

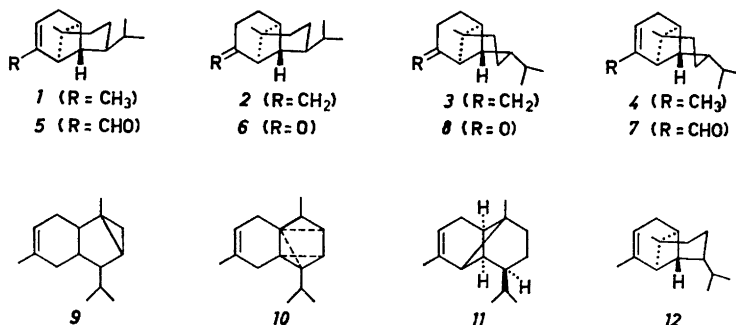
β -Copaene and β -Ylangene, Minor Sesquiterpenes of the Wood of *Pinus silvestris* L. and of Swedish Sulphate Turpentine*

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The new sesquiterpene β -copaene (2), one of the minor sesquiterpenes occurring in the wood of *Pinus silvestris* L. and in Swedish sulphate turpentine has been shown to possess the assigned structure by partial synthesis from copaene (1). The structure of β -ylangene (3),⁴ present in the same sources, has been confirmed by an analogous correlation with ylangene (4).

During an investigation of the high-boiling neutral constituents of the wood of Scots pine (*Pinus silvestris* L.) and of Swedish sulphate turpentine, the three closely related sesquiterpenes copaene (1), β -copaene (2), and β -ylangene (3) were isolated.^{1,2} It was pointed out² that the copaene isolated was possibly contaminated with ylangene (4). These sesquiterpenes were present in relatively small amounts, the major C₁₅ hydrocarbons of Scots pine wood being muurolenes.³



β -Copaene contained a vinylidene group as demonstrated by the consumption of one mole of hydrogen on hydrogenation (platinum, acetic acid) and by the formation of formaldehyde and a monoketone on ozonolysis. The con-

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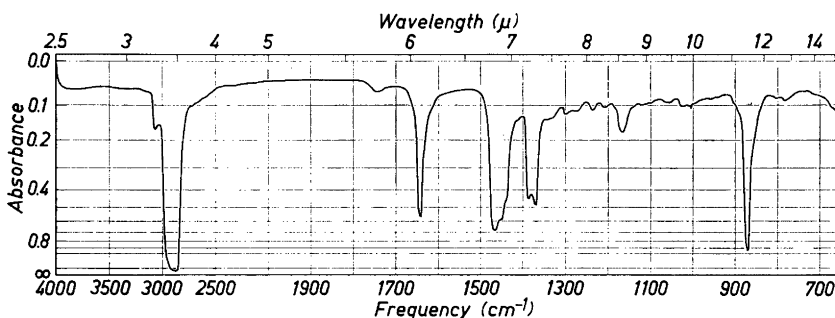


Fig. 1. IR spectrum of β -copaene (2) as liquid film (0.025 mm).

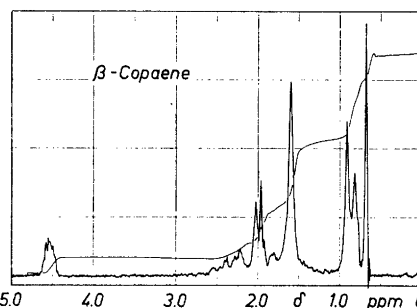


Fig. 2. NMR spectrum of β -copaene (2).

version of β -copaene to (–)-cadinene dihydrochloride and comparison of the products obtained on hydrogenation with those formed on hydrogenation of copaene indicated that the compound was a double bond isomer of copaene. The compositions of the saturated products were almost identical as indicated by comparing their IR spectra, gas-liquid chromatography (GLC) patterns and specific rotations. The ratio of the two stereoisomeric products detected by GLC was slightly different for copaene and β -copaene.

The IR and NMR spectra of β -copaene (Figs. 1 and 2, respectively) support the above conclusions. In the IR spectrum of β -copaene (Fig. 1) the absorption bands characteristic of the exocyclic double bond appear at 3065, 1642, and 870 cm^{-1} . According to the NMR spectrum (Fig. 2) β -copaene contains one isopropyl group, one methyl group linked to a saturated carbon atom bearing no hydrogen atom, and two olefinic protons.

Final proof for the assignment of structure (2) to β -copaene was obtained by the conversion of copaene (1) into β -copaene as follows. Copaene was oxidized with selenium dioxide to give copaenal (5), which was reduced by the Wolff-Kishner procedure affording β -copaene (2) (*cf.* Wolff-Kishner reduction of myrtenal to β -pinene⁵). The IR spectra and the behaviour on GLC and argentative thin layer chromatography (Ag-TLC) of the synthetic and natural β -copaene were identical. Ozonolysis of the two samples gave the same ketone (6), 2,4-dinitrophenylhydrazone, m.p. 164°.

For the above conversion of copaene to β -copaene, an authentic sample of the former compound was used.* When apparently pure (IR, GLC, Ag-TLC) copaene obtained from Swedish sulphate turpentine was treated in the same way, a mixture of hydrocarbons was obtained. According to GLC it consisted of β -copaene and β -ylangene (ratio 9:1). This supported the suspicion² that the high rotation of the copaene sample isolated from Swedish sulphate turpentine could be due to contamination with (+)-ylangene.

It has been proposed⁴ that β -ylangene possesses structure (3) on the basis of spectral data, hydrogenation experiments and its conversion to ylangene by acid treatment. This structural assignment has now been confirmed in a manner analogous to that described above for the proof of the structure of β -copaene.

Ylangene (4)* was oxidized by selenium dioxide to ylangenal (7), which, on Wolff-Kishner reduction, gave β -ylangene (3), identical with β -ylangene from *Pinus silvestris*. Ozonolysis of the synthetic and natural products gave formaldehyde and identical ketones (8); 2,4-dinitrophenylhydrazones, m.p. 189°.

Comments on the identities of copaene and ylangene. Copaene has been characterized by conversion to a ketoacid (semicarbazone, m.p. 221°)⁶ by ozonolysis, and to a diol, m.p. 73°,⁷ by osmium tetroxide oxidation. On treatment with hydrogen chloride copaene has been reported to yield mainly cadinene dihydrochloride (*e.g.* Ref. 8). Muurolene dihydrochloride is a minor product (see experimental).

Ylangene has apparently not been similarly characterized. It has been reported not to give a crystalline hydrochloride.⁹

Proper identification of copaene and ylangene on the basis of published IR data appears to be difficult. The IR spectrum of "copaene" published in "Die Terpene I"^{10a} originated from a hydrocarbon, which was different¹¹ from copaene (1) obtained by Büchi *et al.*⁷ and by Sukh Dev *et al.*⁸ The same collection of spectra included an IR spectrum^{10b} of ylangene. This hydrocarbon was obviously impure, as its IR spectrum was found to be different from that of pure ylangene isolated by Motl.

Hunter and Brogden reported¹² that the IR spectra of copaene and ylangene are very similar. However, according to these authors, the hydrocarbons may be distinguished by their absorption bands at 780 and 790 cm^{-1} , respectively, and by GLC.

As mentioned above, "copaene" from Swedish sulphate turpentine was probably a mixture of copaene and ylangene, although, according to IR and GLC, it appeared to be homogeneous. The IR and GLC comparisons reported by Hunter and Brogden¹² were therefore repeated. As briefly mentioned in a preceding communication² copaene (sample from G. Büchi), ylangene (sample from O. Motl), and a mixture (ratio 1:1) of these two hydrocarbons were compared. It was found that the difference in the positions of the respective absorption bands of the two compounds at *ca.* 790 cm^{-1} were not great enough to allow the detection of a minor quantity of one of the hydrocarbons in a mixture consisting mainly of the other one. The band of copaene in the above

* I thank Prof. G. Büchi and Dr. O. Motl for generous gifts of copaene and ylangene, respectively.

region appeared at a *higher* frequency (784 cm^{-1}) than that of ylangene (779 cm^{-1}). This is at variance with the data reported by Hunter and Brogden.¹² Moreover, the 1:1 mixture of copaene and ylangene could not be resolved by GLC, not even using the conditions described by the latter authors.¹²

It can be concluded that a certain ambiguity appears to exist concerning the purity and the identity of samples of copaene and ylangene isolated by different research groups.

Comments on the structures and conformations of copaene and ylangene. Although ylangene¹³ and, especially, copaene¹⁴ have been known for a long time, it was only recently that the correct structures of these hydrocarbons were elucidated. In 1947 copaene was proposed to possess structure (9).¹⁵ Some doubt concerning the correctness of this structure was put forward by de Mayo in 1958.¹⁶ Recently, two research groups independently, and on almost identical evidence, arrived at structure (1) for (–)-copaene.^{7,8} Its absolute configuration⁷ followed from a correlation with (–)-cadinene dihydrochloride.

Motl *et al.* proposed⁹ the partial structure (10) for ylangene. On the basis of hydrogenation experiments and on the similarity of IR, NMR, and mass spectra of ylangene and copaene, Hunter and Brogden suggested¹² structure (11) for ylangene. As the result of degradation studies, Motl *et al.* recently concluded that ylangene was represented by structure (12).¹⁷ The absolute configuration of ylangene has not been determined.

Hunter and Brogden claimed¹² that if ylangene, like copaene, has a β -oriented isopropyl group, both angular hydrogen atoms of ylangene must be α -oriented as in structure (11), oppositely to the corresponding atoms of copaene (1). The Czech group appeared to have the same opinion concerning the nature of the difference in structure between ylangene and copaene, but published the antipodal structure (12) for ylangene.¹⁷

Motl *et al.* claimed¹⁷ that the arguments used by the American authors¹² required that, in the biogenesis, ylangene should arise *via* a *trans*-decalin precursor and copaene *via* a *cis*-decalin precursor. However, this conclusion is obviously irrelevant, since the structure (12) (Motl *et al.*) and (11) (Hunter and Brogden) for ylangene are mirror images. Moreover, the absolute configurations of (+)- and (–)-ylangene (both isolated⁹) are unknown, and, as a matter of fact, Hunter and Brogden did not report¹² any rotation of their ylangene.

Motl *et al.*¹⁷ published the perspective structure (12) for ylangene, in which the isopropyl group is axial. It seems very probable that this structure does not represent the most stable conformer of ylangene. If the isopropyl group was absent, the two conformations of the C_3 -bridge of the bicyclo[3.1.1]heptane ring system of ylangene shown in structures (12) and (4), respectively, would be almost equally stable. The difference in stability caused by the asymmetry of the ring containing the double bond should be negligible. Accordingly, structure (4), in which the isopropyl group is equatorial, would be expected to represent the preferred conformation of ylangene. The latter conformation accounts most satisfactorily for the above-mentioned great similarities in the IR spectra of ylangene and copaene (1).

EXPERIMENTAL

Melting points were taken on a Kofler micro hot stage. IR spectra were recorded on a Perkin-Elmer No. 21 instrument (NaCl prism, sample as liquid film, or, for solids, in KBr), UV spectra on a Beckman DK 2 recording spectrophotometer (solvent ethanol) and NMR spectra on a Varian A 60 instrument operating at 60 Mc/s (solvent carbon tetrachloride, internal standard tetramethylsilane). For gas-liquid chromatography (GLC) a PYE argon chromatograph (column length 1.2 m, inner diameter 4 mm) was used.

Identifications with authentic samples were made by mixed melting point determinations, comparisons of optical rotations, GLC, and thin layer chromatographic (TLC) behaviour, and by comparisons of IR and UV spectra.

The procedures used to prepare columns for GLC, plates for argentative TLC (Ag-TLC), and adsorbent (Ag-silica) for argentative column chromatography have been described previously.¹⁸

Rotations were taken in chloroform. Light petroleum refers to the fraction, b.p. 40–60°.

The isolation of copaene, β -copaene, and β -ylangene from Swedish sulphate turpentine together with their physical constants has been described previously.²

Hydrogenation of copaene. Copaene from Swedish sulphate turpentine² was hydrogenated (platinum oxide, glacial acetic acid) and the product was worked up in the usual manner.³ The product had $[\alpha]_D^{22} + 7.2^\circ$ (c 2.5). The GLC pattern consisted of two peaks (ratio 1:19), retention times relative to longifolene 0.95 and 1.21, respectively, (column 1% E 301 on Gas-Chrom P; conditions, see Ref. 1).

Treatment of copaene with hydrogen chloride. The compound (0.870 g, from Swedish sulphate turpentine) was treated with hydrogen chloride as described previously for α -muurolene³ to give a semisolid product. After removal of the oil by suction on a glass filter and recrystallization of the solid once from light petroleum, needles contaminated with a small amount of plates were obtained, yield 0.210 g. The plates melted at 40–60° and the needles at 90–100°. Further recrystallization from methanol gave (–)-*cadinene dihydrochloride*, m.p. 117–118°, $[\alpha]_D - 36.0^\circ$ (c 2.7). The combined mother liquors (0.780 g) were chromatographed¹⁹ on hexane impregnated polyvinyl chloride powder as described³ for the hydrochloride mixture from α -muurolene. Almost pure muurolene dihydrochloride (0.045 g), m.p. 78–84°, was obtained, which, after one recrystallization from light petroleum and one from methanol, yielded (–)-*muurolene dihydrochloride*, m.p. 84–86°, $[\alpha]_D - 11^\circ$ (c 0.8).*

Selenium dioxide oxidation of copaene (1). A solution of copaene ** (1.5 g) and selenium dioxide (1.0 g) in ethanol (95%, 30 ml) was refluxed for 9 h. The reaction mixture was filtered, concentrated under reduced pressure, water (100 ml) was added, and the mixture was extracted with ether. The ethereal extract was washed with aqueous sodium bicarbonate solution (5%), with water, dried (sodium sulphate), and the solvent was evaporated to give a dark red oil (2.1 g). The oil was chromatographed on silica gel (100 g). Ether (5%) in light petroleum (300 ml) eluted a colourless oil (0.08 g), a hydrocarbon mixture mainly consisting of unchanged copaene (IR, GLC). The next portion of the same solvent (600 ml) eluted an orange-coloured oil (1.10 g) showing IR absorptions at 2720 and 1675 cm^{-1} (unsaturated aldehyde). Rechromatography on Ag-silica (50 g) gave as the main fraction, eluted with ether (5%) in light petroleum, *copaenal (5)* (0.55 g) as an almost colourless oil, which crystallized after standing in the refrigerator for two weeks. After vacuum sublimation it melted at 57.5–58°, $[\alpha]_D^{24} - 2.6^\circ$ (c 1.0). (Found: C 82.4; H 10.3. $\text{C}_{15}\text{H}_{22}\text{O}$ requires C 82.5; H 10.2). λ_{max} 248 $\text{m}\mu$ (ϵ 5800).

From the silica gel column, ether (10%) in light petroleum (1500 ml) eluted a mixture of compounds. The following portion (900 ml) of the same solvent eluted a viscous oil (0.21 g). Comparison by IR, GLC, and TLC indicated that it consisted mainly of copanenol, also obtained by sodium borohydride reduction of copanenal. It was not further investigated.

* This product was incorrectly referred to as (+)-muurolene dihydrochloride in a preliminary communication.²⁰

** I thank Prof. G. Büchi for a generous gift of copaene.

Wolff-Kishner reduction of copaenal (5). Copaenal (0.26 g) was treated with hydrazine (0.44 ml) and potassium hydroxide (0.30 g) in diethylene glycol (2 ml) at 90° for 2 h. The temperature was then raised to 160° allowing water to evaporate from the reaction mixture. After 1.5 h at 150–160°, water was added and the mixture was extracted with ether. The ether extract was washed with water, dried, and the ether was evaporated. The residue was passed rapidly* through alumina (8 g, eluent light petroleum, 20 ml) to give an oil (0.22 g) which, according to GLC and Ag-TLC, consisted of β -copaene contaminated with a very small amount of copaene. Purification by column chromatography on Ag-silica gave β -copaene (2) (0.19 g), $[\alpha]_{\text{D}}^{22} - 7.5^\circ$ (c 0.9).

This hydrocarbon (0.18 g) was ozonized (methylene chloride, -80°) and the ozonides were decomposed as described³ previously for γ - and ϵ -muurolene. Acidic products were removed by washing with aqueous sodium bicarbonate, and the neutral residue (0.16 g) was chromatographed on silica gel (8 g). Benzene (30 ml) eluted an oil (0.064 g), probably containing epoxy compounds (IR band at 3035 cm^{-1}). Ether (5 %) in benzene (40 ml) eluted β -copaene norketone (6) (0.076 g), $[\alpha]_{\text{D}}^{22} + 5.4^\circ$ (c 1.4). (Found: C 81.3; H 10.7. $\text{C}_{14}\text{H}_{22}\text{O}$ requires C 81.5; H 10.8). The 2,4-dinitrophenylhydrazone had m.p. 163–164°.

Conversion of copaene from Swedish sulphate turpentine to a mixture of β -copaene and β -ylangene. Copaene from Swedish sulphate turpentine² was oxidized with selenium dioxide as above and the crude copaenal thus obtained was reduced by the Wolff-Kishner procedure. According to GLC (conditions and retention data, see Ref. 1) and Ag-TLC, the product was a mixture containing β -copaene, β -ylangene (ratio 9:1, GLC), and a trace of copaene.

Reactions on β -copaene from Swedish sulphate turpentine. Hydrogenation. Hydrogenation of β -copaene from Swedish sulphate turpentine² in the usual manner³ with platinum catalyst in acetic acid afforded a mixture of stereoisomeric saturated dihydro compounds, $[\alpha]_{\text{D}} + 5.8^\circ$ (c 2.5). This mixture had an IR spectrum almost identical to that of hydrogenated copaene, and the GLC pattern consisted of two peaks with the same retention times as those of hydrogenated copaene, but with a different peak area ratio (1:5) (1 % E 301 column, conditions, see Ref. 1). The retention times were also identical on two other columns: 1 % Reoplex 470 on Chromosorb W at 90° and 15 % 2,4-dinitrophenyl-2-naphthyl ether + 0.75 % dibenzylpyridine on Silocel (firebrick type) at 150°.

Treatment with hydrogen chloride. The hydrocarbon (0.120 g) in dry ether on treatment with dry hydrogen chloride in the usual way³ gave pure *cadinene dihydrochloride* (0.040 g) after three recrystallizations from methanol, m.p. 116–117°, $[\alpha]_{\text{D}} - 37.4^\circ$ (c 3.0).

Ozonolysis. The hydrocarbon was ozonized and a ketone (yield 40 %) was isolated as described above for β -copaene derived from copaene. The ketone and its 2,4-dinitrophenylhydrazone were identical with the corresponding derivatives of β -copaene from copaene (Büchi⁷). From the steam volatile part of the ozonisation products formaldehyde was isolated as the dimedone adduct, m.p. 189–191°.

β -Ylangene from ylangene. Ylangene* was converted into β -ylangene (3) in ca. 15 % yield as described above for the conversion of copaene to β -copaene.

Ozonolysis as above gave β -ylangene norketone (8); 2,4-dinitrophenylhydrazone, m.p. 187–189°.

Reactions on β -ylangene from Swedish sulphate turpentine.² Hydrogenation as above gave a dihydro product, $[\alpha]_{\text{D}} + 30.4^\circ$ (c 2.3), the IR spectrum of which was very similar to that of "dihydrocopaene" (see above).

It was not possible to prepare any crystalline hydrochloride from β -ylangene.

Ozonolysis. The hydrocarbon was ozonized as above to give formaldehyde as the steam volatile product. From the non-volatile part of the products a ketone was isolated in ca. 35 % yield. The ketone and its 2,4-dinitrophenylhydrazone were identical with the corresponding derivatives of β -ylangene derived from ylangene.

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* On standing in contact with alumina (neutral or basic) overnight, β -copaene was almost quantitatively isomerized to copaene.

* I thank Dr. O. Motl for a generous gift of ylangene.

REFERENCES

1. Westfelt, L. *Acta Chem. Scand.* **20** (1966) 2829.
2. Westfelt, L. *Acta Chem. Scand.* **20** (1966) 2841.
3. Westfelt, L. *Acta Chem. Scand.* **20** (1966) 2852.
4. Hunter, G. L. K. and Brogden, W. B., Jr. *J. Org. Chem.* **29** (1964) 2100.
5. Fisher, R., Lardelli, G. and Jeger, O. *Helv. Chim. Acta* **34** (1951) 1577.
6. Simonsen, J. and Barton, D. H. R. *The Terpenes* (2nd Ed.), Vol. III, Cambridge 1951, p. 89.
7. de Mayo, P., Williams, R. E., Büchi, G. and Fearheller, S. H. *Tetrahedron* **21** (1965) 619.
8. Kapadia, V. H., Nagasampagi, B. A., Naik, V. G. and Sukh Dev. *Tetrahedron* **21** (1965) 607.
9. Motl, O., Bucharov, V. G., Herout, V. and Šorm, F. *Chem. Ind. (London)* **1963** 1759.
10. Pliva, J., Horák, M., Herout, V. and Šorm, F. *Die Terpene I*, Berlin 1960; a S 198, b S 221.
11. Herout, V. *Private communication*.
12. Hunter, G. L. K. and Brogden, W. B., Jr. *J. Org. Chem.* **29** (1964) 982.
13. Herout, V. and Dimitrov, D. I. *Chem. Listy* **46** (1952) 432.
14. *Schimmel's Report 1914*, April, p. 48.
15. Briggs, L. H. and Taylor, W. I. *J. Chem. Soc.* **1947** 1338.
16. de Mayo, P. *Perfumery and Ess. Oil Record* **49** (1958) 238.
17. Motl, O., Herout, V. and Šorm, F. *Tetrahedron Letters* **1965** 451.
18. Norin, T. and Westfelt, L. *Acta Chem. Scand.* **17** (1963) 1828.
19. Wickberg, B. *J. Org. Chem.* **27** (1962) 4652.
20. Westfelt, L. *Acta Chem. Scand.* **18** (1964) 572.

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