) 6473.
10. Doddrell, D. M., Khong, P. W. and Lewis, K. G. *Tetrahedron Lett.* (1974) 2381.
11. Aasen, A. J., Hlubucek, J. R. and Enzell, C. R. *Acta Chem. Scand. B 29* (1975) 677.
12. Almqvist, S.-O., Enzell, C. R. and Wehrli, F. W. *Acta Chem. Scand. B 29* (1975) 695.
13. Allerhand, A., Doddrell, D., Glushko, V., Cochran, D. W., Wenkert, E., Lawson, P. J. and Gurd, F. R. N. *J. Amer. Chem. Soc. 93* (1971) 544.
14. Wehrli, F. W. *Chem. Commun.* (1973) 379.
15. Stothers, J. B., Tan, C. T., Nickon, A., Huang, F., Sridhar, R. and Weglein, R. *J. Amer. Chem. Soc. 94* (1972) 8581.
16. Eggert, H. and Djerassi, C. *J. Org. Chem. 38* (1973) 3788.
17. Bhacca, N. S., Giannini, D. D., Jankowski, W. S. and Wolff, M. E., *J. Amer. Chem. Soc. 95* (1973) 8421.
18. Reich, H. J., Jautelat, M., Messe, M. T., Weigert, F. J. and Roberts, J. D. *J. Amer. Chem. Soc. 91* (1969) 7445.
19. Lukacs, G., Piriou, F., Gero, D., Van Dorp, D. A., Hagaman, E. W. and Wenkert, E. *Tetrahedron Lett.* (1973) 515.
20. Bach, N. J., Boaz, H. E., Kornfeld, E. C., Chang, C.-J., Floss, H. G., Hagaman, E. W. and Wenkert, E. *J. Org. Chem. 39* (1974) 1272.
21. Stothers, J. B. *Carbon-13 NMR Spectroscopy*, Academic, New York 1972, Chapter 3.
22. Stothers, J. B. *Carbon-13 NMR Spectroscopy*, Academic, New York 1972, p. 193.
23. Roberts, J. D., Weigert, F. J., Kroschwitz, J. I. and Reich, H. J. *J. Amer. Chem. Soc. 92* (1970) 1338.
24. Grover, S. H. and Stothers, J. B. *Can. J. Chem. 52* (1974) 870.
25. Grutzner, J. B., Jautelat, M., Dence, J. B., Smith, R. A. and Roberts, J. D. *J. Amer. Chem. Soc. 92* (1970) 7107.
26. Dalling, D. K., Grant, D. M. and Paul, E. G. *J. Amer. Chem. Soc. 95* (1973) 3718.
27. Weigert, F. J. and Roberts, J. D. *J. Amer. Chem. Soc. 92* (1970) 1347.
28. Herz, W. and White, D. H. *J. Org. Chem 39* (1974) 1.
29. Wahlberg, I., Karlsson, K. and Enzell, C. R. *Org. Mass Spectrom. 10* (1975) 162.
30. Wahlberg, I. and Enzell, C. R. *To be published.*

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