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Constituents of *Solidago* Species

III.[1] The Constitution and Stereochemistry of Diterpenoids from *Solidago missouriensis* Nutt.

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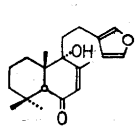
The constitution and stereochemistry of several diterpenoids isolated from root extracts of *Solidago missouriensis* Nutt. are deduced from their spectroscopic and chemical properties. Two of them are *ent*-13-epimanoyl oxide and its 3-oxo derivative; the remaining ones are non-acidic members of the abietane group.

Investigations of the genus *Solidago* belonging to the Compositae family have shown that plants in this genus have an extraordinary ability to produce diterpenoids. The first species to be examined in this respect was the very common Canadian goldenrod *S. canadensis* L.[2] which gives solidagenone (*1*) in very high yield. Since then, *S. serotina* Ait.,[3] *S. altissima* L.,[4] *S. elongata* Nutt.,[5] *S. Shortii* Torr. & Gray [6], and now *S. missouriensis* Nutt. have been investigated and the total number of diterpenoids isolated is not far from thirty. They all belong to the labdane (*2*) or clerodane [7] (*3*) group except for some of the diterpenoids now reported from *S. missouriensis* Nutt. which are abietanes (*4*).



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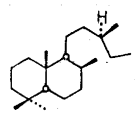

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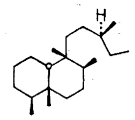

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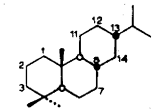

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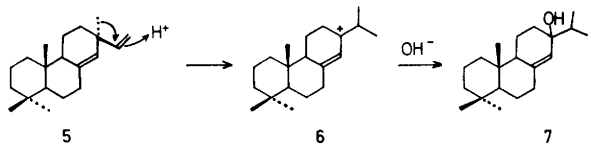
The majority of abietanes found in nature are either resin acids from conifers or diterpenoids with an aromatized ring A or C as found in conifers and labiates.[8,9] In a previous communication [10] we have reported that the abietanes from *S. missouriensis* Nutt. are 7,13-abietadienes. However, we did not exclude the possibility that they were artefacts formed during our work up. We now verify that our assumption was right and that the naturally occurring com-

pounds are indeed 8(14)-abieten-13-ols and as such fit very neatly into the commonly accepted biosynthetic scheme. The abietanes are believed to arise from a rearrangement of pimaradiene (*5*) to the carbonium ion *6* (Scheme 1).[11]



5 6 7

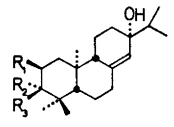
Scheme 1.

Hydroxylation of this ion leads directly to the 13-hydroxy-8(14)-abietenes (*7*) which are enantiomers of the abietenes found in *S. missouriensis* Nutt. In the following they will be designated missourienols.

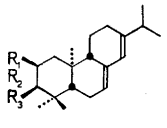
The characteristic features of the allylic alcohol system are firstly that the missourienols do not show a molecular ion peak in their mass spectra, but $M-H_2O$ and $M-C_3H_7$. Secondly, their NMR spectra exhibit the resonance of only one olefinic proton as a rather narrow ($W_{1/2}$ 5 Hz) peak around τ 4.5. The hydroxy group is detected by its absorption in the IR (3440 cm^{-1}) and by a concentration dependent signal around τ 8.7 in the NMR spectrum, which disappears when the solution is shaken with D_2O.

Dehydration of the missourienols under mild acidic conditions furnishes dienes, more precisely heteroannular dienes as indicated by their UV spectra λ_{max} (EtOH) 234 (21 000), 241 (22 800), 249 (15 000) nm.[12] Their NMR spectra have resonances due to two olefinic protons, one narrow ($W_{1/2}$ 4 Hz) at τ 4.2 and one fairly broad ($W_{1/2}$ 9 Hz) at 4.5. The narrow signal is due to H-14 being only allylically coupled whereas H-7, which is vicinally coupled, gives rise to the broader peak. The 7,13-abietadienes were also isolated from the natural material in various amounts.

Missourienol A, $C_{20}H_{32}O_2$, m.p. 82–84°C, which is the major diterpenoid of *Solidago missouriensis*, is a ketone (ν_{max} 1705 cm^{-1}). It has been identified as *ent*-13-hydroxy-8(14)-abieten-3-one (*8*). The NMR spectrum contains, in addition to the peaks due to the allylic alcohol system already mentioned, resonances of three tertiary (τ 8.91, 8.93 and 8.99) and two secondary (9.06, 9.11 $J=7$ Hz) methyl groups. The dehydration product, a heteroannular diene (*9*), $C_{20}H_{30}O$ (*vide supra*), is still an unconjugated six ring ketone (ν_{max} 1712 cm^{-1}). Its NMR spectrum in addition to the resonances due to the olefinic protons H-7 and H-14 shows three tertiary (τ 8.86, 8.91, 8.97) and two secondary (8.97 $J=7$ Hz) methyl groups. The isopropyl methyl groups show chemical shift equivalence in all the dienes while they are non-equivalent in all the missourienols. This ketone yields on Wolff-Kishner reduction a hydro-



8 R_1=H, R_2R_3=O
14 R_1=R_2=H, R_3=OH
15 R_1=OAc, R_2=R_3=H
11 R_1=R_2=R_3=H



9 R_1=H, R_2R_3=O
12 R_1=R_2=H, R_3=OH
16 R_1=OAc, R_2=R_3=H
17 R_1=OH, R_2=R_3=H
10 R_1=R_2=R_3=H

carbon $C_{20}H_{32}$ (*10*) which is identical with a compound also isolated from the plant material and also has spectroscopic and chromatographic properties similar to a synthetic sample of 7,13-abietadiene. However, its optical rotation $[\alpha]_D^{24} + 127°$ suggests that it belongs to the *enantio* series. The reported value of 7,13-abietadiene isolated from *Pinus sibirica* is $[\alpha]_D^{20} - 75°$ [13] and synthetic $[\alpha]_D^{21} - 86°$.[14] We consider the naturally occurring *ent*-7,13-abietadiene (*10*) to be an artefact. However, we were unable to isolate the corresponding missourienol (*11*).

The position of the keto function in missourienol A (*8*) and the corresponding diene (*9*) was deduced as follows. Since the dienone (*9*) was not a conjugated ketone, only positions 1, 2, 3, and 11 were possible. LAH reduction of the dienone yields the alcohol (*12*). The NMR spectrum of this compound exhibits the carbinyl proton at τ 6.76 as a doublet of doublets ($J = 8.5$ and 6.0 Hz) thus revealing its axial nature and in turn the equatorial nature of the hydroxy function. Moreover, it shows that it is flanked by only two protons and consequently C-1 and C-3 are the two remaining positions for the keto function. Benzene induced solvent shifts lead to a choice of the latter. The Δ-values $\Delta = \tau(\text{benzene}) - \tau(CDCl_3)$ for the methyl group resonances in the NMR spectrum of missourienol A, -0.07 and -0.02 (isopropyl methyl groups), $+0.28$ (C-10 Me), $+0.19$ (C-4 axial Me), and -0.03 ppm (C-4 equatorial Me) accord only with a C-3 keto function.[15,16]

Treatment of the dieneol (*12*) with PCl_5 [17] yielded a dehydration product which is a triene $C_{20}H_{30}$. Its NMR spectrum showed resonances due to two secondary (τ 8.98), one tertiary (9.37) and two olefinic (8.29, 8.39) methyl groups and no additional olefinic hydrogen. This hydrocarbon, therefore, must be the rearrangement product (*13*) and thus is the conclusive evidence for the hydroxy group being at C-3 and equatorial. The remarkable upfield shift of the tertiary C-10 methyl group must be due to the disappearance of the 1,3 diaxial collision with the axial C-4 methyl group.

Missourienol B (*14*), $C_{20}H_{34}O_2$, m.p. 155–156°C is a secondary alcohol. Its dehydration product (*12*) is identical with the reduction product of the dienone (*9*).

The last of the 8(14)-abietenes in *Solidago missouriensis* Nutt. is an oily secondary acetate, missourienol C (*15*), $C_{22}H_{36}O_3$ (IR 1739 cm^{-1}, NMR τ 8.05 3 H *s*). The carbinyl proton in the NMR spectrum (Fig. 1) resonates at τ 5.12 as a triplet of triplets ($J = 12$ and 4 Hz) thus indicating that it is axial and consequently that the acetoxy group has equatorial stereochemistry. Furthermore, the multiplicity of this peak demonstrates that it is flanked by two methylene groups. Consequently, on the basis of a 8(14)-abietene skeleton, the only possible position of attachment is at C-2.

Its dehydration product the dieneacetate (*16*) yielded on hydrolysis an oily dieneol (*17*) $C_{20}H_{32}O$. In its NMR spectrum the methine proton gives resonance at τ 6.07 (*t,t*) and is thus moved upfield by nearly one ppm compared with the corresponding proton of the dieneacetate (τ 5.08).

Hydrogenation of missourienol A (*8*) furnished a hydrogenolysis product $C_{20}H_{32}O$ (*18*). The mass spectrum of this ketone exhibits a prominent molecular ion peak (81 %) in contrast to the mass spectra of the missourienols (*vide supra*). The NMR spectrum contains a peak due to the olefinic proton (H-14)

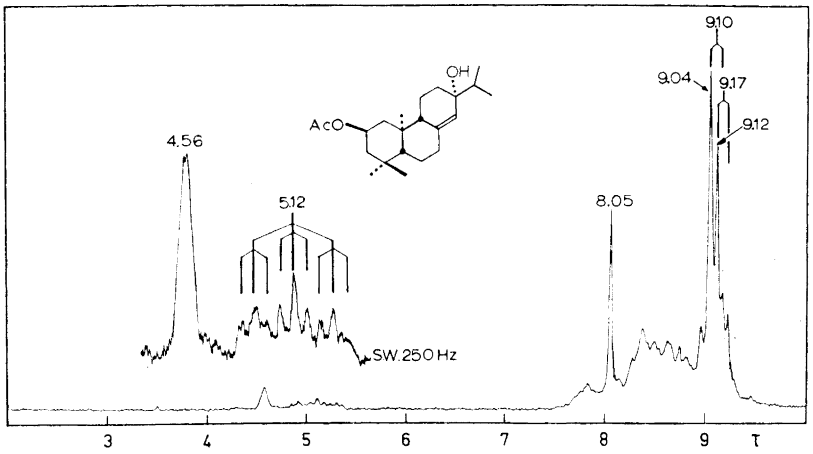


Fig. 1. The 60 MHz spectrum of Missourienol C in CCl_4 solution.

at τ 4.50 slightly broadened ($W_1/_2$ 7 Hz) in comparison with the corresponding peak in the NMR spectrum of the 8(14)-en-13-ols.

The final point to be settled concerning the missourienols is the stereochemistry at C-13. We have not been able to solve this problem on the basis of the data so far presented. However, the $Eu(DPM)_3$ shift in the NMR spectrum of missourienol A (*8*) suggested an axial (α) hydroxy group. The shift values observed for the methyl groups at the molar ratio substrate/complex 0.5 are: 2.94, 2.66 (isopropyl methyls), 2.54, 1.63 and 1.39 ppm.

The two isopropyl methyl groups and one tertiary methyl group show considerably larger downfield shifts than the two remaining methyl groups. Assuming that the complexing takes place preferentially at the hydroxy group,[18,19] it seems reasonable that the methyl group at C-10 will suffer a relatively larger shift than the geminal methyls at C-4 when the C-13 hydroxyl is axial (α) than when it is equatorial. An equatorial hydroxy group would probably cause a more similar shift in all the three tertiary methyl groups. We consider, however, this final question of stereochemistry not to be satisfactorily answered.

The two remaining diterpenoids in *S. missouriensis* are labdanes, more specifically manoyl oxides. Previously four not further oxygenated manoyl oxides have been described, one of them in both the normal and the enantiomeric form. Their melting points and optical rotations are given in Table 1.

The not further oxygenated manoyl oxide we have isolated had $[\alpha]_D^{24} - 31°$ and melted at 97 – 98°C. It is thus *ent*-13-epimanoyl oxide (*19*) or more precisely [7] *ent*-8,13β-epoxy-14-labdene. The NMR spectrum exhibits, beside resonances due to five tertiary methyl groups (8.86, 8.97, 9.16, 9.24 and 9.30), the characteristic ABC pattern of a vinyl group τ_A 4.03, τ_B 5.08, τ_C 5.14, $J_{AB} = 18.0$, $J_{AC} = 10.5$ and $J_{BC} = 1.3$ Hz). According to Wenkert *et al.*[24] there exists a characteristic difference between the appearance of this ABC pattern in the NMR spectra of manoyl and 13-epimanoyl oxide. This difference is

Table 1. Melting points and optical rotations of the known manoyl oxides.

	M.p.	$[\alpha]_D$	Ref.
Manoyl oxide	24.5 – 26°	+23°	20
13-Epimanoyl oxide	100.5 – 101.5°	+35.3°	21
ent-13-Epimanoyl oxide	99°	−35.8°	22
8-Epimanoyl oxide	44 – 45°	−9.5°	23
8,13-Diepimanoyl oxide	79 – 84°	+23.4	23

mainly due to the chemical shift difference between H_B and H_C which is 0.21 ppm in manoyl oxide and 0.06 ppm in 13-epimanoyl oxide. The corresponding value of our oxide is 0.06 and the ABC part of our NMR spectrum is superimposable with that of 13-epimanoyl oxide [24] (see Fig. 2).

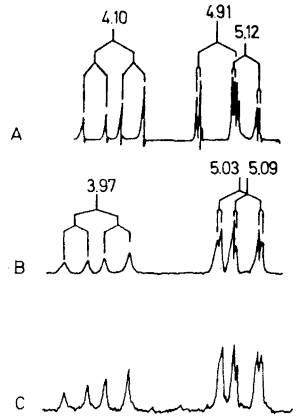
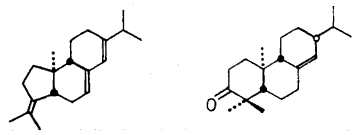
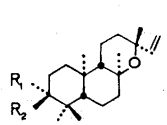


Fig. 2. The characteristic vinyl ABC pattern in the 60 MHz NMR spectra of manoyl oxide (A) and 13-epimanoyl oxide (B) redrawn after Wenkert *et al.*[24] compared with the corresponding ABC pattern in the NMR spectrum of 13-epimanoyl oxide (C) isolated from *S. Missouriensis*. The spectra are redrawn here due to earlier obscurities [21,24] and analyzed according to ABX rules.

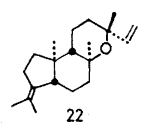
The further oxygenated manoyl oxide ($C_{20}H_{32}O_2$, m.p. 94 – 95°C, $[\alpha]_D^{23}$ −53°) is a ketone (IR 1705 cm^{-1}). It was converted to *ent*-13-epimanoyl oxide (*19*) on Wolff-Kishner reduction. The strong peaks in the mass spectrum at *m/e* 206 and *m/e* 191 arising from cleavage of bond C-9, C-11, and the C-8 oxide bond indicate that the keto group is in ring A or B.



13 18



19 $R_1=R_2=H$
20 $R_1R_2=O$
21 $R_1=OH, R_2=H$



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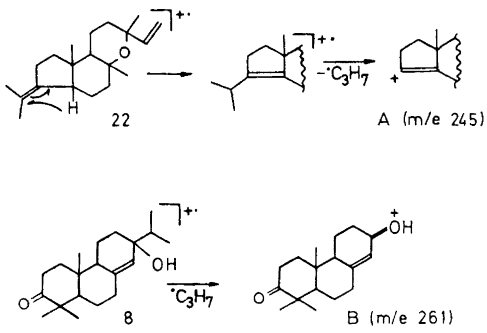
The values obtained from the benzene induced solvent shifts in the NMR spectrum accord only with *ent*-8,13β-epoxy-14-labden-3-one (*20*).[15] τ(benzene) $-\tau(CDCl_3)$ – +0.25 (C-10 Me), +0.03 (C-8 Me), +0.04 (C-13 Me), +0.08 (C-4 axial Me) and −0.17 ppm (C-4 equatorial Me).

Furthermore, on LAH reduction an alcohol (*21*) was produced. The NMR spectrum revealed that its hydroxy group is equatorial (τ 6.78 1H *dd*, $J = 6$ and 9 Hz). Consequently, treatment with PCl_5 yielded the rearranged product *22*. The NMR spectrum of this dienoxide also showed the remarkable upfield shift for the C-10 methyl group (τ 9.50) as observed for compound *1*.

The C-13 epimer of this oxide in the normal series, 8,13-epoxy-14-labden-3-one, has previously been isolated from *Xylia dolabriformis*.[17]

The mass spectra

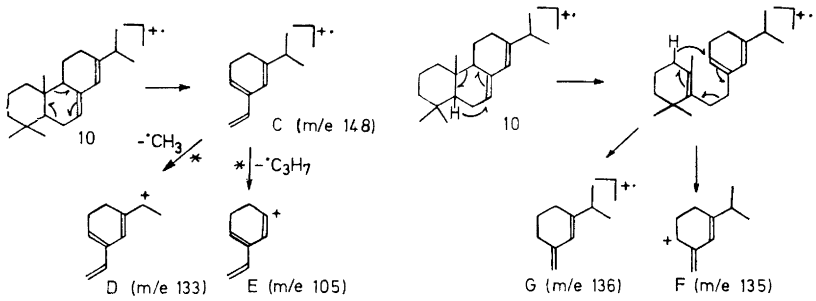
In the discussion of the mass spectra the present diterpenoids are preferably divided into three groups, the 8,13-oxides, the 8(14)-abieten-13-ols, and the 7,13-abietadienes. The spectra of the diterpenoids in the first group which comprises *19*, *20*, *21*, and *22* are thoroughly discussed in the review by Enzell and Ryhage.[25] The fragmentation patterns in our spectra are easily explainable on the basis of the principles of Enzell and Ryhage. However, the base peak in their spectrum of 3-ketomanoyl oxide (*m/e* 81, $C_6H_9^{+\cdot}$) is of minor importance in our spectrum of the 13-epimer. In the spectrum of the rearrangement product with exocyclic double bond (*22*), loss of a C_3H_7 radical is important. A prominent peak at *m/e* 245 may be explained as ion *A* (Scheme 2).



Scheme 2.

As previously mentioned the dominating feature in the mass spectral behaviour of the missourienols (*8*), (*14*), and (*15*) is their immediate loss of $\cdot C_3H_7$ or water, thus missing the molecular ion peak. The result is ions like *B* (Scheme 2) and simply the corresponding 7,13-dienes ($M - H_2O$). Consequently the remaining spectra after loss of water are almost identical with the spectra of the dienes.

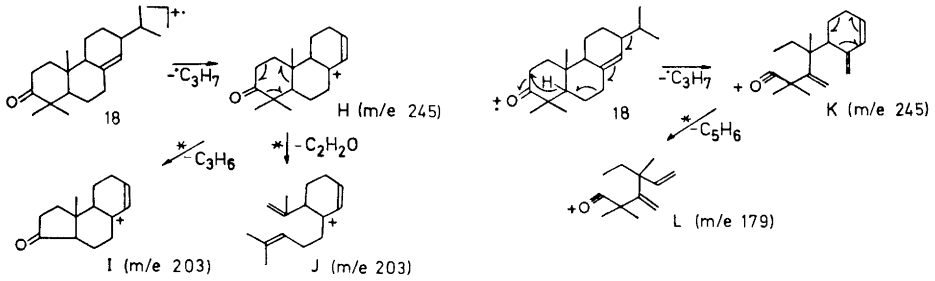
In contrast to the missourienols the abietadienes show remarkably abundant molecular ion peaks in their mass spectra. Apart from this the spectra are



Scheme 3.

characterized by peaks due to ions such as $C-G$ (Scheme 3). Ions due to loss of an isopropyl radical are also visible in the spectra. Particularly abundant is this ion in the spectrum of the rearrangement product (*13*) similar to the corresponding oxide (*22*) (see Scheme 2).

The ketone (*18*) lacking the C-13 hydroxy group exhibits a fragmentation pattern markedly different from the missourienols. As in the latter spectra the base peak of *18* is due to loss of an isopropyl radical. However, the molecular ion is now of high abundance (70 %). Peaks of importance in the spectrum



Scheme 4.

may be accounted for by ions $H-L$ (Scheme 4). Ion L seems to be of particular significance (45 %). Most reactions leading to these ions are accompanied by metastable transitions (marked by an asterisk).

EXPERIMENTAL

NMR spectra were recorded on a Varian A-60A spectrometer in CCl_4 or $CDCl_3$ solutions with TMS as internal standard. UV spectra were recorded on a Hitachi 124 spectrophotometer in 96 % ethanol unless otherwise stated. IR spectra were recorded on a Perkin-Elmer 257 spectrophotometer. Mass spectra were run on an AEI MS 902 equipped with a PDP 8 computer using direct inlet probe, ion source temperature 150 – 180°C and electron bombardment energy 70 eV. Optical rotations were measured on a Zeiss circular polarimeter in $CHCl_3$ solutions. Solvents for spectroscopy were *p.a.* grade. For GLC was used Perkin-Elmer F-11 and Aerograph Hy-Fi 600 instruments. Melting points are uncorrected. TLC plates were prepared from silica gel G (Merck) and silica gel $PF_{254+366}$ (Merck). Silica gel 70 – 325 mesh (Merck) and neutral alumina grade III (Woelm) was used for column chromatography. Solvents were either analytical grade or distilled. (% e-lp) refers to % ether in light petroleum.

Isolation of diterpenoids

Roots of *S. missouriensis* Nutt. were collected at Bergianska Trädgården, Stockholm. The material was washed, dried, ground and Soxhlet extracted for 5 h with dry, peroxide-free, distilled ether. Evaporation of the solvent yielded a pale yellow oil (9.3 g) which was separated into 12 crude fractions by chromatography on alumina. Fractions 1 – 8 (0 – 50 % e-lp) yielded diterpenoids, fractions 9 – 12 (0 – 50 % methanol in ether) yielded no terpenoids on methylation and acetylation.

ent-*7,13-Abietadiene* (*10*) was isolated as an oil (200 mg) from the first 3 fractions (0 – 10 % e-lp). Rechromatography on TLC (light petroleum) yielded an oil which was pure on GLC. $[\alpha]_D^{24}$ +127° (*c* 2.05), λ_{max} (hexane) 234 (21 000), 241 (22 800), and 249 (15 600) nm. NMR signals (CCl_4) at τ 4.32 (*m*, 1H; H-14), 4.68 (*m*, 1H; H-7), 9.01 (*d*, $J = 7$ Hz, 6H; isopropyl methyls, 9.10, 9.13 and 9.23 (all, *s*, 3H; 3 tertiary methyls). M^+ 272.2498, calc. for $C_{20}H_{32}$ 272.2504.

ent-*13-Epimanoyloxide* (ent-*8,13β-epoxy-14-labdene*) (*19*) was isolated from the already mentioned TLC plates as an oil (54 mg) which was pure on GLC. Crystallization twice from methanol yielded white plates, m.p. 97 – 98°C, $[\alpha]_D^{24}$ −31° (*c* 1.95), ν_{max} (KBr) 1100 (ether), 990 and 920 cm^{-1} (vinyl). NMR signals (CCl_4) at τ 4.03, 5.08, 5.14 (ABC, $J_{AB} = 18.0$, $J_{AC} = 10.5$, and $J_{BC} = 1.3$ Hz, 3H; vinyl), 8.86, 8.97, 9.16, 9.24 and 9.30 (all, *s*, 3H; 5 tertiary methyls). M^+ 290.2631, calc. for $C_{20}H_{34}O$ 290.2610.

ent-*8,13β-Epoxy-14-labden-3-one* (*20*) was isolated from fraction *3* after recromatography on alumina (0 – 30 % e-lp) and TLC (30 % e-lp) as an oil (254 mg). Two crystallizations from methanol gave long white needles, m.p. 94 – 95°,C $[\alpha]_D^{23}$ −53° (*c* 2.47), ν_{max} (KBr) 1705 (ketone), 990 and 920 cm^{-1} (vinyl). NMR signals (CCl_4) at τ 4.02, 5.06, 5.12 (ABC, 3H; vinyl), 8.79, 8.84, 8.87, 9.04 and 9.18 (all, *s*, 3H; 5 tertiary methyls). M^+ 304.2410, calc. for $C_{20}H_{32}O_2$ 304.2402.

ent-*7,13-Abietadien-2α-ol acetate* (*16*) was isolated from fractions 2 – 4 (5 – 20 % e-lp) after further purifications on TLC (30 % e-lp) as a colourless oil (280 mg). $[\alpha]_D^{27}$ +111° (*c* 6.1), λ_{max} 234 (18 600), 240 (19 400) and 248 (13 200) nm, ν_{max} (neat) 1740 and 1712 cm^{-1} (ester). NMR signals (CCl_4) at τ 4.30 (*m*, 1H; H-14), 4.65 (*m*, 1H; H-7), 5.08 (*tt*, $J_{2\beta,1\alpha} = J_{2\beta 3\alpha} = 12$ Hz and $J_{2\beta 1\beta} = J_{2\beta 3\beta} = 4$ Hz, 1H; H-2β), 8.06 (*s*, 3H; acetoxy CH_3), 8.97, 9.07, 9.12 (all, *s*, 3H; 3 tertiary methyls) and 9.00 (*d*, $J = 7$ Hz, 6H; isopropyl methyls). M^+ 330.2576, calc. for $C_{22}H_{34}O_2$ 330.2559.

ent-*7,13-Abietadien-3-one* (*9*) was isolated from fractions 2 – 4 after further purifications on TLC (30 % e-lp) as an oil (470 mg). $[\alpha]_D^{27}$ +100° (*c* 13.3), λ_{max} 234 (16 400), 240 (17 600), and 248 (12 400) nm, ν_{max} (neat) 1712 cm^{-1} (ketone). NMR signals (CCl_4) at τ 4.24 (*m*, 1H; H-14), 4.62 (*m*, 1H; H-7), 7.5 (*m*, 2H; 2 H-2), 8.93, 9.00, 9.00 (all, *s*, 3H; 3 tertiary methyls) and 8.98 (*d*, $J = 7$ Hz, 6H; isopropyl methyls). M^+ 286.2299, calc. for $C_{20}H_{30}O$ 286.2297.

ent-*7,13-Abietadien-3β-ol* (*12*) was isolated as a colourless oil (48 mg) from fraction 6 (40 % e-lp) after further purifications on TLC (30 % e-lp). $[\alpha]_D^{25}$ +108° (*c* 2.3), ν_{max} (neat) 3400 cm^{-1} (bonded OH). NMR signals ($CDCl_3$) at τ 4.19 (*m*, 1H; H-14), 4.57 (*m*, 1H; H-7), 6.76 (*d d*, $J_{3\alpha 2\beta} = 8.5$ and $J_{3\alpha 2\alpha} = 6.0$ Hz, 1H; $H_{3\alpha}$), 9.00 (*d*, $J = 7$Hz, 6H: isopropyl methyls), 9.04, 9.12 and 9.21 (all, *s*, 3H; 3 tertiary methyls). M^+ 288.2457, calc. for $C_{20}H_{32}O$ 288.2453.

Missourienol C (ent-*2α-acetoxy-8(14)-abieten-13-ol)* (*15*) was iaolated from fractions 4 and 5 (20 – 30 % e-lp) by rechromatography on alumina. Fractions eluted with 30 % ether in light petroleum yielded a colourless oil (90 mg), pure on TLC, $[\alpha]_D^{26}$ +7° (*c* 1.67), ν_{max} (CCl_4) 3620 (free OH), 3450 (bonded OH), 1735, 1245 (ester) and 1660 cm^{-1} (trisubstituted double bond). NMR signals at τ 4.56 (*m*, 1H; H-14) 5.12 (*t t*, $J_{2\beta 3\alpha} = J_{2\beta 1\alpha} = 12$ and $J_{2\beta 3\beta} = J_{2\beta 1\beta} = 4$ Hz, 1H; H-2β), 8.05 (*s*, 3H; acetoxy CH_3), 8.70 (D_2O exchangeable, hydroxyl H), 9.04, 9.04, 9.12 (all, *s*, 3H; 3 tertiary methyls), 9.10 and 9.17 (both, *d*, $J = 7$ Hz, 3H; isopropyl methyls). $(M-18)^+$ 330.2570, calc. for $C_{22}H_{34}O_2$ 330.2559, $(M-43)^+$ 305.2115, calc. for $C_{19}H_{29}O_3$ 305.2117.

Missourienol A (ent-*13-hydroxy-8(14)abieten-3-one)* (*8*) crystallized from fraction 4. Two recrystallizations from 50 % ether in CCl_4 yielded white crystals (700 mg), m.p. 80 – 84°C, $[\alpha]_D^{25}$ −3° (*c* 2.25), ν_{max} ($CHCl_3$) 3610 (free OH), 3470 (bonded OH), 1705 (ketone) and 1660 cm^{-1} (trisubstituted double bond). NMR signals ($CDCl_3$) at τ 4.50 (*m*, 1H; H-14), 7.39 (*m*, 2H; 2 H-2), 8.70 (D_2O exchangeable, hydroxyl H), 8.92, 8.9,2 8.99 (all, *s*, 3H; 3 tertiary methyls), 9.06 and 9.11 (both, *d*, $J = 7$ Hz, 3H; isopropyl

methyls). $(M-18)^{+\cdot}$ 286.2296, calc. for $C_{20}H_{30}O$ 286.2297, $(M-43)^{+}$ 261.1847, calc. for $C_{17}H_{25}O_2$ 261.1854. Workup of fractions 6–8 yielded more missourienol A (1110 mg total).

Missourienol B (ent-*8(14)-abietene-3β,13-diol)* (*14*) crystallized from fraction 7 (50 % e-lp). White crystals (60 mg) recrystallized from ether, m.p. 155–156°C, $[\alpha]_D^{26}$ −47° (*c* 1.65), ν_{max} (KBr) 3400 (bonded OH) and 1670 cm^{-1} (trisubstituted double bond). NMR signals ($CDCl_3$) at τ 4.53 (*m*, 1H, H-14), 6.72 (*d d*, $J_{2\beta 3\alpha}=12$ and $J_{2\alpha 3\alpha}=4$ Hz, 1H; H-3α), 8.63 (D_2O exchangeable, hydroxyl H), 8.99, 9.18, 9.21 (all, *s*, 3H; 3 tertiary methyls), 9.09 and 9.13 (both, *d*, $J=7$ Hz, 3H; isopropyl methyls). $(M-18)^{+\cdot}$ 288.2452, calc. for $C_{20}H_{32}O$ 288.2453, $(M-43)^{+}$ 263.2032, calc. for $C_{17}H_{27}O_2$ 263.2011.

Dehydration of missourienols. The missourienols A, B and C were dehydrated by chromatography over silica (e-lp), yielding the abietadienes (*9*), (*12*), and (*16*), respectively. Missourienol A (45 mg) was refluxed with 1 % *p*-toluenesulphonic acid in methanol (7 ml) for 4 h, yielding abietadien-3-one (*9*) (36 mg) after workup and purification on TLC. The identity of the dehydration products to the abietadienes from the plant was established by IR, UV, NMR, MS, and mixed TLC.

Wolff-Kishner reduction of ent-*7,13-abietadien-3-one* (*9*). The ketone (65 mg) and 80 % hydrazine hydrate (400 mg) were heated in refluxing diethylene glycol (2 ml) for 5 h, and the temperature raised to 220°C during 6 h. After cooling, KOH (500 mg) was added, and refluxing was continued for 3 h. After cooling, dilution with water and extraction with ether, the crude product was purified on TLC, yielding abietadiene (31 mg). $M^{+\cdot}$ 272.2503, calc. for $C_{20}H_{32}$ 272.2504.

Abietadiene from abietinol. A sample of abietinol prepared from abietic acid was purified by chromatography. Pure abietinol (272 mg) in pyridine (1 ml) was added to a solution of CrO_3 (275 mg) in pyridine (6 ml), dropwise with stirring. The reaction mixture was left for 24 h at 20°C, water was added and the crude aldehyde extracted with ether. The aldehyde (154 mg) was pure on TLC and showed an aldehyde proton at 0.72 τ. It yielded abietadiene (111 mg) on Wolff-Kishner reduction as above. The NMR spectrum was identical with that of the abietadiene from the plant. $M^{+\cdot}$ 272.2488, calc. for $C_{20}H_{32}$ 272.2504.

The two synthetic abietadienes and the abietadiene from the plant material exhibited identical properties on mixed TLC on ordinary and $AgNO_3$ treated plates.

Reduction of ent-*7,13-abietadien-3-one* (*9*). The ketone (72 mg) and excess LAH in anhydrous ether (15 ml) were refluxed for 2 h. Aqueous ether and then water were added, the product was extracted with ether and purified on TLC (40 % e-lp), yielding *ent*-7,13-abietadien-3β-ol (57 mg), identical with that from the plant by NMR, MS and TLC. $M^{+\cdot}$ 288.2453, calc. for $C_{20}H_{32}O$ 288.2453.

Retropinacol rearrangement. ent-7,13-Abietadien-3β-ol (*12*) (57 mg) in light petroleum (10 ml) was shaken with PCl_5 (87 mg) for 10 min at 20°C. The solution was filtered, washed with aqueous 2 N NaOH and then water, dried and purified on TLC (10 % e-lp), yielding the triene *13* (28 mg). $[\alpha]_D^{25}$ +136° (*c*. 0.93), NMR signals (CCl_4) at τ 4.22 (*m*, 1H; H-14), 4.68 (*m*, 1H; H-7), 8.28, 8.39 (both, *m*, 3H; isopropylidene methyls), 8.97 (*d*, $J=7$ Hz, 6H; isopropyl methyls) and 9.37 (*s*, 3H; C-10 CH_3). $M^{+\cdot}$ 270.2352, calc. for $C_{20}H_{30}$ 270.2347.

Hydrolysis of ent-*7,13-abietadien-2α-ol acetate* (*16*). The acetate (97 mg) was heated in refluxing 1.5 N methanolic KOH (5 ml) for 2 h. The mixture, after standing for 12 h at 20°C, was concentrated, diluted with water, extracted with ether, and purified on TLC (50 % e-lp), yielding *ent*-7,13-abietadien-2α-ol (*17*) as an oil (57 mg), pure on TLC. ν_{max} (CCl_4) 3610 (free OH) and 3300 cm^{-1} (bonded OH). NMR signals ($CDCl_3$) at τ 4.18 (*m*, 1H; H-14), 4.53 (*m*, 1H; H-7), 6.07 (*t t*, $J_{2\beta 1\alpha}=J_{2\beta 3\alpha}=12$ and $J_{2\beta 1\beta}=J_{2\beta 3\beta}=4$ Hz, 1H; H-2β), 8.98 (*d*, $J=7$ Hz, 6H; isopropyl methyls), 9.05, 9.05 and 9.16 (all, *s*, 3H; 3 tertiary methyls). M^{+} 288.2450, calc. for $C_{20}H_{32}O$ 288.2453.

Hydrogenation of missourienol A. The ketone (21 mg) in ethanol (5 ml) was hydrogenated with 10 % Pd on alumina as catalyst. Filtration, evaporation of the solvent, extraction with ether and purification on TLC (30 % e-lp) yielded *ent*-8(14)-abieten-3-one (*18*) (14 mg), $M^{+\cdot}$ 288.2457, calc. for $C_{20}H_{32}O$ 288.2453.

Reduction and retropinacol rearrangement of ent-*8,13β-epoxy-14-labden-3-one* (*20*). The ketone (72 mg) was reduced with LAH and worked up as above, yielding the alcohol *21* (69 mg). NMR signals ($CDCl_3$) at τ 3.92, 5.03, 5.07 (ABC, 3H; vinyl), 6.77 (*d d*, $J_{3\alpha 2\beta}=9$ and $J_{3\alpha 2\beta}=6$ Hz, 1H; H-3α), 8.77, 8.87, 9.02, 9.24 and 9.24 (all, *s*, 3H; 5 tertiary methyls).

$M^{+\cdot}$ 306.2545, calc. for $C_{20}H_{34}O_2$ 306.2559. The alcohol (69 mg) was heated with PCl_5 (99 mg) in light petroleum (10 ml) and worked up as above, yielding the ether *22* (43 mg), pure on TLC (10 % e-lp). $[\alpha]_D^{25}$ −13° (*c* 1.00), ν_{max} (CCl_4) 1080 (ether), 970 and 915 cm^{-1} (vinyl). NMR signals (CCl_4) at τ 3.97, 5.08, 5.13 (ABC, 3H; vinyl), 8.30, 8.43 (both, *m*, 3H; isopropylidene methyls) 8.81, 8.93 (both, *s*, 3H; 2 tertiary methyls) and 9.50 (*s*, 3H; C-10 CH_3). $M^{+\cdot}$ 288.2475, calc. for $C_{20}H_{32}O$ 288.2453.

Wolff-Kishner reduction of ent-*8,13β-epoxy-14-labden-3-one* (*20*). The ketone (55 mg) was reduced and worked up as above, yielding an oil (52 mg) pure on TLC (10 % e-lp). The product was identical with *ent*-13-epimanoyloxide (*19*) isolated from the plant (TLC, GLC). $M^{+\cdot}$ 290.2612, calc. for $C_{20}H_{34}O$ 290.2610.

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