

IDENTIFICATION OF ACYL GROUPS OCCURRING IN SESQUITERPENE LACTONES: PROTON AND CARBON-13 NMR STUDY*

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Characteristic ^1H NMR parameters of 88 acyl groups, hitherto found as ester substituents in natural sesquiterpenic lactones, were determined from the measured spectra as well as literature data. Characteristic ^{13}C NMR chemical shifts for 45 acyl groups were obtained in the same way; for the remaining acyls with hitherto unknown ^{13}C NMR data the values were calculated on the basis of semiempirical relationships.

In natural hydroxyl-containing sesquiterpenic lactones some of the hydroxyl groups are esterified with carboxylic acids. Next to the lactone grouping, acyl residues of various carboxylic acids are the most frequently occurring functional groups in these molecules. Therefore, determination of structure of native sesquiterpenic lactones very often requires identification of acyl groups. This can be achieved by various methods. The chemical approach consists in hydrolysis of the ester and subsequent identification of the free acid. It implies destruction of the original molecule and requires relatively large amounts of material. Also the removal of the acyl, or its structural modification during the hydrolysis, may present difficulties. Acyls can be identified also by mass spectrometry from the fragments of the studied molecule (peaks $M - \text{RCOOH}$ or $M - \text{ketene}$ or the ion RCO^+). However, the method does not afford detailed information on the acyl structure and mostly gives only its elemental composition. With acyls containing polar groups, detection of secondary fragmentation ions may lead to artifacts. The third method of determination is based on NMR spectroscopy. Usually greater amounts of material are required than in the mass spectrometry approach but this drawback is outweighed by the nondestructive principle of the method and by the more detailed information obtained. However, even this method has its pitfalls. In general, signals due to the acyl groups cannot be unequivocally assigned directly from the spectra. One has first to identify signals of all protons attached to the sesquiterpenic skeleton (*via* their spin-spin coupling); the remaining signals then belong to the acyl groups. This

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procedure often requires a series of decoupling experiments or measurement of a homocorrelated hydrogen 2D NMR spectrum. The situation may be complicated by signal overlapping, occurrence of not well analyzable multiplets of strongly interacting protons or interruption of the spin-spin coupling continuity by quaternary carbon atoms.

The enormous number of possible sesquiterpenic lactones is the result of variability of the skeleton but first of all of the number, character and position of the substituents. So far, more than two thousands of various native sesquiterpenic lactones have been described. On the other hand, the number of acyl types in these lactones is relatively small (about 80). This lends us an opportunity to identify ester groups in the NMR spectrum on the basis of known NMR data. We investigated therefore in detail this question, using both the ^1H and ^{13}C NMR spectroscopy. The aim of our study was: (i) to obtain a survey of all the acyl groups hitherto identified in sesquiterpenic lactones, (ii) to determine how frequently individual acyl types occur, (iii) to obtain a set of ^1H and ^{13}C NMR data for the acyl groups and to verify their reliability (the effect of the substrate and solvent), and (iv) to verify the potentialities of calculation of ^{13}C NMR chemical shifts for acyls and to calculate usable ^{13}C NMR parameters for acyl groups whose experimental data are so far not known.

RESULTS AND DISCUSSION

Table I lists the 88 acyl groups, hitherto found in sesquiterpenic lactones. They are arranged according to the increasing number of carbon, hydrogen, and oxygen atoms. Elemental composition, structural formula, name, and frequency of occurrence are given for each acyl group. Instead of systematic names of acyl groups we frequently use trivial or semi-systematic names. Our list is based on the reviews of Fischer and coworkers¹ and Seaman² and is completed by us for the period 1980 to 1984.

As seen from Table I, the by far most often occurring acyl in sesquiterpenic lactones is the acetyl group. Other abundant acyls are angeloyl, methacroyl, 2-methylbutanoyl, and isobutanoyl residues which have been found in more than 100 cases. On the other hand, many acyls occur only very rarely and some have been found even in only one compound.

Proton NMR Study

The proton NMR data of acyls, collected both from the literature and from our own measurements, are given in Table II. We preferred more recent papers appearing in the years 1980–1984 and only in cases of less common acyls which had not been described during this period we used earlier sources. In this way, we tried to get a representative set of as accurate as possible parameters (chemical shifts and

TABLE I

List of acyl groups occurring in sesquiterpene lactones

Acyl	Elemental composition	Name	Occurrence ^a
<i>I</i>	C ₂ H ₃ O	acetyl	920
<i>II</i>	C ₃ H ₃ O ₂	2-oxopropionyl	6
<i>III</i>	C ₃ H ₅ O	propionyl	9
<i>IV</i>	C ₄ H ₅ O	methacryloyl	256
<i>V</i>	C ₄ H ₅ OS	(<i>E</i>)-3-methylthioacryloyl	1
<i>VI</i>	C ₄ H ₅ OS	(<i>Z</i>)-3-methylthioacryloyl	2
<i>VII</i>	C ₄ H ₅ O ₂	epoxymethacryloyl	15
<i>VIII</i>	C ₄ H ₅ O ₂	4-hydroxymethacryloyl	45
<i>IX</i>	C ₄ H ₆ ClO ₂	3-chloro-2-hydroxyisobutyryl	10
<i>X</i>	C ₄ H ₇ O	butyryl	11
<i>XI</i>	C ₄ H ₇ O	isobutyryl	170
<i>XII</i>	C ₄ H ₇ O ₂	2-hydroxyisobutyryl	6
<i>XIII</i>	C ₄ H ₇ O ₂	3-hydroxyisobutyryl	5
<i>XIV</i>	C ₄ H ₇ O ₃	2,3-dihydroxyisobutyryl	5
<i>XV</i>	C ₅ H ₃ O ₂	3-furoyl	4
<i>XVI</i>	C ₅ H ₃ O ₃	4-(2,5-dihydro-2-oxo)furoyl	1
<i>XVII</i>	C ₅ H ₅ O ₂	4-oxotigloyl	2
<i>XVIII</i>	C ₅ H ₅ O ₃	4-(2,5-dihydro-2-hydroxy)furoyl	2
<i>XIX</i>	C ₅ H ₇ O	angeloyl	496
<i>XX</i>	C ₅ H ₇ O	senecioidyl	55
<i>XXI</i>	C ₅ H ₇ O	tigloyl	172
<i>XXII</i>	C ₅ H ₇ O ₂	epoxyangeloyl	80
<i>XXIII</i>	C ₅ H ₇ O ₂	3,4-epoxyisovaleryl	1
<i>XXIV</i>	C ₅ H ₇ O ₂	2-(1-hydroxyethyl)acryloyl	5
<i>XXV</i>	C ₅ H ₇ O ₂	2-hydroxy-2-methylbut-3-enoyl	1
<i>XXVI</i>	C ₅ H ₇ O ₂	(<i>E</i>)-4-hydroxysenecioidyl	3
<i>XXVII</i>	C ₅ H ₇ O ₂	(<i>Z</i>)-4-hydroxysenecioidyl	2
<i>XXVIII</i>	C ₅ H ₇ O ₂	4-hydroxytigloyl	24
<i>XXIX</i>	C ₅ H ₇ O ₂	5-hydroxytigloyl	17
<i>XXX</i>	C ₅ H ₇ O ₂	2-methyl-3-oxobutanoyl	2
<i>XXXI</i>	C ₅ H ₇ O ₂	sarracinoyl	28
<i>XXXII</i>	C ₅ H ₇ O ₂	2-oxoisovaleryl	2
<i>XXXIII</i>	C ₅ H ₇ O ₃	4,5-dihydroxyangeloyl	4
<i>XXXIV</i>	C ₅ H ₇ O ₃	2-(1,2-dihydroxyethyl)acryloyl	2
<i>XXXV</i>	C ₅ H ₇ O ₃	4,5-dihydroxytigloyl	20
<i>XXXVI</i>	C ₅ H ₇ O ₃	epoxysarracinoyl	1
<i>XXXVII</i>	C ₅ H ₇ O ₃	2-hydroxy-2-methyl-3-oxobutanoyl	17
<i>XXXVIII</i>	C ₅ H ₈ BrO	3-bromo-2-hydroxy-2-methylbutanoyl	1
<i>XXXIX</i>	C ₅ H ₉ O	isovaleryl	82
<i>XL</i>	C ₅ H ₉ O	2-methylbutanoyl	158
<i>XLI</i>	C ₅ H ₉ O ₂	2-hydroxyisovaleryl	2

TABLE I
(Continued)

Acyl	Elemental composition	Name	Occurrence ^a
<i>XLII</i>	C ₅ H ₉ O ₂	3-hydroxyisovaleryl	4
<i>XLIII</i>	C ₅ H ₉ O ₂	3-hydroxy-2-methylbutanoyl	17
<i>XLIV</i>	C ₅ H ₉ O ₃	2,3-dihydroxy-2-methylbutanoyl	18
<i>XLV</i>	C ₅ H ₉ O ₃ S	2,5-dihydroxy-3-mercapto-2-methylbutanoyl	1
<i>XLVI</i>	C ₆ H ₇ O ₃	4-acetoxymethacryloyl	2
<i>XLVII</i>	C ₆ H ₇ O ₃	4-(2,5-dihydro-2-methoxy)furoyl	1
<i>XLVIII</i>	C ₆ H ₉ O	2,3-dehydromethylvaleryl	6
<i>IL</i>	C ₆ H ₉ O ₃	2-ethyl-2-hydroxy-3-oxobutyryl	1
<i>L</i>	C ₆ H ₁₁ O	hexanoyl	6
<i>LI</i>	C ₆ H ₁₁ O ₃	2-ethoxy-3-hydroxyisobutyryl	2
<i>LII</i>	C ₇ H ₅ O	benzoyl	1
<i>LIII</i>	C ₇ H ₉ O ₃	4-acetoxangeloyl	10
<i>LIV</i>	C ₇ H ₉ O ₃	2-(1-acetoxyethyl)acryloyl	2
<i>LV</i>	C ₇ H ₉ O ₃	(<i>Z</i>)-4-acetoxyseneciroyl	4
<i>LVI</i>	C ₇ H ₉ O ₃	4-acetoxytigloyl	7
<i>LVII</i>	C ₇ H ₉ O ₃	5-acetoxytigloyl	28
<i>LVIII</i>	C ₇ H ₉ O ₃	acetylsarracinoyl	30
<i>LIX</i>	C ₇ H ₉ O ₄	4-acetoxy-5-hydroxytigloyl	1
<i>LX</i>	C ₇ H ₉ O ₄	5-acetoxy-4-hydroxytigloyl	4
<i>LXI</i>	C ₇ H ₉ O ₄	2-acetoxy-2-methyl-3-oxobutanoyl	4
<i>LXII</i>	C ₇ H ₁₁ O ₃	3-acetoxyisovaleryl	3
<i>LXIII</i>	C ₇ H ₁₁ O ₃	3-acetoxy-2-methylbutanoyl	4
<i>LXIV</i>	C ₇ H ₁₁ O ₄	3-acetoxy-2-hydroxy-2-methylbutanoyl	28
<i>LXV</i>	C ₈ H ₇ O	phenylacetyl	1
<i>LXVI</i>	C ₈ H ₇ O ₂	4-hydroxyphenylacetyl	1
<i>LXVII</i>	C ₈ H ₇ O ₂	4-methoxybenzoyl	1
<i>LXVIII</i>	C ₈ H ₁₁ O ₃	O,O-isopropylidene-4,5-dihydroxytigloyl	4
<i>LXIX</i>	C ₈ H ₁₅ O	6-methylheptanoyl	1
<i>LXX</i>	C ₈ H ₁₅ O	octanoyl	9
<i>LXXI</i>	C ₉ H ₇ O	cinnamoyl	2
<i>LXXII</i>	C ₉ H ₉ O ₃	3,4-dimethoxybenzoyl	1
<i>LXXIII</i>	C ₉ H ₁₁ O ₅	4,5-diacetoxytigloyl	4
<i>LXXIV</i>	C ₉ H ₁₃ O ₅	2,3-diacetoxy-2-methylbutanoyl	7
<i>LXXV</i>	C ₉ H ₁₇ O	6-methyloctanoyl	2
<i>LXXVI</i>	C ₁₀ H ₁₃ O ₄	4-hydroxy-5-angeloyloxytigloyl	1
<i>LXXVII</i>	C ₁₀ H ₁₃ O ₄	4-hydroxy-5-tigloyloxytigloyl	3
<i>LXXVIII</i>	C ₁₀ H ₁₃ O ₄	5-(5-hydroxytigloyloxy)tigloyl	16
<i>LXXIX</i>	C ₁₀ H ₁₃ O ₅	4-hydroxy-5-(5-hydroxytigloyloxy)tigloyl	4
<i>LXXX</i>	C ₁₂ H ₁₅ O ₅	5-(5-acetoxytigloyloxy)tigloyl	1
<i>LXXXI</i>	C ₁₄ H ₁₅ O ₇	4-acetoxy-5-(5-acetoxytigloyloxy)tigloyl	1
<i>LXXXII</i>	C ₁₆ H ₃₁ O	palmitoyl	1

TABLE I
(Continued)

Acyl	Elemental compositions	Name	Occurrence ^a
LXXXIII	C ₁₈ H ₂₉ O	linolenoyl	1
LXXXIV	C ₁₈ H ₃₁ O	linoloyl	1
LXXXV	C ₁₈ H ₃₅ O	stearoyl	1
LXXXVI	C ₂₃ H ₄₁ O ₄	4-(3-hydroxystearoyloxy)tigloyl	1
LXXXVII	C ₂₃ H ₄₃ O ₃	4-stearoyloxyisovaleroyl	1
LXXXVIII	C ₂₅ H ₄₃ O ₅	4-(3-acetoxystearoyloxy)tigloyl	1

^a Number of compounds containing current type of acyl (from literature till the end of 1984).

coupling constants) obtained with high-field spectrometers. Most of the listed values are obtained from data for several compounds and represent mean values.

The space does not allow to list the references to the original papers; most of them can be found in the review of Seaman².

Although most of the ¹H NMR data were obtained in deuteriochloroform, we give also values for other solvents, if available (Table III) because it is known that proton chemical shifts may be significantly solvent-dependent. This fully holds for the proton shifts in polar acyl groups in such different solvents as chloroform, benzene, pyridine, acetone or dimethyl sulfoxide. Thus, *e.g.* for epoxymethacroyl (VII) the H-3 shifts differ by 0.7 ppm on transition from chloroform to benzene. On the contrary, the proton chemical shifts for a given acyl are markedly less affected by structure of the sesquiterpenic hydroxy lactone, character of the esterified hydroxyl (primary, secondary or tertiary) or its position in the molecule. The apparent reason is that the acyl protons are separated by four or more bonds from the nearest carbon atom in the sesquiterpenic skeleton and that the whole acyl, or at least its part bearing hydrogen atoms, is usually more or less mobile, which substantially averages the possible shielding effects of the alcohol part (the skeleton or substituents). As shown by the collected data, the scatter of proton shift values in a given solvent is not large (maximum deviations from the mean values in Table II are not greater than 0.2 ppm). Therefore, the values in Table II can be taken as sufficiently characteristic.

As follows from comparison of the NMR parameters in Table II, unsaturated acyl groups can be relatively easy identified. Their olefinic protons resonate in the spectral region where only few protons of the sesquiterpenic lactone occur. There is no great danger of error in the acyl assignment, since the spectrum usually contains also well-discernible signals due to the remaining acyl protons. Thus, *e.g.* for the methacroyl moiety (IV) we observe one signal of methyl on a double bond, for

TABLE II
Proton NMR parameters of acyl groups occurring in sesquiterpene lactones (in C^2HCl_3)

Acyl ^a		$\delta(H-2)$	$\delta(H-3)$	$\delta(H-4)$	$\delta(H-5)$	Other parameters
<i>I</i>	(^b)	2.00 s	—	—	—	—
<i>II</i>	(4)	—	2.39 s	—	—	—
<i>III</i>	(4)	2.35 q	1.14 t	—	—	$J(2, 3) = 7$
<i>IV</i>	(97)	—	5.62 dq 6.11 dq	1.92 t	—	$J(3a, 3b) = 2$; $J(3a, 4) = 1$; $J(3b, 4) = 1.5$
<i>VI</i>	(1)	5.78 d	7.04 d	—	—	$J(2, 3) = 10$; SCH_3 : 2.39 s
<i>VII</i>	(9)	—	2.78 d 3.16 d	1.59 s	—	$J(3a, 3b) = 6.5$
<i>VIII</i>	(18)	—	5.91 m 6.29 m	4.35 bd 4.36 bd	—	$J(3a, 3b) = J(3a, 4) =$ $= J(3b, 4) = 1$
<i>IX</i>	(6)	—	3.70 d 3.92 d	1.55 s	—	$J(3a, 3b) = 11$
<i>X</i>	(7)	2.30 m	1.60 m	0.94 t	—	$J(2, 3) = J(3, 4) = 7$
<i>XI</i>	(39)	2.52 m	1.16 d	1.14 d	—	$J(2, 3) = J(2, 4) = 7$
<i>XII</i>	(4)	—	1.28 s	1.28 s	—	—
<i>XIII</i>	(3)	2.45 m	3.75 bs	1.13 d	—	$J(2, 3)^c$; $J(2, 4) = 7$
<i>XIV</i>	(2)	—	3.60 d 3.87 d	1.40 s	—	$J(3a, 3b) = 11$
<i>XV</i>	(3)	7.99 dd	—	7.43 dd	6.70 dd	$J(2, 4) = 0.7$; $J(2, 5) = 1.6$; $J(4, 5) = 1.9$
<i>XVI</i>	(1)	—	6.71 t	—	4.97 d	$J(3, 5) = 2.2$
<i>XVII</i>	(1)	—	5.66 tq	10.15 d	2.28 m	$J(3, 4) = 7$; $J(3, 5) = 1.5$
<i>XVIII</i>	(1)	4.89 ddd	6.65 ddd	—	4.69 ddd	$J(2, 3) = J(2, 5) = J(3, 5) = 2.2$
<i>XIX</i>	(135)	—	6.12 qq	1.96 dq	1.83 dq	$J(3, 4) = 7$; $J(3, 5) =$ $= J(4, 5) = 1.5$
<i>XX</i>	(10)	5.75 qq	—	2.18 d	1.90 d	$J(2, 4) = J(2, 5) = 1$
<i>XXI</i>	(60)	—	6.83 m	1.42 d	1.82 d	$J(3, 4) = 7$; $J(3, 5) = J(4, 5) = 1$
<i>XXII</i>	(32)	—	3.05 d	1.27 d	1.55 s	$J(3, 4) = 5$
<i>XXIII</i>	(1)	2.14 m 2.24 d	—	2.12 bd 2.33 bd	1.07 bs	$J(2a, 2b) = 14$; $J(4a, 4b) = 5$; $J(4, 5) = 0.5$
<i>XXIV</i>	(2)	—	5.87 bs 6.08 s	4.55 q	1.33 d	$J(4, 5) = 6.5$
<i>XXV</i>	(1)	—	5.87 dd	5.46 dd 5.20 dd	1.37 s	$J(3, 4a) = 17$; $J(3, 4b) = 10.5$; $J(4a, 4b) = 1$
<i>XXVIII</i>	(11)	—	6.77 tq	4.31 bd	1.88 d	$J(3, 4a) = J(3, 4b) = 6$; $J(3, 5) = 1.5$
<i>XXIX</i>	(12)	—	6.92 q	1.93 d	4.35 d 4.43 d	$J(3, 4) = 7$; $J(5a, 5b) = 12$
<i>XXX</i>	(2)	3.48 q	—	2.17 s	1.25 d	$J(2, 5) = 7$
<i>XXXI</i>	(8)	—	6.43 q	2.02 d	4.23 m 4.27 m	$J(3, 4) = 7$; $J(5a, 5b) = 13$

TABLE II
(Continued)

Acyl ^a		δ (H-2)	δ (H-3)	δ (H-4)	δ (H-5)	Other parameters
XXXIII	(2)	—	6.85 t	4.40 d 4.43 bd	4.33 bd 4.35 s	$J(3, 4) = 6$; $J(4a, 4b)^c$; $J(5a, 5b)^c$
XXXIV	(1)	—	5.38 t 6.08 t	4.57 m	3.60 m 3.84 m	$J(3a, 3b) = 1.4$; $J(3a, 4) =$ $= J(3b, 4) = 1.2$; $J(4, 5a) = 4.0$; $J(4, 5b) = 6.5$; $J(5a, 5b) = 11.0$
XXXV	(5)	—	6.84 t	4.40 d	4.33 s	$J(3, 4a) = J(3, 4b) = 5.8$
XXXVI	(1)	—	3.26 d	1.22 d	3.82 d 4.12 d	$J(3, 4) = 5.5$; $J(5a, 5b) = 13$
XXXVII	(6)	—	—	2.16 s	1.49 s	—
XXXVIII	(1)	—	3.82 q	1.44 d	1.16 s	$J(3, 4) = 6.5$
XXXIX	(18)	2.22 s 2.24 d	2.09 m	0.97 d	0.94 d	$J(2a, 2b)^c$; $J(2a, 3) =$ $= J(2b, 3) = J(3, 4) = J(3, 5) = 7$
XL	(77)	2.35 m	1.44 m 1.65 m	0.88 t	1.12 d	$J(2, 3a) = J(2, 3b) = J(2, 5) =$ $= J(3a, 4) = J(3b, 4) = 7$
XLII	(1)	2.44 s	—	1.22 s	1.22 s	—
XLIII	(7)	2.38 m	3.83 m	1.18 d	1.04 d	$J(2, 3) = J(2, 5) = 7$; $J(3, 4) = 6.5$
XLIV	(4)	—	3.85 q	1.20 d	1.15 s	$J(3, 4) = 6.5$
XLV	(1)	—	4.10 q	1.45 d	3.68 d 3.77 d	$J(3, 4) = 7$; $J(5a, 5b) = 12$
XLVI	(2)	—	5.91 m 6.31 m	4.75 bd	—	$J(3a, 3b) = J(3a, 4) =$ $= J(3b, 4) = 1$
XLVII	(1)	5.58 dd	6.55 dd	—	4.70 m	$J(2, 3) = 2$; $J(2, 5) = 4$; $J(3, 5) = 1.5$
XLVIII	(3)	5.76 tq	—	2.13 q	1.05 t	$J(2, 4) = J(2, 6) = 1$; $J(4, 5) = 7.5$; H-6: 2.13 bs
IL	(1)	—	—	2.19 s	1.85 q	H-6: 0.81 t; $J(5, 6) = 7$
L	(4)	2.35 t	2.33 t	1.66 tt	1.30 m	$J(2a, 2b) = 15.5$; $J(2, 3) =$ $= J(3, 4) = J(4, 5) = 7$; H-6: 0.89 t; $J(5, 6) = 7$
LI	(1)	—	3.44 d 3.76 d	1.40 s	3.49 dq 3.63 dq	$J(3a, 3b) = 11$; $J(5a, 5b) = 13$; H-6: 1.16 t; $J(5a, 6) = J(5b, 6) = 7$
LII	(1)	—	8.07 m	7.60 m	7.48 m	—
LIII	(3)	—	6.06 bt	5.01 m 5.06 m	2.00 s	$J(3, 4a) = J(3, 4b) = 5$; $J(3, 5) = J(4a, 5) = 1.5$ $J(4b, 5) = 1.5$; $J(4a, 4b) = 17$
LV	(2)	5.73 tq	—	5.14 m	1.94 d	$J(2, 4) = J(2, 5) = 1.5$
LVI	(5)	—	6.70 tq	4.72 bd	1.88 d	$J(3, 4) = 6$; $J(3, 5) = 1$
LVII	(23)	—	7.14 q	1.97 d	4.80 d 4.85 d	$J(3, 4) = 7$; $J(5a, 5b) = 12$

TABLE II
(Continued)

Acyl ^a	$\delta(\text{H-2})$	$\delta(\text{H-3})$	$\delta(\text{H-4})$	$\delta(\text{H-5})$	Other parameters	
<i>LVIII</i>	(8)	—	6.56 q	2.12 d	4.67 m 4.71 m	$J(3, 4) = 7$; $J(5a, 5b) = 10.5$
<i>LIX</i>	(1)	—	6.78 t	4.87 d	4.40 m	$J(3, 4) = 6$
<i>LXI</i>	(4)	—	—	2.23 s	1.60 s	—
<i>LXII</i>	(1)	2.99 d	—	1.56 s	1.52 s	—
<i>LXIII</i>	(3)	2.46 m	4.97 m	1.18 d	1.08 d	$J(2, 3) = J(2, 5) = 7$; $J(3, 4) = 6.5$
<i>LXIV</i>	(4)	—	5.13 q	1.27 d	1.17 s	$J(3, 4) = 6$
<i>LXV</i>	(1)	3.60 d 3.67 d	—	—	—	arom. H: 7.20 m (3 H); 7.35 m (2 H); $J(2a, 2b)^c$
<i>LXVI</i>	(1)	3.68 s	—	—	—	arom. H: 7.06 m (2 H); 7.28 m (2 H)
<i>LXVII</i>	(1)	—	8.02 m	6.98 m	—	OCH ₃ : 3.90 s
<i>LXVIII</i>	(3)	—	6.84 m	4.41 m	4.50 m	$J(3, 4)^c$; H-6: 1.40 s
<i>LXIX</i>	(1)	2.30 t	1.1—1.6	1.1—1.6	1.1—1.6	H-6: 1.1—1.6 m; H-7: 0.80 d; H-8: 0.80 d; $J(6, 7) = J(6, 8) = 7$
<i>LXX</i>	(4)	2.30 t	1.60 m	1.60 m	1.60 m	H-6: 1.60 m; H-7: 1.30 m; H-8: 0.87 t; $J(7, 8) = 7$
<i>LXXI</i>	(2)	6.47 d	7.76 d	—	—	$J(2, 3) = 16$; arom. H: 7.43 m (3 H); 7.56 m (2 H)
<i>LXXII</i>	(1)	—	7.54 m	—	—	H-6: 6.91 m; H-7: 7.68 m; $2 \times \text{OCH}_3$: 3.90 s
<i>LXXIII</i>	(3)	—	6.89	4.84 dd	4.87 d 4.91 d	$J(3, 4a) = J(3, 4b) = 7$; $J(4a, 4b) = 15$; $J(5a, 5b) = 12.5$
<i>LXXIV</i>	(3)	—	5.30 q	1.18 d	1.54 s	$J(3, 4) = 6.5$
<i>LXXV</i>	(2)	2.30 t	1.60 m	1.60 m	1.60 m	H-6: 1.30 m; H-7: 1.30 m; H-8: 1.10 t; H-9: 0.90 d; $J(6, 9) = J(7, 8) = 7$
<i>LXXVI</i>	(1)	—	7.02 t	4.46 dd 4.56 m	4.87 d 5.02 d	$J(3, 4a) = J(3, 4b) = 5.9$; $J(4a, 4b) = 15.8$; $J(5a, 5b) =$ $= 12.2$; H-8: 6.09 qq; H-9: 1.92 dq H-10: 1.80 m; $J(8, 9) = 7.2$; $J(8, 10) = 1.5$; $J(9, 10) = 1.5$
<i>LXXVII</i>	(1)	—	7.08 t	4.46 m 4.56 m	4.89 d 5.01 d	$J(3, 4a) = J(3, 4b) = 7$; $J(4a, 4b) = 13$; $J(5a, 5b) = 15$; H-8: 6.77 qq; H-9: 1.78 d; H-10: 1.80 bs; $J(8, 9) = 7$; $J(8, 10) = 1$; $J(9, 10) = 1.5$
<i>LXXVIII</i>	(4)	—	7.09 q	1.96 d	4.75 d 4.90 d	$J(3, 4) = 7$; $J(5a, 5b) = 13$; H-8: 6.89 q; H-9: 1.90 d; H-10: 4.31 m; $J(8, 9) = 7$

TABLE II
(Continued)

Acyl ^a		δ (H-2)	δ (H-3)	δ (H-4)	δ (H-5)	Other parameters
LXXXIX	(2)	—	7.03 t	4.43 d	4.90 d 5.01 d	$J(3, 4) = 5.8$; $J(5a, 5b) = 12$; H-8: 6.96 q; H-9: 1.91 d; H-10: 4.32 bs; $J(8, 9) = 7.3$
LXXX	(1)	—	6.94 q	1.40 d	4.70 d 4.90 d	$J(3, 4) = 7$; $J(5a, 5b) = 13$; H-8: 6.99 q; H-9: 1.58 d; H-10: 4.89 m; $J(8, 9) = 7$
LXXXI	(1)	—	6.90 t	4.88 d	4.85 d 4.89 d	$J(3, 4) = 6$; $J(5a, 5b) = 12$; H-8: 7.04 q; H-9: 1.93 d; H-10: 4.80 s; $J(8, 9) = 7.5$
LXXXII	(1)	2.30 t	1.62 p	1.26 bs	1.26 bs	H-6 to H-15: 1.26 bs; H-16: 0.88 t; $J(15, 16) = 6.5$
LXXXIII	(1)	2.30 t	1.63 m	1.31 bs	1.31 bs	$J(2, 3) = 7$; H-6, H-7: 1.31 bs; H-9, H-10, H-12, H-13, H-15, H-16: 5.36 m; H-11, H-14: 2.81 t; H-17: 2.08 m; H-18: 0.98 t; $J(10, 11) = J(11, 12) =$ $= J(13, 14) = J(14, 15) = 5.5$ $J(17, 18) = 7.5$
LXXXIV	(1)	2.30 t	1.62 m	1.30 bs	1.30 bs	$J(2, 3) = 7$; H-6, H-7, H-15, H-16, H-17: 1.30 bs; H-8, H-14: 1.98 m; H-9, H-10, H-12, H-13: 5.40; H-11: 2.67 m; H-18: 0.88 t; $J(17, 18) = 7$
LXXXV	(1)	2.28 t	1.61 m	1.25 bs	1.25 bs	$J(2, 3) = 7.5$; H-6 to H-17: 1.25 bs; H-18: 0.88 t; $J(17, 18) = 6.5$
LXXXVI	(1)	—	6.70 m	4.75 bd	1.85 bs	$J(3, 4) = 6$; H-8: 4.03 m; $J(7, 8) = 6.5$; H-9 to H-22: 1.24 bs; H-23: 0.86 t; $J(22, 23) = 7$
LXXXVII	(1)	2.23 dd	3.35 m	3.91 dd	0.98 d	$J(2a, 3) = J(2b, 3) = 6$; $J(2a, 2b) = 15$; $J(3, 4a) = 5$; $J(3, 4b) = 6$; $J(4a, 4b) = 11$; $J(3, 5) = 6.5$; H-7: 2.30 t; H-8: 1.62 m; H-9 to H-22: 1.25 bs; H-23: 0.88 t; $J(7, 8) =$ $= J(22, 23) = 7.5$
LXXXVIII	(1)	—	6.69 m	4.75 bd	1.86 bs	$J(3, 4) = 6$; H-8: 5.21 q; $J(7, 8) = 6.5$; H-9 to H-22: 1.24 bs; H-23: 0.86 t; $J(22, 23) = 7$

^a Number of substances with used NMR data is given in parentheses; for XXVI, XXVII, XXXII, LIV, and LX only the data in other solvents are available (see Table III); the NMR data for V and XLI are missing; ^b number of acetyl groups not determined; ^c the NMR data not given in literature; ^d data taken from methyl ester.

TABLE III

Proton NMR parameters of acyl groups occurring in sesquiterpene lactones (data in different solvents)

Acyl	Solvent ^a	$\delta(\text{H-2})$	$\delta(\text{H-3})$	$\delta(\text{H-4})$	$\delta(\text{H-5})$	Other parameters ^b
<i>II</i>	B (1)	—	2.14 s	—	—	—
<i>III</i>	B (1)	2.02 q	0.92 t	—	—	$J(2, 3) = 7$
<i>IV</i>	B (12)	—	5.22 dq 6.10 dq	1.77 t	—	$J(3a, 3b) = 2$; $J(3a, 4) = 1$; $J(3b, 4) = 1.5$
	P (2)	—	5.69 dq 6.20 dq	1.97 t	—	
<i>VII</i>	B (1)	—	2.05 d	1.13 s	—	$J(3a, 3b) = 6.5$
<i>VIII</i>	B (1)	—	5.38 m 5.96 m	3.86 bd 3.93 bd	—	$J(3a, 3b) = J(3a, 4) =$ $= J(3b, 4) = 1$; $J(4a, 4b) = 14$
<i>XI</i>	B (1)	2.70 m	1.03 d	1.03 d	—	$J(2, 3) = J(2, 4) = 7$
	A (1)	2.44 m	1.07 d	1.05 d	—	
<i>XII</i>	B (1)	—	1.28 s	1.22 s	—	—
<i>XIV</i>	A (1)	—	3.56 d	1.39 s	—	$J(3a, 3b) = 11$
<i>XIX</i>	B (9)	—	5.75 qq	1.88 dq	1.74 dq	$J(3, 4) = 7$; $J(3, 5) =$
	P (5)	—	5.89 qq	1.96 dq	1.82 dq	$= J(4, 5) = 1.5$
	S (1)	—	6.12 qq	1.98 dq	1.89 dq	
	A (1)	—	6.07 qq	1.93 dq	1.87 dq	
<i>XX</i>	B (1)	5.69 qq	—	2.11 d	1.54 d	$J(2, 4) = J(2, 5) = 1$
<i>XXI</i>	B (13)	—	6.93 m	1.42 d	1.74 d	$J(3, 4) = 7$; $J(3, 5) =$ $= J(4, 5) = 1$
<i>XXII</i>	B (7)	—	2.55 d	1.09 d	1.30 s	$J(3, 4) = 5$
<i>XXIV</i>	B (2)	—	5.16 bs 5.34 s	4.20 q	1.15 d	$J(4, 5) = 6.5$
<i>XXVI</i>	B (2)	6.11 tq	—	3.60 bs	1.99 bs	$J(2, 4) = J(2, 5b) = 1$; $J(2, 5a) = 1.5$
<i>XXVII</i>	B (1)	5.70 tq	—	4.39 bs	1.64 bs	$J(2, 4) = J(2, 5a) =$ $= J(2, 5b) = 1$
<i>XXVIII</i>	B (3)	—	6.85 m	3.97 bd	1.74 d	$J(3, 4a) = J(3, 4b) = 6$; $J(3, 5) = 1.5$
<i>XXIX</i>	B (1)	—	6.89 m	1.58 d	4.29 bs	$J(3, 4) = 7$
<i>XXXII</i>	B (2)	—	3.26 h	1.06 d	1.17 d	$J(3, 4) = J(3, 5) = 7$
<i>XXXV</i>	A (3)	—	6.77 t	4.32 d	4.21 d	$J(3, 4a) = J(3, 4b) = 5.8$
	M (1)	—	6.79 t	4.37 m	4.37 m	
<i>XXXVIII</i>	B (5)	—	—	1.85 s	1.36 s	—
<i>XXXIX</i>	B (1)	2.03 d 2.25 d	1.99 m	0.88 d	0.89 d	$J(2a, 3) = J(2b, 3) =$ $= J(3, 4) = J(3, 5) = 7$

TABLE III
(Continued)

Acyl	Solvent ^a	$\delta(\text{H-2})$	$\delta(\text{H-3})$	$\delta(\text{H-4})$	$\delta(\text{H-5})$	Other parameters ^b
XL	B (9)	2.21 m	1.32 m 1.58 m	0.79 t	1.02 d	$J(2, 3a) = J(2, 3b) =$ $= J(2, 5) = J(3a, 4) =$ $= J(3b, 4) = 7$
	P (4)	2.45 m	1.43 m 1.69 m	0.83 d	1.21 d	
	A (1)	2.46 m	1.43 m 1.72 m	0.81 d	1.23 d	
XLIII	B (5)	2.28 m	3.77 m	0.94 d	0.85 d	$J(2, 3) = J(2, 5) = 7;$ $J(3, 4) = 6.5$
XLIV	B (4)	—	3.85 q	1.17 d	1.09 s	$J(3, 4) = 6.5$
XLVIII	B (1)	5.80 tq	—	1.82 q	0.81 t	$J(2, 4) = 1; J(4, 5) = 7.5;$ H-6: 2.23 bs
	P (1)	5.67 tq	—	1.88 q	0.74 t	H-6: 2.18 bs; $J(2, 6) = 1$
L	B (2)	2.07 t	2.07 t	1.55 tt	1.17 m	$J(2, 3) = J(3, 4) =$ $= J(4, 5) = 7; J(2a, 2b) =$ $= 15.5; \text{H-6: } 0.85 \text{ t};$ $J(5, 6) = 7$
	B (2)	—	5.52 bs	5.24 q	1.06 d	$J(4, 5) = 7$
LV	B (1)	5.74 tq	—	4.97 d 5.04 d	1.64 bs	$J(2, 4) = J(2, 5) = 1.5$
LVI	B (1)	—	7.10 q	1.56 d	4.95 bs	$J(3, 4) = 7$
LX	B (1)	—	7.16 t	4.08 bd	4.78 d	$J(3, 4a) = J(3, 4b) = 6.6;$ $J(5a, 5b) = 16$
LXIII	B (1)	2.46 m	5.02 m	0.96 d	0.94 d	$J(2, 3) = J(2, 5) = 7;$ $J(3, 4) = 6.5$
LXIV	B (4)	—	5.22 q	1.14 d	1.12 s	$J(3, 4) = 6$
	A (2)	—	^c	1.34 d	1.20 s	
LXXIII	B (1)	—	7.06 t	4.85 dd	5.06 d	$J(3, 4a) = J(3, 4b) = 7;$ $J(4a, 4b) = 15;$ $J(5a, 5b) = 12.5$
			4.95 m	5.11 d	5.11 d	
LXXVIII	B (2)	—	7.07 q	1.41 d	4.66 d 4.82 d	$J(3, 4) = 7; J(5a, 5b) = 13;$ H-8: 6.87 q; H-9: 1.54 d; H-10: 4.27 m; $J(8, 9) = 7$

^a Abbreviations of solvents: B hexadeuteriobenzene, S hexadeuteriodimethyl sulfoxide, A hexadeuterioacetone, M tetradeuteriomethanol, P pentadeuteriopyridine; number of substances with used NMR data is given in parentheses; ^b values of coupling constants are practically independent of solvent; ^c the value of the NMR parameter is not given in the literature.

angeloyl (*XIX*), tigloyl (*XXI*), and seneciroyl (*XX*) groups two such signals. Relatively easy differentiation exists also for isomeric acyl groups: *e.g.* of the three isomeric acyls of general formula C_5H_7O , the tigloyl group (*XXI*) shows an olefinic proton signal at δ 6.8 whereas for the angeloyl (*XIX*) and seneciroyl (*XX*) groups the corresponding signals occur at δ 6.1 and δ 5.75, respectively. The largest group of isomeric acyls in our set (11) has the composition $C_5H_7O_2$ (*XXII*–*XXXIII*). Even such a number of isomeric acyls can be satisfactorily distinguished by means of the 1H NMR data (Table II).

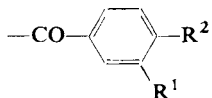
A somewhat more complicated situation exists with acyls of saturated carboxylic acids. In many cases some of their signals are discernible only with difficulty because they overlap with multiplets of the skeletal protons. As starting points for the identification we may use methyl signals of the acyl (their number, position and multiplicities); signals in other spectral regions (according to Table II) can be used for confirmation of the given ester structure. Thus, *e.g.* the 2-methylbutanoyl group (*XL*) shows a characteristic triplet of the $C_{(4)}$ -methyl at δ 0.88 and a doublet of the $C_{(5)}$ -methyl at δ 1.12. Similarly, the presence of isobutyryl group (*XI*) is indicated by doublets of secondary methyl groups at about δ 1.15. Sometimes the methyl signals help to decide between two isomeric acyls, *e.g.* 2-hydroxy- and 3-hydroxyisobutyryl (*XII* and *XIII*, respectively).

Acyls of hydroxy acids can be identified using *in situ* acylation of the hydroxy groups with trichloroacetyl isocyanate (TAI)^{3,4}. The observed characteristic TAI-acylation induced proton shifts in acyls of current hydroxy acids are given in Table

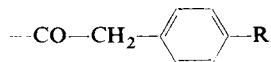
TABLE IV
TAI-Acylation induced chemical shifts of protons in some hydroxy acid acyls

Hydroxy acid acyl	TAI-Induced chemical shifts ^a		
	H-3	H-4	H-5
<i>VIII</i>	0.21 (γ); 0.23 (γ)	0.65 (α)	—
<i>IX</i>	0.28 (β); 0.30 (β)	0.29 (β)	—
<i>XXVIII</i>	—0.08 (β)	0.57 (α)	0.09 (γ)
<i>XXXIII</i>	0.18 (β , γ)	0.68 (α , δ); 0.80 (α , δ)	0.57 (α , δ); 0.83 (α , δ)
<i>XXXIV</i>	1.37 (α , β)	0.83 (α , β); 0.96 (α , β)	0.18 (γ , δ); 0.18 (γ , δ)
<i>XXXV</i>	0.18 (β , γ)	0.70 (α , δ); 0.84 (α , δ)	0.23 (α , δ); 1.08 (α , δ)
<i>XLIV</i>	1.36 (α , β)	0.06 (β , γ)	0.50 (β , γ)
<i>LXIV</i>	0.18 (β)	0.01 (γ)	0.38 (β)
<i>LXXVI</i>	—0.08 (β)	0.57 (α); 0.67 (α)	0.05 (δ); —0.10 (δ)

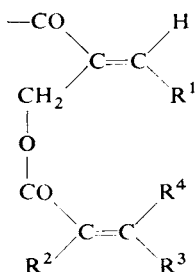
^a Relative positions of H-i with respect to OH group (or two OH groups in diols) are given in parentheses.



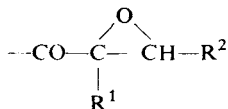
LII: $R^1, R^2 = H$
 LXVII: $R^1 = H; R^2 = OCH_3$
 LXXII: $R^1, R^2 = OCH_3$



LXV: $R = H$
 LXVI: $R = OH$



LXXVI: $R^1 = CH_2OH; R^2, R^4 = CH_3; R^3 = H$
 LXXVII: $R^1 = CH_2OH; R^2, R^3 = CH_3; R^4 = H$
 LXXVIII: $R^1, R^3 = CH_3; R^2 = CH_2OH; R^4 = H$
 LXXIX: $R^1, R^2 = CH_2OH; R^3 = CH_3; R^4 = H$
 LXXX: $R^1, R^3 = CH_3; R^2 = CH_2OAc; R^4 = H$
 LXXXI: $R^1, R^2 = CH_2OAc; R^3 = CH_3; R^4 = H$

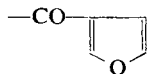


VII: $R^1 = CH_3; R^2 = H$
 XXII: $R^1, R^2 = CH_3$
 XXXVI: $R^1 = CH_2OH; R^2 = CH_3$

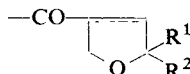


XI: $R^1, R^2 = CH_3$
 XIII: $R^1 = CH_2OH; R^2 = CH_3$
 XXX: $R^1 = COCH_3; R^2 = CH_3$
 XL: $R^1 = CH_2CH_3; R^2 = CH_3$

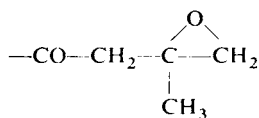
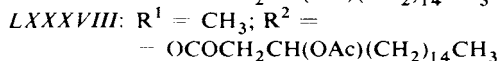
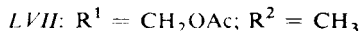
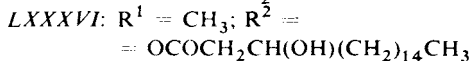
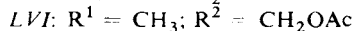
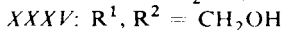
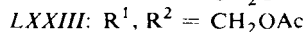
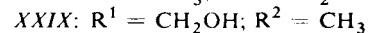
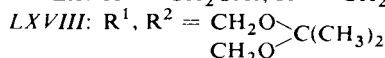
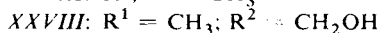
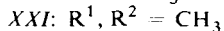
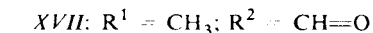
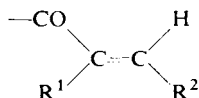
XLI: $R^1 = OH; R^2 = CH(CH_3)_2$
 XLIII: $R^1 = CH(OH)CH_3; R^2 = CH_3$
 LXIII: $R^1 = CH(OAc)CH_3; R^2 = CH_3$



XV



XVI: $R^1, R^2 = O$
 XVIII: $R^1 = OH; R^2 = H$
 XLVII: $R^1 = OCH_3; R^2 = H$



XXIII

Carbon-13 NMR Study

The wide range of chemical shifts, together with the line character of the proton-decoupled ¹³C NMR spectra, usually allow the observation of separated signals of all the carbon atoms in the spectrum. There are thus no problems with obtaining the NMR parameters, discussed for the ¹H NMR spectra. The ¹³C NMR spectroscopy has been applied to natural compounds only in the last decade: the ¹³C NMR spectra of about 500 sesquiterpenic lactones have been described. For this reason, not for all the acyl groups, found in the sesquiterpenic lactones, the ¹³C NMR data are available. We tried to fill this gap and obtain such set of ¹³C NMR data, that could be utilized for a reliable identification of acyl groups in sesquiterpenic lactones and other natural compounds.

Search in the literature and results of our own measurements furnished ¹³C NMR chemical shifts for 45 of the 88 acyls; their values are given in Table V. In some cases the values represent arithmetic means obtained from more published data (whose number is also given in Table V) in the same solvent. Generally, data obtained in deuteriochloroform were preferred; if not available, data for other solvent were used. Standard deviations of the values thus obtained do not exceed ±0.8 ppm. In a few cases of markedly differing values it appeared that the original assignment was erroneous (interchange of the acyl signal with some skeleton signal) or that the difference was due to a typographic error. In Table V we included also ¹³C NMR data for 2-oxopropionyl (*II*), benzoyl (*LII*), cinnamoyl (*LXXI*), linolenoyl (*LXXXIII*), linoloyl (*LXXXIV*), palmitoyl (*LXXXII*), and stearoyl (*LXXXV*) from our own

TABLE V
Carbon-13 chemical shifts of acyl groups occurring in sesquiterpene lactones

Acyl ^a	C-1	C-2	C-3	C-4	C-5	Other carbon atoms
<i>I</i>	(179) 169.9 s	21.0 q	—	—	—	—
<i>II</i> ^b	(—) 160.7 s	191.1 s	26.1 q	—	—	—
<i>III</i>	(1) 174.1 s	27.7 t	9.0 q	—	—	—
<i>IV</i>	(27) 165.7 s	135.0 s	127.0 t	18.0 q	—	—
<i>VII</i>	(2) 169.5 s	53.8 s	52.8 t	17.3 q	—	—
<i>VIII</i>	(1) 166.6 s	139.3 s	126.0 t	61.6 t	—	—
<i>IX</i>	(1) 171.7 s	74.7 s	51.1 t	23.4 q	—	—
<i>X</i>	(6) 174.4 s	37.7 t	19.2 t	14.7 q	—	—
<i>XI</i>	(18) 176.1 s	34.0 d	18.9 q	18.5 q	—	—
<i>XII</i>	(1) 175.4 s	72.2 s	26.8 q	26.8 q	—	—
<i>XV</i>	(1) 161.9 s	119.2 d	109.6 s	144.2 d	147.8 d	—
<i>XVII</i>	(1) 166.0 s	126.8 s	144.4 d	191.1 d	11.9 q	—
<i>XIX</i>	(97) 166.4 s	126.9 s	140.0 d	15.8 q	20.3 q	—
<i>XX</i>	(3) 164.9 s	115.1 d	159.3 s	20.4 q	27.5 q	—
<i>XXI</i>	(19) 166.8 s	127.9 s	138.5 d	14.5 q	12.1 q	—
<i>XXII</i>	(11) 168.6 s	59.5 s	59.9 d	13.7 q	19.0 q	—
<i>XXIV</i>	(1) 165.0 s	145.3 s	123.3 t	64.5 d	23.3 q	—
<i>XXV/III</i>	(8) 166.1 s	126.9 s	142.8 d	59.4 t	12.6 q	—
<i>XXIX</i>	(8) 166.2 s	131.6 s	142.6 d	14.5 q	56.2 t	—
<i>XXXI</i>	(6) 165.6 s	131.4 s	142.5 d	15.7 q	63.8 t	—
<i>XXXIV</i>	(1) 165.1 s	132.1 s	127.8 t	70.3 d	65.5 t	—
<i>XXXV</i>	(17) 165.9 s	131.5 s	145.1 d	58.8 t	56.8 t	—
<i>XXXVI</i>	(1) 167.2 s	64.1 s	54.9 d	13.5 q	61.9 t	—
<i>XXXIX</i>	(8) 171.9 s	43.1 t	25.3 d	22.3 q	22.3 q	—
<i>XL</i>	(23) 175.4 s	41.3 d	26.6 t	11.5 q	16.5 q	—
<i>XLV</i>	(1) 171.3 s	81.3 s	59.5 d	19.9 q	62.5 t	—
<i>XLVI</i>	(1) 164.3 s	135.0 s	129.3 t	62.2 t	—	OAc: 170.3 s; 20.6 q

<i>XLVII</i>	(1)	161.1 s	137.5 s	136.0 d	109.4 d	72.8 t	OCH ₃ : 54.4 q
<i>XLVIII</i>	(1)	165.5 s	113.5 d	164.5 s	34.0 t	12.0 q	
<i>L</i>	(3)	174.5 s	35.4 t	25.9 t	32.6 t	23.6 t	C-6: 14.6 q
<i>LII^c</i>	(-)	166.4 s	130.7 s	129.5 d	128.2 d	132.6 d	C-6: 128.2 d; C-7: 129.5 d
<i>LIII</i>	(4)	165.5 s	127.8 s	140.2 d	63.0 t	19.3 q	OAc: 171.3 s; 20.9 q
<i>LV</i>	(1)	167.8 s	116.9 d	157.8 s	63.8 t	20.4 q	OAc: 170.7 s; 20.4 q
<i>LVII</i>	(1)	165.2 s	127.5 s	145.9 d	14.7 q	57.3 t	OAc: 170.6 s; 20.7 q
<i>LVIII</i>	(7)	164.7 s	127.0 s	147.0 d	15.9 q	65.6 t	OAc: 169.9 s; 20.8 q
<i>LXIV</i>	(1)	174.0 s	76.0 s	73.5 d	13.7 q	22.0 q	OAc: 170.0 s; 20.9 q
<i>LXVIII</i>	(1)	163.8 s	132.3 s	142.2 d	60.7 t	59.6 t	CH(CH ₃) ₂ : 102.3 s; 23.6 q
<i>LXX</i>	(4)	174.9 s	35.4 t	26.1 t	30.1 t	30.1 t	C-6: 32.9 t; C-7: 23.7 t; C-8: 14.3
<i>LXXI^d</i>	(-)	165.1 s	116.3 d	142.6 d	132.5 s	126.1 d	C-6: 126.9 d; C-7: 128.2 d; C-8: 126.9 d; C-9: 126.1 d
<i>LXXVI</i>	(1)	164.7 s	126.7 s	147.9 d	59.4 t	57.5 t	C-6: 167.7 s; C-7: 126.9 s; C-8: 139.5 d; C-9: 15.8 q; C-10: 20.3 q
<i>LXXVIII</i>	(4)	164.7 s	127.6 s	145.7 d	14.6 q	57.5 t	C-6: 166.7 s; C-7: 131.7 s; C-8: 141.9 d; C-9: 14.3 q; C-10: 56.2 t
<i>LXXXII^b</i>	(-)	174.3 s	34.1 t	25.0 t	29.2 t	29.3 t	C-6 to C-16: 32.0 t; 29.7 t (5 × C); 29.6 t; 29.5 t; 29.4 t; 22.7 t; 14.1 q
<i>LXXXIII^b</i>	(-)	174.3 s	34.1 t	25.0 t	29.1 t	29.1 t	C-6 to C-18: 132.0 d; 130.3 d; 128.3 d (2 × C); 127.7 d; 127.1 d; 29.6 t; 27.1 t; 25.6 t; 25.5 t; 20.6 t; 14.3 q
<i>LXXXIV^b</i>	(-)	174.3 s	34.1 t	25.0 t	29.1 t	29.1 t	C-6 to C-18: 131.1 d; 130.9 d; 128.7 d; 128.6 d; 35.7 t; 32.6 t (2 × C); 31.4 t; 29.5 t; 29.2 t; 29.0 t; 22.6 t; 14.1 q
<i>LXXXV^b</i>	(-)	173.9 s	34.4 t	25.0 t	29.2 t	29.3 t	C-6 to C-18: 32.0 t; 29.7 t (7 × C); 29.6 t; 29.5 t; 29.4 t; 22.7 t; 14.3 q
<i>LXXXVI</i>	(1)	165.7 s	129.3 s	137.3 d	61.2 t	12.9 q	C-6 to C-23: 172.6 s; 41.6 t; 60.2 d; 37.0 t; 32.1 t; 32.0 t; 29.8 t (8 × C); 29.4 t; 25.6 t; 22.8 t; 14.2 q

^a Number of compounds with used NMR data is given in parentheses; ^b data for methyl esters are given; ^c data taken from ref. ⁸; ^d data for n-propyl ester.

measurements of the corresponding methyl esters. As follows from Table V, the ^{13}C NMR data for the esters are highly characteristic and if all the acyl carbon signals are used, an error in the structural assignment is very unlikely.

There is a characteristic difference between acyls of saturated and α,β -unsaturated carboxylic acids. Spectra of the unsaturated acyls exhibit not only signals of olefinic carbon atoms at δ 100–150, but also an upfield shift of the carboxyl carbon signal ($\delta(\text{C}=\text{O}) = 168-164$) as compared with saturated acyls ($\delta(\text{C}=\text{O}) = 176-167$). The region between these two groups is typical of α,β -epoxyacyls ($\delta(\text{C}=\text{O}) = 169$ to 167).

The structural identification of acyls derived from hydroxy acids can be supported by the *in situ* acylation with trichloroacetyl isocyanate and the acylation-induced shifts in the ^{13}C NMR spectra⁵ may be used analogously as in the ^1H NMR spectra. The TAI-acylation-induced shifts, observed by us for some acyls of hydroxy acids bonded to sesquiterpenic lactones, are given in Table VI.

Since ^{13}C NMR data for almost half of the acyl groups in Table I are not known and their obtaining by direct measurements was impossible, we tried to calculate the missing values on the basis of empirical relationships.

For acyls of unsaturated acids we used the relationship (I) described by Dostovalova and coworkers⁶, where $\delta_{\text{C}^i(\text{RCOOR}')}$ is the calculated chemical shift of the atom C^i in the ester, $\delta_{\text{C}^i(\text{RH})}$ is the shift of the same carbon atom in the corresponding hydrocarbon (where COOR' is replaced by an atom of hydrogen) or its substitution derivative. The values of coefficients A, B and C depend on the position of the carbon atom in question (α , β or γ) relative to the carboxyl group and n is the degree of branching in position α to the carboxyl (for an unbranched derivative $n = 1$).

$$\delta_{\text{C}^i(\text{RCOOR}')} = A\delta_{\text{C}^i(\text{RH})} + Bn + C \quad (I)$$

Position	A	B	C
α	0.761	-1.860	25.710
β	0.931	0.260	3.310
γ	1.020	0.430	-3.390

Thus, *e.g.* in the calculation of shifts for propionate we used the data for ethane, for 2-hydroxyisovalerate the data for 2-methylpropanol, *etc.* If experimental ^{13}C NMR data of the required reference compound were not available, they were calculated from those of the nearest accessible precursor and the described substitution effects⁷. Such calculations were performed also for esters whose ^{13}C NMR data were known, in order to check the reliability and accuracy of the calculation. The calculated carbon atom shifts for acyls of saturated acids are listed in Table VII.

The applied procedure does not determine shifts of carboxyl carbon atoms whose signals should appear in the region δ 167–176 (*vide supra*). As seen from Table VII, the accuracy of the calculated shifts is highest for acyls of unsubstituted acids and the calculation error increases with increasing number of substituents. For acyls with available experimental data the mean deviation amounts to ± 1.5 ppm.

The described procedure cannot be applied to acyls of α,β -unsaturated acids. To calculate chemical shifts for this type of acyls, we used the procedure of Lippmaa and coworkers^{8,9}. Their empirical rule (2) for calculating the shifts of carbon atoms C^α and C^β in α,β -unsaturated carboxylic acids is based on acrylic acid (values $\delta_{C^\alpha_0}$ and $\delta_{C^\beta_0}$); Z_i represents the contribution of the corresponding substituent to the chemical shift in the given position. In our calculations we used methacrylate as model compound ($\delta_{C^\alpha_0} = 128.7$ and $\delta_{C^\beta_0} = 129.9$; ref.¹⁰).

$$\begin{aligned}\delta_{C^\alpha} &= \delta_{C^\alpha_0} + \sum_i Z_i(\alpha) \\ \delta_{C^\beta} &= \delta_{C^\beta_0} + \sum_i Z_i(\beta)\end{aligned}\quad (2)$$

From the published ¹³C NMR data for acyls of α,β -unsaturated acids we estimated the substituent contributions, required for calculation of shifts in acyls with missing ¹³C NMR data. These estimated contributions were refined in the calculation of data for the set of acyls with known ¹³C NMR data, with the use of a program employing the gradient method of Fletcher and Powell¹¹. The optimized values Z_i are given in Table VIII. Of course, chemical shifts of the carboxyl and sp^3 carbon atoms cannot be determined by the relationship (2). The carbonyl carbon signals of α,β -unsaturated acyls should occur in the region $\delta(C=O)$ 168–164. Chemical shifts

TABLE VI
TAI-Acylation induced chemical shifts of carbons in some hydroxy acid acyls

Hydroxy acid acyl	TAI-Induced chemical shifts ^a				
	C-1	C-2	C-3	C-4	C-5
<i>IX</i>	−3.83 (β)	6.87 (α)	−4.43 (β)	−2.81 (β)	—
<i>XXXV</i>	−1.91 (γ, δ)	−3.35 (β, γ)	−1.37 (β, γ)	3.76 (α, δ)	3.04 (α, δ)
<i>LXIV</i>	−6.35 (β)	8.37 (α)	−1.92 (β)	0.93 (γ)	−5.59 (β)
<i>LXXVI</i>	−0.71 (δ)	2.96 (γ)	−7.30 (β)	3.59 (α)	−0.26 (δ)

^a Relative positions of C-i with respect to the OH group (or two groups in dihydroxyacyl *XXXV*) are given in parentheses.

TABLE VII

Calculated carbon-13 chemical shifts in acyl groups of saturated carboxylic acids and comparison with accessible experimental data^a

Acyl	C-2	C-3	C-4	C-5
<i>III</i>	27.9 (0.2)	8.5 (-0.5)	—	—
<i>VII</i>	56.4 (2.6)	48.1 (-4.7)	20.9 (3.6)	—
<i>IX</i>	72.6 (-2.1)	53.3 (2.2)	21.1 (-2.3)	—
<i>X</i>	35.6 (-2.1)	18.4 (-0.8)	12.8 (-1.9)	—
<i>XI</i>	34.1 (0.1)	18.2 (-0.7)	18.2 (-0.3)	—
<i>XII</i>	67.8 (-4.4)	26.8 (0.0)	26.8 (0.0)	—
<i>XIII</i>	41.6	63.0	13.1	—
<i>XIV</i>	75.5	70.8	25.5	—
<i>XXII</i>	63.3 (3.8)	56.9 (-3.0)	12.9 (-0.8)	18.6 (-0.4)
<i>XXIII</i>	42.2	47.1	47.2	21.6
<i>XXV</i>	70.5	137.5	114.9	17.8
<i>XXX</i>	49.8	197.1	27.1	11.3
<i>XXXVI</i>	68.1 (4.0)	54.1 (-3.8)	13.8 (0.3)	61.9 (0.0)
<i>XXXVII</i>	75.8	200.7	23.3	22.2
<i>XXXVIII</i>	73.6	42.6	18.1	20.6
<i>XXXIX</i>	42.3 (-0.8)	26.9 (1.6)	21.8 (-0.5)	21.8 (-0.5)
<i>XL</i>	40.9 (-0.4)	27.0 (0.4)	10.8 (-0.7)	16.0 (-0.5)
<i>XLI</i>	74.8	32.3	16.5	16.5
<i>XLII</i>	47.4	68.3	29.5	29.5
<i>XLIII</i>	46.3	67.8	20.5	13.1
<i>XLIV</i>	73.7	69.6	15.3	20.0
<i>XLV</i>	78.7 (-2.6)	29.1 (-0.1)	18.1 (-1.8)	65.1 (2.6)
<i>IL^b</i>	95.3	198.0	17.9	29.9
<i>L^c</i>	34.2 (-1.2)	24.4 (-1.5)	32.1 (-0.5)	22.4 (-1.2)
<i>LI</i>	74.2	70.4	21.8	—
<i>LXI</i>	81.5	164.8	23.3	22.2
<i>LXII</i>	45.0	77.5	25.4	25.4
<i>LXIII</i>	44.1	71.0	12.9	17.4
<i>LXIV</i>	70.1 (-5.9)	73.4 (-0.1)	13.5 (-0.5)	18.3 (-3.7)
<i>LXIX^d</i>	33.8	24.8	29.6	29.3
<i>LXX^e</i>	34.4 (-1.0)	24.8 (-1.3)	29.9 (-0.2)	29.3 (-0.8)
<i>LXXIV</i>	73.6	69.5	12.0	16.9
<i>LXXV^f</i>	34.4	24.8	29.9	29.3

^a Differences between calculated and observed values are in parentheses; ^b C-6: 5.2; ^c C-6: 13.6 (-1.0); ^d C-6: 27.9; C-7: 22.6; C-8: 22.6; ^e C-6: 32.2 (-0.7); C-7: 22.8 (-0.9); C-8: 13.8 (-0.5); ^f C-6: 27.9; C-7: 29.1; C-8: 11.1; C-9: 18.4.

for sp^3 carbon atoms can be only approximately estimated from ^{13}C NMR data of similar described compounds. These served for estimation of the effect on a methyl carbon atom, induced by replacement of methylhydrogen with hydroxyl (+43.8 ppm) or O-acyl (+45.2 ppm). These values were used for estimation of the shifts of sp^3 carbon atoms in positions 4, 5 or 10. The calculated and found ^{13}C chemical shifts for esters of α,β -unsaturated acids are given in Table IX. The mean deviation of values for the α and β carbon atoms of double bond and sp^3 carbon atoms, calculated according to this procedure, is ± 0.7 ppm (for compounds with accessible experimental data).

The high structural reliability of the ^{13}C chemical shifts, line character of the spectra and wide set of the experimental and calculated data for acyl groups led us to writing a program for automatic identification of the acyl type from the ^{13}C NMR data. The program¹² was written for the ADT 4316 minicomputer in FORTRAN-IV and searches the ester type on the basis of a full set of ^{13}C chemical shifts. It was checked on 70 random-chosen sets of ^{13}C NMR data for sesquiterpenic lactones, containing acyl. The reliability of the acyl structure determination did not depend much on the accuracy of the experimental ^{13}C chemical shifts and for the values ± 0.7 ppm to ± 2.0 ppm it ranged between 90% and 97%. In some cases, acetyl was erroneously identified in the tested molecule, because its data are least characteristic among the acyl data. However, since its identification presents no difficulty in the ^1H NMR spectra (and with knowledge of the elemental formula even in the ^{13}C NMR spectra), this drawback does not devalue the significance of the program.

TABLE VIII

Increments Z_i for chemical shift calculation of α - and β -carbons in acyls of α,β -unsaturated acids

Substituent	$Z_i(\alpha)$			$Z_i(\beta)$		
	<i>gem</i>	<i>cis</i>	<i>trans</i>	<i>gem</i>	<i>cis</i>	<i>trans</i>
CH_3	5.6	-7.3	-6.6	-4.2	15.1	14.2
$\text{CH}(\text{CH}_3)\text{OR}$	16.5 ^a	^b	^b	-6.6 ^a	^b	^b
$\text{CH}(\text{OH})\text{CH}_2\text{OH}$	3.4 ^a	^b	^b	2.1 ^a	^b	^b
CH_2OR	10.1	-7.1	-7.3	-2.8	15.5	16.7
CH_2OCOR	5.8	-5.9	-5.0	1.2	14.0	11.5
$\text{CH}=\text{O}$	^b	^b	-7.5 ^a	^b	^b	18.6 ^a
C_6H_5	^b	^b	-12.5 ^a	^b	^b	12.6 ^a

^a The value of increment was not optimized; ^b the increment was not determined.

TABLE IX

Calculated carbon-13 chemical shifts in acyl groups of α,β -unsaturated carboxylic acids and comparison with accessible experimental data^a

Acyl	C-2	C-3	C-4	C-5
<i>IV</i>	134.3 (-0.7)	125.7 (-1.3)	^b	—
<i>VIII</i>	138.3 (0.5)	127.1 (1.1)	62.0 (0.4)	—
<i>XVII</i>	126.8 (0.0)	144.4 (0.0)	^b	^b
<i>XIX</i>	127.0 (0.1)	140.8 (0.8)	^b	^b
<i>XX</i>	114.8 (-0.3)	159.2 (-0.1)	^b	^b
<i>XXI</i>	127.0 (-0.2)	139.9 (1.4)	^b	^b
<i>XXIV</i>	145.3 (0.0)	123.3 (0.0)	^b	^b
<i>XXVI</i>	114.1	161.7	64.4	^b
<i>XXVII</i>	115.0	159.6	71.5	^b
<i>XXVIII</i>	127.0 (0.1)	142.4 (-0.4)	58.5 (-1.0)	^b
<i>XXIX</i>	132.3 (0.7)	141.4 (-1.3)	^b	56.1 (-0.1)
<i>XXXI</i>	131.5 (0.1)	142.3 (0.2)	^b	64.3 (0.5)
<i>XXXIII</i>	131.5	143.8	^b	64.3
<i>XXXIV</i>	132.1 (0.0)	127.8 (0.0)	^b	^b
<i>XXXV</i>	131.6 (0.1)	143.8 (-1.3)	58.5 (-0.3)	56.6 (-0.2)
<i>XLVI</i>	134.3 (-0.7)	131.1 (1.8)	63.4 (1.2)	—
<i>LIII</i>	128.4 (0.6)	139.7 (-0.5)	61.2 (-1.8)	^b
<i>LIV</i>	145.3	123.3	^b	^b
<i>LV</i>	116.2 (-0.7)	158.2 (0.3)	65.8 (2.0)	^b
<i>LVI</i>	129.3	137.2	59.9	^b
<i>LVII</i>	127.7 (0.2)	145.4 (-0.5)	^b	57.5 (-0.2)
<i>LVIII</i>	127.0 (0.0)	146.2 (-0.8)	^b	65.7 (-0.1)
<i>LIX</i>	133.8	142.6	59.9	56.1
<i>LX</i>	127.2	147.8	58.5	57.5
<i>LXVIII</i>	131.6 (-0.7)	143.8 (1.6)	59.9 (-0.8)	57.5 (-2.1)
<i>LXXI</i>	116.3 (0.0)	142.6 (0.0)	^b	^b
<i>LXXIII</i>	129.5	142.6	59.9	57.5
<i>LXXVI^c</i>	127.0 (0.3)	147.8 (-0.1)	58.3 (-1.1)	58.0 (0.5)
<i>LXXVII^d</i>	127.2	147.8	58.5	57.5
<i>LXXVIII^e</i>	127.7 (0.1)	145.4 (-0.3)	^b	57.5 (0.0)
<i>LXXIX^f</i>	127.2	147.8	58.5	57.5
<i>LXXX^g</i>	127.9	145.3	^b	57.5
<i>LXXXI^h</i>	129.5	142.6	59.9	57.5
<i>LXXXVI</i>	129.3 (0.0)	137.3 (0.0)	59.9 (-1.3)	^b
<i>LXXXVIII</i>	129.3	137.3	59.9	^b

^a Differences between calculated and observed values are in parentheses; ^b the value was not calculated; ^c C-7: 127.0 (0.1); C-8: 140.8 (1.3); ^d C-7: 127.9; C-8: 138.5; ^e C-7: 132.2 (0.5); C-8: 141.3 (-0.6); C-10: 56.1 (-0.1); ^f C-7: 132.2; C-8: 141.3; C-10: 56.1; ^g C-7: 127.9; C-8: 145.3; C-10: 57.5; ^h C-7: 127.9; C-8: 145.3; C-10: 57.5.

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