nmr (CCl_4) δ 7.45–7.87 (3 H, m), 7.20–7.27 (2 H, m), 5.43 (2 H, q, J = 8 and 6 Hz), 2.53–2.78 (2 H, m), 1.57 (3 H, s), 1.20 (3 H, s), 1.09 (6 H, s).

Anal. Calcd for $C_{22}H_{30}O_2$: C, 80.94; H, 9.26. Found: C, 81.22; H, 9.01.

1,4,8,8-Tetramethyl[5.4.0]undeca-3,6-diene (22)—A mixture of 3.8 g of widdrol benzoate and 100 ml of freshly distilled *N,N*-dimethylaniline was heated under reflux for 40 hr, diluted with 500 ml of 2 *N* aqueous hydrochloric acid, and extracted three times with hexane. The hexane extract was washed with saturated aqueous sodium bicarbonate solution and dried, and the solvent was rotary evaporated to give 3.1 g of oily material. Glpc analysis (20% DEGS, Chromosorb P, HMDS, 130°, 5 ft × 0.25 in.) indicated three hydrocarbons in a ratio of 70, 25, and 5% yields. This crude material after filtration through Woelm neutral alumina (activity II) was used directly in the next experiment.

A 250-mg portion was chromatographed on 20 g of silica gel impregnated with 22% silver nitrate. Elution with 72 ml of hexane–benzene (9:1) afforded a total of 185 mg of the diene **22** in six fractions. The major product from the middle chromatography fraction was still impure as indicated by a low residual uv absorption in the 255–273-nm region. No further purification was attempted and the purified diene had the following properties: uv max (cyclohexane) 185 nm (ϵ 17,400), 254 (1120), 263 (1240), 273 (860); nmr (CCl_4) δ 5.17–5.83 (2 H, poorly formed quartet, J = 7 and 3 Hz), 3.17 (1 H, d, J = 20 Hz), 1.72 (3 H, narrow multiplet), 1.10 (3 H, s), 1.08 (3 H, s), 1.09 (3 H, s).

Anal. Calcd for $C_{15}H_{24}$: C, 88.16; H, 11.84. Found: C, 88.20; H, 11.67.

1,4,8,8-Tetramethyl[5.4.0]undeca-4,6-diene (8).—To a solution of 2.0 g (72% pure) of diene **22** in 2 ml of dry benzene and 100 ml of dry dimethyl sulfoxide (distilled from calcium hydride) was added 3.1 g of potassium *tert*-butoxide. The dark red solution was stirred at room temperature for 6 hr, poured into water, and processed in the usual fashion. The crude product was chromatographed on 20 g of Woelm neutral alumina (activity II) to give 1.7 g (85%) of hydrocarbon mixture which upon glpc analysis showed two peaks (78 and 22%). The minor product has a retention time identical with starting diene **22**. The dominant reaction product was purified by preparative glpc; the retention time and all spectra were identical with those of diene **8** prepared from *trans*-thujopsene.

3β,4β-Oxa-1α,4α,8,8-tetramethylbicyclo[5.4.0]undec-6-ene (23).—A solution of 469 mg (2.24 mmol) of 82.5% *m*-chloroperbenzoic acid in 7 ml of chloroform was slowly added to a solution of 551 mg (2.70 mmol) of diene **22** (70% purity) in 5 ml of chloroform at 0°. The reaction was allowed to proceed for 3.5 hr at 0°, diluted with pentane, and worked up in the standard fashion. The crude product was chromatographed on 25 g of Woelm neutral alumina (activity II). Elution with 32 ml of hexane gave 100 mg of unreacted hydrocarbon; elution with hexane–ether (increasingly greater amounts of ether) gave two products. The first product was 70 mg (14%) of impure isomeric 6,7-oxa-3-ene: nmr (CCl_4) δ 5.13 (1 H, d, J = 8 Hz), 2.83 (1 H, t, J = 3 Hz), 2.43–2.75 (2 H, m), 2.00–2.38 (2 H, broad multiplet), 1.63 (3 H, narrow multiplet), 1.11 (6 H, s), 0.76 (3 H, s).

The second product was 248 mg (51%) of pure epoxide **23**: $[\alpha]D$ +67° (*c* 16.9, $CHCl_3$); ir max (CCl_4) 1650, 840 cm^{-1}; nmr (CCl_4) δ 5.52 (1 H, q, J = 7, 4 Hz), 2.79 (1 H, q, J = 8, 7 Hz), 2.25–2.50 (1 H, m), 1.29 (6 H, s), 1.13 (3 H, s), 1.05 (3 H, s).

Anal. Calcd for $C_{15}H_{24}O$: C, 81.76; H, 10.98. Found: C, 81.87; H, 10.77.

***epi*-Widdrol (5).**—A mixture of 1.44 g (6.54 mmol) of epoxide **23**, 1.17 g (31 mmol) of $LiAlH_4$, and 125 ml of glyme was heated under reflux in a nitrogen atmosphere for 16 hr. The cooled mixture was diluted with ether and water carefully added until a clear organic layer was obtained. The organic layer was decanted and processed in the usual manner. The 1.47 g of crude product was 95% pure *epi*-widdrol (glpc, 10% KOH, 10% Carbowax 6000, 185°). A portion of the crude product (365 mg) was chromatographed on Woelm neutral alumina to yield *epi*-widdrol: mp 54–56°; $[\alpha]D$ +132° (*c* 5.81, $CHCl_3$).

Registry No.—**1,** 32435-95-3; **4,** 32436-14-9; **5,** 25490-91-9; **7,** 32436-16-1; **8,** 32436-17-2; **14,** 32436-18-3; **15,** 32436-19-4; **16,** 32436-20-7; **17,** 32436-21-8; **18,** 32436-22-9; **19,** 32436-23-0; **20,** 32436-24-1; **21,** 32436-25-2; **22,** 32436-26-3; **23,** 32436-27-4; **23** 6,7-oxa-3-ene isomer, 32436-28-5.

A Stereoselective Nonannelation Synthesis of Eudalene Sesquiterpenes[1]

J. W. HUFFMAN* AND M. L. MOLE

Department of Chemistry and Geology, Clemson University, Clemson, South Carolina 29631

Received May 17, 1971

A new stereoselective synthetic approach to the eudalene sesquiterpenes has been devised which does not utilize the Robinson annelation sequence. Clemmensen reduction of 5-methoxy-1-tetralonecarboxylic acid (**4**) gives 8-methoxytetralin-2-carboxylic acid (**5**), which on Birch reduction affords 3,4,5,6,7,8-hexahydronaphthalen-1(2*H*)-one-7-carboxylic acid (**3**) as the major product. Conjugate addition of lithium dimethyl cuprate to **3** gives a mixture of three stereoisomeric 4a-methyl-3,4,4a,5,6,7,8,8a-octahydronaphthalen-1(2*H*)-one-7-carboxylic acids (**9**, **10**, and **11**). Treatment of the mixture of acids with methylenetriphenylphosphorane, followed by esterification, equilibration, and hydrolysis affords 4aβ-methyl-8-methylene-1,2,3,4,4a,5,6,7,8aα-decahydronaphthalene-2β-carboxylic acid (**12**), a compound which has previously been converted to β-eudesmol (**1**).

Although several syntheses of eudalene-type sesquiterpenes have been reported,[2] every successful synthetic approach has utilized the Robinson annelation sequence to construct the bicyclic skeleton characteristic of this group of natural products. Unfortunately, owing to the steric course of the annelation reaction, this approach necessitates multistep synthetic schemes with the stepwise introduction of the various substituents on the perhydronaphthalene ring system.[3]

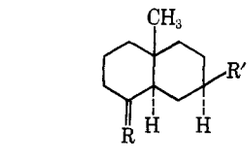
In order to circumvent these problems, we attempted to design a new, general synthesis of these sesquiterpenes which did not utilize the annelation reaction and which would permit stereochemical control at each step. Examination of the structure of β-eudesmol (**1**) reveals that this molecule is basically a 9-methyl-*trans*-decalin with an equatorial substituent

(1) (a) A preliminary communication describing a portion of this work appeared in *Tetrahedron Lett.*, 501 (1971). (b) Abstracted in part from the Ph.D. dissertation of M. L. Mole, Clemson University, May 1971. (c) Supported in part by Career Development Award GM-5433 from the National Institutes of Health.

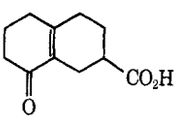
(2) Earlier synthetic approaches to these sesquiterpenes are described: (a) C. H. Heathcock and T. R. Kelly, *Tetrahedron*, **24**, 1801 (1968); (b) J. A. Marshall, M. T. Pike, and R. D. Carroll, *J. Org. Chem.*, **31**, 2933 (1966); (c) J. A. Marshall and M. T. Pike, *ibid.*, **33**, 435 (1968); (d) D. C. Humber, A. R. Pinder, and R. A. Williams, *ibid.*, **32**, 2335 (1967); (e) J. M. Mellor and S. Munavelli, *Quart. Rev., Chem. Soc.*, **18**, 270 (1964).

(3) The details of these stereochemical problems are particularly apparent in the syntheses described in ref 2a, b, and d.

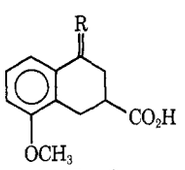
at C-7 and any stereoselective synthesis must control the stereochemistry at these centers. A suitable precursor which permits this steric control is the keto acid **2** utilized earlier by Heathcock in a synthesis of eudesmol.[2a]



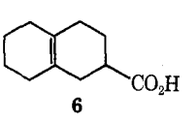
1, R = CH_2; R′ = $C(CH_3)_2OH$
2, R = O; R′ = CO_2H
12, R = CH_2; R′ = CO_2H
14, R = α-OH; β-CH_3; R′ = $C(CH_3)_2OH$
15, R = β-OH; α-CH_3; R′ = $CH_2{=}CHCH_3$



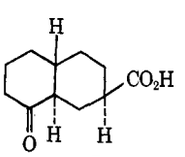
3



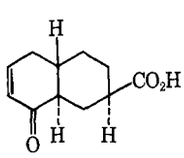
4, R = O
5, R = H, H



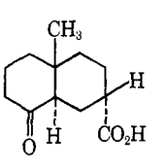
6



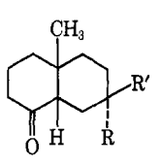
7



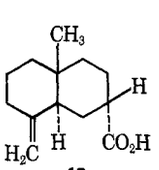
8



9



10, R = H; R′ = CO_2H
11, R = CO_2H; R′ = H



13

Although **2** was synthesized by these workers *via* a rather lengthy annelation sequence, it appeared to be also available from the unsaturated keto acid **3**, which in turn could be obtained by reduction of an aromatic compound.

A suitable starting point for the preparation of **3** seemed to be the readily available 5-methoxytetralone-3-carboxylic acid (**4**).[4] Clemmensen reduction of **4** afforded 8-methoxytetralin-2-carboxylic acid (**5**), which on Birch reduction followed by acid hydrolysis of the crude reaction products[5] gave a mixture of four acids. Separation of this mixture by chromatography gave an unsaturated acid, $C_{11}H_{16}O_2$, in 18% yield, plus three keto acids. The nmr spectrum of the unsaturated acid exhibits no vinyl protons and, assuming no unusual side reactions, it is almost certainly the octalin carboxylic acid, **6**.

Separation of the keto acids was effected by a combination of chromatography on silica gel and treatment with Girard's-T reagent. By this method a saturated keto acid, $C_{11}H_{16}O_3$ could be isolated in 9% yield and on the basis of the analytical data, rather featureless nmr spectrum, and appropriate carboxyl absorption in the infrared, this material must be 1-decalone-7-carboxylic acid (**7**). The major product of the reduction (25%) was an unsaturated acid, $C_{11}H_{14}O_3$, which shows no vinyl protons in the nmr, has the ultraviolet maximum expected for **3** (calcd λ_{max} 249, obsd 244), and shows α,β-unsaturated ketone carbonyl absorption in the infrared. Finally, a small quantity of a compound isomeric with **3** was obtained which shows vinyl protons at δ 5.83 and 6.72 and which has the ultraviolet absorption predicted for a monosubstituted α,β-unsaturated ketone (calcd λ_{max} 227, obsd 226). On the basis of these data this material must be keto acid **8**. The stereochemistry of compounds **7** and **8** was not investigated, but it is assumed that they have the more stable trans ring fusion with an equatorial carboxyl group.

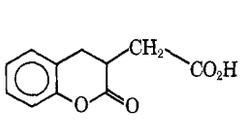
Glc data from several runs indicated that the product ratios were somewhat variable, but a typical reaction mixture consisted of 42% of **3**, 21% of **6**, 24% of **7**, 7% of **8**, 2% recovered starting material, **5**, and trace amounts of several other unidentified products.

Reaction of **3** with lithium dimethyl cuprate[6] gave a mixture of three saturated keto acids in a ratio of 4:3:2 (A, B, and C). On the basis of spectral data (see Experimental Section) and subsequent conversions these are three of the four possible isomers of the desired eudalene precursor, **2**. In addition to **2**, which has an equatorial carboxyl group, there is a trans isomer with an axial carboxyl group, **9**, and a pair of cis isomers, **10** and **11**. The principal isomer, A, could be isolated in pure form and, in order to gain some insight into the stereochemistry of these compounds, was subjected to equilibration studies.

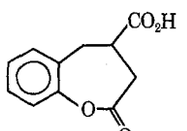
Treatment of the methyl ester of A with methanolic sodium methoxide gave a mixture of A and a new isomer, D, in a ratio of 3:5. Since these conditions should effect equilibration at both C-5 and C-7 (sesquiterpene numbering), D should be the most stable of the four isomers, almost certainly **2**, with the trans ring fusion and equatorial substituent at C-7. Not only is **2** expected to be the most stable of these isomers, but Heathcock has obtained this compound by equilibration of a mixture of **2** and **11**. Isomer A, which was obtained in pure form, is almost certainly one of the two compounds with a cis ring fusion, since it has been shown that there is relatively little energy difference between *cis*- and *trans*-10-methyl-1-decalone, while $\Delta G_{CO_2CH_3}$ is in excess of 1 kcal/mol.[7]

On the basis of the physical properties of A, it is dif-

(4) A. Sieglitz and C. Jordanides, *Justus Liebigs Ann. Chem.*, **702**, 94 (1967). The modified Friedel-Crafts cyclization of the benzylsuccinic anhydride described in the Experimental Section proceeds much more smoothly than the original procedure. In addition to a 45% yield of **4**, a significant quantity of a 1:1 mixture of lactones (i and ii) was obtained.



i



ii

The structures of i and ii were assigned on the basis of analytical and spectral data, and hydrolysis and methylation to the starting benzylsuccinic acid (see Experimental Section).

(5) H. L. Dryden, Jr., O. M. Webber, R. R. Burtner, and J. A. Cella, *J. Org. Chem.*, **26**, 3237 (1961).

(6) H. O. House, W. L. Respess, and G. M. Whitesides, *ibid.*, **31**, 3128 (1966).

(7) E. L. Eliel, N. L. Allinger, S. J. Angyal, and G. A. Morrison, "Conformational Analysis," Wiley, New York, N. Y., 1965, pp 231–232, 441. Assuming no complicating stereoelectronic factors, equilibration of the methyl esters of **2** and **9** should give approximately 80–85% **2**.

ferent from the cis keto acid prepared by Heathcock and to which stereoformula **11** can be assigned with a high degree of certainty;[2a] thus A must be assigned structure **10**. Of the two methyl singlets in the nmr spectrum of the isomerized mixture of esters, the most intense appeared at the same position as that reported for compound **2** by Heathcock and Kelly,[2a] strengthening the above assignment of configuration to D.

Some insight into the stereochemistry of isomers B and C follows from the equilibration of A as the free acid. This gave only A and B in a ratio of 3:1. Since the carboxylate anion would not be expected to equilibrate under the basic conditions of this isomerization, B must be epimeric with A at C-5 but retain the same stereochemistry at C-7. Consequently B is **9** and C is the cis acid reported earlier by Heathcock (**11**).

It has been noted that the reaction of both *cis*- and *trans*-1-decalones with methylene triphenylphosphorane in dimethyl sulfoxide leads predominantly to products with a trans ring fusion.[2b,8] Since β-eudesmol has this stereochemistry, the mixture of isomeric acids described above was subjected to these reaction conditions to give a mixture of three acids in a ratio of *ca.* 5:4:1. The major product could be isolated by direct crystallization and was not identical with acid **12**, a compound which has earlier been converted to β-eudesmol.[2a,b,9] On the basis of glc data the component present to the extent of 40% was the desired product, and by analogy with other systems the major product, **13**, was epimeric to **12** at C-7. This assignment of stereochemistry was verified when it was found that equilibration of the methyl ester of either the principal product of the Wittig reaction or the crude reaction mixture, followed by hydrolysis, gave **12**, identical in all respects with a sample prepared by Marshall's route.[2b,9]

Since acid **12** has been converted to β-eudesmol,[2b] and β-eudesmol has in turn been converted to cryptomeridiol[10] (**14**) and neointermediol[11] (**15**), the synthesis of **12** constitutes a formal total synthesis of these three sesquiterpenes. In addition, this is the first total synthesis of any eudalene sesquiterpene which does not utilize the Robinson annelation reaction, and this synthetic sequence may serve as a prototype for other syntheses in the sesquiterpene series.

Experimental Section[12]

o-Methoxybenzylidenesuccinic Acid.—This compound was prepared using a modification of Horning's procedure.[13] To 770 ml of *tert*-butyl alcohol was added 52 g of potassium and the mixture was mechanically stirred and heated at reflux under nitrogen for 4.5 hr. To the resulting heterogeneous mixture of potassium *tert*-butoxide and *tert*-butyl alcohol was added as quickly as possible 177 ml (184 g) of diethyl succinate in 100 ml of *tert*-butyl alcohol. Immediately 127 g of *o*-anisaldehyde in 100 ml of *tert*-butyl alcohol was added as rapidly as feasible without losing control of the vigorous reaction. The resulting heterogenous mixture was stirred and heated at reflux for 2 hr. After cooling, 1400 ml of water was added and 1600 ml of *tert*-butyl alcohol–water was removed by distillation (final head temperature, 99°). To the reaction mixture was added a solution of 120 g of potassium hydroxide in 400 ml of water and the dark solution was heated at reflux for 4 hr. The cooled mixture was washed with ether and, after heating on the steam bath to drive off any dissolved ether, concentrated hydrochloric acid was added carefully (vigorous foaming) until pH 1 was reached. After chilling in an ice bath for 3 hr, the precipitate was filtered, washed with water, air-dried, and finally dried *in vacuo* for 4 hr to give 199 g (90%) of brown solid. A 5.60-g portion of the crude product was triturated with a small portion of ether and recrystallized from 95% ethanol, giving 3.75 g of tan crystals, mp 186–201°. A second recrystallization gave 1.3 g of slightly colored material: mp 207–210.5° dec (lit. mp 208.5–211°);[13] ir 3.0–4.2, 5.82–5.96, 11.87–13.22 μ; nmr (DMSO-d_6) 3.38 (s, 2 H, CH_2), 3.87 (s, 3 H, OCH_3), 6.91–7.60 (m, 4 H, ArH), 7.90 (s, 1 H, vinyl H).

o-Methoxybenzylsuccinic Acid.—From 170 g of crude benzylidenesuccinic acid, catalytic hydrogenation by Horning's method[13] gave after crystallization from benzene 100 g (55% based on anisaldehyde) of reduced acid, mp 133–136°. A small sample was dissolved in ether and filtered, the solvent was removed, and the residue was recrystallized from benzene to give off-white crystals: mp 143–144° (lit. mp 142–145°);[13] ir 2.9–3.9, 5.90 μ; nmr 2.22–3.23 (m, 5 H, CH_2 and CH), 3.77 (s, 3 H, OCH_3), 6.72–7.35 (overlapping AB systems, 4 H, ArH).

o-Methoxybenzylsuccinic Anhydride.—To 63.6 g of *o*-methoxybenzylsuccinic acid, mp 133–136°, protected from atmospheric moisture, was added 54 ml of acetyl chloride. A vigorous reaction was apparent after 15 min and was allowed to continue for an additional 30 min; stirring and gentle reflux were then begun and continued for 2 hr. After standing at room temperature for 18 hr the excess acetyl chloride was removed *in vacuo* with warming on the steam bath. Three 15-ml portions of dry benzene were added and then removed *in vacuo* at steam bath temperature, leaving 58.8 g of brown, viscous anhydride, ir 5.34, 5.57 μ. When 0.300 g of this material was allowed to stand at −10° for several weeks it crystallized. The resulting solid was recrystallized from ether–hexane and a second recrystallization gave white crystals mixed with a brown solid. The solvent was decanted, and 0.100 g of white crystals (mp 67.5–68.5°) were separated and recrystallized from ether–hexane to give 0.070 g of *o*-methoxybenzylsuccinic anhydride: mp 68–69°; ir 5.34, 5.43, 5.61 μ; nmr δ 2.78 (d, J = 7.5 Hz, 2 H, $ArCH_2$), 2.98–3.67 (m, 3 H, $-CH_2CH-$), 3.85 (s, 3 H, OCH_3), 6.85–7.45 (m, 4 H, ArH).

Anal. Calcd for $C_{12}H_{12}O_4$: C, 65.45; H, 5.49. Found: C, 65.17; H, 5.44.

5-Methoxy-1-tetralonecarboxylic Acid (4).—The crude anhydride, 58.5 g, was dissolved in 880 ml of nitrobenzene and added over a 50-min period to a stirred solution of 103 g of aluminum chloride in 470 ml of nitrobenzene protected from atmospheric moisture. Stirring was continued for 5 min and a mixture of 500 g of ice and 500 ml of concentrated hydrochloric acid was added. After standing for 1.5 days, the nitrobenzene was removed by steam distillation. The hot solution was filtered, allowed to cool, and seeded. After standing overnight, the brown crystals were collected and dried *in vacuo* to give 26.6 g (45%) of crude material, mp 125–141°. For characterization, 0.350 g of the tetralone was purified by dissolution in 75 ml of 50% aqueous hydrochloric acid, filtering the hot solution, and chilling in an ice–water bath. The cloudy solution was filtered again and allowed to stand overnight. The crystals (0.055 g) were filtered and dried *in vacuo*. Recrystallization from water afforded 0.045 g of colorless needles: mp (softening) 139–143°, melt 143–144° (lit. mp 145°);[4] ir 5.80, 5.96 μ; nmr δ 2.84–3.59 (m, 5 H, CH_2, CH), 3.88 (s, 3 H, OCH_3), 7.08 (q, J = 8 and J = 1.5 Hz, 1 H, ArH), 7.33 (t, J = 8 Hz, 1 H, ArH), 7.70 (q, J = 8 and J = 1.5 Hz, 1 H, ArH).

The mother liquors from the first crystallization were extracted with ether (six 400-ml portions), the extracts were dried and filtered, and the solvent was removed *in vacuo*, leaving 22.5 g of

(8) M. D. Soffer and L. A. Burke, *Tetrahedron Lett.*, 211 (1970).

(9) We would like to thank Professor J. A. Marshall, Northwestern University, for a sample of this compound.

(10) M. Suminoto, H. I. Hirai, and K. Wada, *Chem. Ind. (London)*, 780 (1963).

(11) V. B. Zalkow, H. Shaligram, and L. H. Zalkow, *ibid.*, 194 (1964).

(12) All melting points were determined on a Kofler hot-stage apparatus and uncorrected. Infrared spectra were taken as potassium bromide disks or liquid films on sodium chloride plates using a Perkin-Elmer Model 137 spectrophotometer and are reported in microns. Ultraviolet spectra were taken in methanol using a Perkin-Elmer Model 202 spectrophotometer and are reported as λ_{max} in millimicrons (log ε). Nuclear magnetic resonance spectra were obtained using a Varian Associates A-60 nuclear magnetic resonance spectrophotometer with deuteriochloroform as a solvent unless stated otherwise. All spectra are reported in parts per million relative to tetramethylsilane (δ). Gas–liquid chromatography was carried out on an F & M Model 810 analytical gas chromatograph using helium as the carrier gas at a flow rate of 35 ml/min through a 1/8 in. × 10 ft copper column of 10% QF1 on HP Chromosorb W (80–100 mesh). Elemental analyses were performed by Galbraith Laboratories, Knoxville, Tenn.

(13) E. C. Horning and G. N. Walker, *J. Amer. Chem. Soc.*, **74**, 5147 (1952).

tan oil which subsequently crystallized. Recrystallization of 9.5 g from ether–hexane gives 2.9 g of lightly colored crystals. A second recrystallization from ether afforded material, mp 136–138°. Repeated recrystallization failed to improve the melting point. Recrystallization several times from benzene or sublimation did not improve the melting point, and tlc (silica gel G, benzene–ethyl acetate) showed two major spots (i and ii, ref 4) (0.74, 0.86): ir 5.67, 5.91 μ; nmr 2.58–3.16 (m, 5 H, CH_2, CH), 6.68–7.20 (m, 4 H, ArH), 9.00 (s, 1 H, CO_2H).

Anal. Calcd for $C_{11}H_{10}O_4$: C, 64.08; H, 4.89. Found: C, 63.88; H, 5.00.

A solution of 0.700 g of this material was heated at reflux under nitrogen in 3 ml of 20% aqueous sodium hydroxide, containing 0.32 ml of dimethyl sulfate. The solution was cooled, diluted with water, and washed twice with ether. The aqueous solution was acidified with concentrated hydrochloric acid to pH 1 and the cloudy solution was extracted with ether. The extracts were combined, washed once with water, dried, and filtered and the solvent was removed under reduced pressure, leaving 0.680 g of nearly colorless oil which crystallized on standing, mp 110–120°. Recrystallization from benzene afforded 0.503 g (62%) of tan crystals, mp 134–138°. The ir and nmr were identical with those of *o*-methoxybenzylsuccinic acid, mp 135–139°.

8-Methoxytetralin-2-carboxylic Acid (5).—The tetralonecarboxylic acid was reduced under the usual conditions of the Clemmensen reduction.[14] From 25.3 g of keto acid there was obtained 22.4 g (95%) of crude **5**, mp 136–141°. Recrystallization from 10% hydrochloric acid and then water gave the analytical sample: mp 142–143°; ir 5.88 μ; nmr δ 1.64–2.25 (m, 2 H, $ArCH_2CH_2$), 2.62–3.12 (m, 5 H, $ArCH_2$, CH), 3.80 (s, 3 H, OCH_3), 6.58–7.25 (m, 3 H, ArH).

Anal. Calcd for $C_{12}H_{14}O_3$: C, 69.89; H, 6.84. Found: C, 69.92; H, 6.85.

3,4,5,6,7,8-Hexahydronaphthalen-1(2*H*)-one-7-carboxylic Acid (3).—A solution of 9.60 g of 8-methoxytetralin-2-carboxylic acid in 487 ml of dry ethanol was added with stirring to 390 ml of liquid ammonia. To this solution was added 45.8 g of sodium spheres in four portions. An additional 200 ml of ammonia was added after the third addition of sodium in order to maintain the blue color. After stirring for 8 hr the ammonia was evaporated and the ethanol was removed at reduced pressure and steam-bath temperature. Water was added and the solvent was removed to give a thick paste to which was added 1 l. of water. The solution was brought to pH 1 with concentrated hydrochloric acid and heated on the steam bath under a reflux condenser for 3 hr. After cooling in an ice bath, the mixture was extracted with ether, the extracts were dried and filtered, and the solvent was removed under reduced pressure, leaving approximately 8 g of yellow oil which crystallized. Analysis by glc of the methyl ester of the combined solids indicated there to be 53% of the desired enone. The crude solid was dissolved in benzene and chromatographed on a column of silica gel (Will, Grade 922, activated 6 hr at 140°). Elution with benzene–ethyl acetate (10:1) gave 1.53 g of an oil which crystallized on standing. Recrystallization from a small volume of hexane gave the analytical sample of **1,2,3,4,5,6,7,8-octahydro-2-naphthoic acid (6)**: mp 108–110°; ir 5.90 μ; nmr δ 1.36–2.85 (m, 15 H, CH and CH_2), 11.62 (s, 1 H, CO_2H).

Anal. Calcd for $C_{11}H_{16}O_2$: C, 73.30; H, 8.95. Found: C, 73.44; H, 8.81.

Elution with benzene–ethyl acetate (5:1) gave 1.72 g of a mixture of saturated and unsaturated ketones. A solution of 1.50 g of this mixture was dissolved in 33.8 ml of dry ethanol containing 4.93 ml of acetic acid and 4.93 g of dry Girard's-T reagent and heated at reflux for 3.5 hr. The solvent was removed and 70.3 ml of water was added. The pH was quickly adjusted to 5–6 with sodium carbonate and the solution was extracted with three portions of ether. The aqueous layer was allowed to stand for 12 hr at room temperature and extracted with four portions of ether. The pH was adjusted to 1 with concentrated hydrochloric acid and the solution was kept at room temperature for 11 hr and extracted with six portions of ether. After standing at room temperature another 48 hr and then at steam bath temperature for 2 hr, the solution was again extracted with ether and then continuously extracted with ether for 56 hr. The final extracts were filtered and dried and the solvent was removed to give 0.223 g of **4,4a,5,6,7,8-hexahydronaphthalen-1(1a*H*)-one-7-carboxylic acid (8)**. Recrystallization from ether–hexane gave the analytical sample: mp 152–156°; ir 3.28, 5.86, 6.00, 6.06 μ; uv λ_{max} 266 mμ (log ε 3.64); nmr δ 0.83–2.70 (m, 11 H, CH, CH_2), 5.83 (d, J = 10 Hz, 1 H, OCCH=), 6.72 (m, 1 H, OCCH=CH), 10.32 (s, 1 H, CO_2H).

Anal. Calcd for $C_{11}H_{14}O_3$: C, 68.02; H, 7.27. Found: C, 68.04; H, 7.34.

The intermediate fractions eluted with benzene–ethyl acetate (5:1) gave 0.830 g of **2,3,4,4a,5,6,7,8-octahydronaphthalen-1-(1a*H*)-one-2-carboxylic acid (7)**, which after repeated recrystallization from anhydrous ether, and finally ether–benzene, had mp 146–149°: ir 5.87 μ; nmr δ 1.1–2.6 (m, 15 H, CH and CH_2), 11.51 (s, 1 H, CO_2H).

Anal. Calcd for $C_{11}H_{16}O_3$: C, 67.32; H, 8.22. Found: C, 67.43; H, 8.33.

Treatment of this compound with ethereal diazomethane gave the oily methyl ester, characterized as the 2,4-dinitrophenylhydrazone, mp 179–181°, from aqueous methanol.

Anal. Calcd for $C_{18}H_{22}N_4O_6$: C, 55.38; H, 5.68; N, 14.35. Found: C, 55.47; H, 5.66; N, 14.37.

The final fractions eluted with benzene–ethyl acetate (5:1) gave 2.23 g of **3,4,5,6,7,8-hexahydronaphthalen-1(2*H*)-one-2-carboxylic acid (3)**. The analytical sample, mp 145–146°, was crystallized from dry ether: ir 2.9–3.8, 5.86, 6.19 μ; uv λ_{max} 244 mμ (log ε 4.18); nmr δ 1.25–2.82 (m, 15 H, CH and CH_2), 11.40 (s, 1 H, CO_2H).

Anal. Calcd for $C_{11}H_{14}O_3$: C, 68.02; H, 7.27. Found: C, 68.11; H, 7.37.

The methyl ester (ir 5.75, 6.01 μ) was prepared with diazomethane and characterized as its 2,4-dinitrophenylhydrazone. Crystallization from methanol–ethyl acetate afforded bright red needles, mp 194.5–196.5°.

Anal. Calcd for $C_{18}H_{20}N_4O_6$: C, 55.67; H, 5.19; N, 14.43. Found: C, 55.50; H, 5.30; N, 14.18.

4a-Methyl-3,4,4a,5,6,7,8,8a-octahydronaphthalen-1(2*H*)-one-7-carboxylic Acid.—To a rapidly stirred mixture of 3.93 g of cuprous iodide in 79 ml of anhydrous ether at 0° under nitrogen was added slowly over a 10-min period, 15–17 ml of a 2 *N* ethereal solution of methyllithium. The solution was allowed to stir for 5 min, and 1 g of 3,4,5,6,7,8-hexahydronaphthalen-1(2*H*)-one-7-carboxylic acid (**3**) in 100 ml of dry ether was added and rinsed in with two 10-ml portions of the same solvent. The yellow, heterogenous mixture was stirred at 0° under nitrogen for 2 hr. The mixture was then slowly poured into a rapidly stirred solution of 530 ml of 1.2 *N* hydrochloric acid at 0°. When all the yellow color had disappeared and only the gray to tan precipitate of cuprous iodide remained, the heterogenous mixture was extracted repeatedly with ether. The extracts were dried and filtered and the solvent was removed under reduced pressure at steam bath temperature, leaving 1.08 g (100%) of a dark brown oil. Analysis by glc of the methyl ester of this oil showed three major components in a ratio of approximately 4:3:2 (A:B:C). The oil was dissolved in ethyl acetate–hexane (1:100) and filtered through 10 g of silica gel which had been activated at 140° for 6 hr. Ethyl acetate–hexane (1:99) was used for elution until the eluate was free of the purple color of iodine. Elution with ethyl acetate–hexane (1:95) gave 0.050 g of a light brown oil which was not characterized. Further elution with ethyl acetate–hexane (1:4) gave 0.940 g (87%) of light brown oil which crystallized and was used in the next step without further purification. One of the components of the reaction mixture was crystallized as follows. The crystalline residue from above was dissolved in 10 ml of ethyl acetate and added to 120 ml of hot cyclohexane. The solution was concentrated to 100 ml, and after standing a brown oil settled out. The supernatant liquid was decanted and concentrated to approximately 50 ml to give a mixture of brown oil and crystals. The supernatant liquid was decanted and the residue was triturated with small amounts of dry ether. The crystals (0.300 g) were dissolved in 5 ml of ethyl acetate and added to 20 ml of cyclohexane and the solution was concentrated to cloudiness. The solution was allowed to cool and seeded, and 0.110 g of light yellow crystals was collected. Another recrystallization afforded the analytical sample of **4aβ-methyl-3,4,4a,5,6,7,8,8aα-octahydronaphthalen-1(2*H*)-one-7-carboxylic acid (10)**: mp 152–154°; ir 3.0, 3.85, 5.88 μ; nmr δ 0.93 (s, 3 H, CH_3), 1.10–2.60 (m, 14 H, CH, CH_2), 11.12 (s, 1 H, CO_2H).

Anal. Calcd for $C_{12}H_{16}O_3$: C, 68.55; H, 8.63. Found: C, 68.51; H, 8.68. Analysis by glc of the methyl ester indicates that this compound represents 41% of the original reaction.

Equilibration Studies. A.—A solution of 0.010 g of 4aβ-methyl-3,4,4a,5,6,7,8,8aα-octahydronaphthalen-1(2*H*)-one-7-carboxylic acid (**10**) in 2 ml of 10% sodium hydroxide was heated on

(14) E. L. Martin, *J. Amer. Chem. Soc.*, **58**, 1438 (1936).

the steam bath for 1 hr. The reaction mixture was acidified with concentrated hydrochloric acid and extracted with four portions of ether. The extracts were dried, the solvent was removed, and the residual acid was converted to the methyl ester with diazomethane. Glc analysis indicated that there were two components present in the mixture in a ratio 3:1 (A:B). The retention time of the major component was the same as that of the starting acid, while that of the minor component was the same as that of the isomer present in intermediate amount in the original reaction mixture.

B.—Keto acid **10** was converted to the methyl ester with diazomethane and 0.010 g was heated at reflux for 16 hr in 2.0 ml of methanolic sodium methoxide. The methanol was removed, 5 ml of water was added, and the solution was acidified (pH 1) with conentrated hydrochloric acid. The turbid solution was extracted with ether, the extracts were dried over magnesium sulfate, and the solvent was removed to give 0.005 g (50%) of a mixture of esters. Glc analysis indicated that there were two components present in a ratio 3:5 (A:D). The retention time of the minor component was the same as that of the starting ester, while the major product was a new ester of longer retention time. The infrared spectrum of this mixture showed absorption at 5.75 and 5.83 μ while the nmr showed two singlets, at δ 0.81 and 0.91, of relative intensities of *ca.* 2.2:1.

4aβ-Methyl-8-methylene-1,2,3,4,4a,5,6,7,8,8aα-decahydronaphthalene-2α-carboxylic Acid (13).—To a solution of methylene triphenylphosphorane, from 4.40 g of methyltriphenylphosphonium bromide in 45 ml of dimethyl sulfoxide, was added 0.500 g of the mixture of isomeric acids, A, B, and C, described above in 10 ml of dimethyl sulfoxide. The deep orange solution was stirred and heated at 62–65° for 36 hr. After cooling to room temperature, the reaction mixture was poured into water, and the basic solution was brought to pH 1 with concentrated hydrochloric acid and extracted with ether. The extracts were washed with water and dried, and the solvent was removed under reduced pressure at steam bath temperature, leaving 2 g of a yellow oil. The oil was dissolved in anhydrous ether–hexane and filtered through a column of silica gel. Elution with hexane gave in the first fraction 0.030 g of a colorless oil which was not characterized. Elution with hexane–anhydrous ether (1:1) gave 0.415 g of yellow oil (84%) which crystallized on standing. Analysis by glc of the methyl ester of this material showed that it consisted of 40% of the desired acid (**12**), and 60% of a mixture of two other compounds in a ratio of *ca.* 6:1. Recrystallization from hexane gave the 2α-acid, **13**, as white crystals: mp 123–125°; ir 5.87, 6.06, and 11.29 μ; nmr δ 0.75 (s, 3 H), 1.27–2.50 (envelope, 13 H), 2.85 (m, 1 H), 4.46 (br s, 1H), 4.76 (br s, 1 H).

Anal. Calcd for $C_{13}H_{20}O_2$: C, 74.96; H, 9.68. Found: C, 75.18; H, 9.76.

When the Wittig reaction was carried out as described above utilizing the methyl esters instead of the mixed acids, a similar mixture of compounds was obtained.

4aβ-Methyl-8-methylene-1,2,3,4,4a,5,6,7,8,8aα-decahydronapthalene-2β-carboxylic Acid (12).—An ethereal solution of 0.150 g of the mixture of stereoisomeric methylene acids described above was treated with diazomethane for 15 min. The ether was evaporated and the resulting oil was heated at reflux for 2 hr with 1 ml of methanol containing 0.108 g of sodium methoxide and protected from atmospheric moisture. The methanol was removed under reduced pressure at steam bath temperature, water was added, and the solution was heated on the steam bath under nitrogen for 1 hr. After cooling to room temperature and acidifying to pH 1 with concentrated hydrochloric acid, the reaction mixture was extracted with ether. The extracts were washed once with water, dried, and filtered and the solvent was removed under reduced pressure, leaving 0.135 g (90%) of yellow oil which crystallized on standing. Crystallization of the acid from hexane at −10° afforded 0.067 g of tan crystals, mp 107–114°. Recrystallization from the same solvent gave 0.054 g of off-white crystals, mp change in crystalline from 95–117°, mp 117.5–118.5°; mmp with an authentic sample,[2b,9] change in crystalline from 95–115°, mp 115–117°. The infrared spectrum was identical with that of the authentic sample, as was the glc retention time of the methyl esters: nmr δ 0.75 (s, 3 H), 1.02–2.67 (envelope, 14 H), 4.47 (br s, 1 H), 4.73 (br s, 1 H) [lit. (in CCl_4) δ 0.75, 4.52, 4.78[2b]].

Registry No.—**3**, 32178-64-6; **3** methyl ester 2,4-DNP, 32298-25-2; **4**, 16035-97-5; **5**, 32178-63-5; **6**, 32298-28-5; **7**, 32298-80-9; **7** methyl ester 2,4-DNP, 32298-29-6; **8**, 32367-43-4; **10**, 32298-30-9; **12**, 32298-31-0; **13**, 32179-13-8; *o*-methoxybenzylidenesuccinic acid, 24289-96-1; *o*-methoxybenzylsuccinic acid, 32298-34-3; *o*-methoxybenzylsuccinic anhydride, 32298-35-4.

Studies on Resin Acids. VII. Isomerization of 19-Norabietatetraenes[1]

J. W. HUFFMAN

Department of Chemistry and Geology, Clemson University, Clemson, South Carolina 29631

Received June 23, 1971

The composition of the mixture of olefins obtained by lead tetraacetate decarboxylation of 4-epidehydroabietic acid (**4**) has been found to be very nearly the same as that obtained from dehydroabietic acid. Acid-catalyzed isomerization of this mixture of olefins leads to a mixture of 19-norabieta-4,8,11,13-tetraene (**2**) and 19-nor-5β-abieta-3,8,11,13-tetraene (**7**), in which the latter predominates. Hydroboration–oxidation of **7** gives 18-nor-5β-abieta-8,11,13-trien-3α-ol (**9**), which on oxidation affords the corresponding ketone **14**. The course of the isomerization of the olefin mixture is discussed.

In the course of the hydroboration–oxidation of the mixture of olefins obtained by lead tetraacetate decarboxylation of dehydroabietic acid, there was obtained, among other products, 19-norabieta-8,11,13-trien-7-one (**1**).[2] It was suggested that this ketone was probably derived from 19-norabieta-4,8,11,13-tetraene (**2**), but this was not confirmed[2] and in an effort to gain additional information concerning the origin of **1**, a convenient source of olefin **2** was sought. Although **2** has been isolated from the decarboxylation mixture by chromatography,[3] this substance constitutes less than 30% of that mixture.[2,3] Since it had been reported that lead tetraacetate decarboxylation of podocarpic acid methyl ether (**3**) gives a mixture of olefins which contains 63% of the analog of **2**,[4] this reaction was carried out on 4-epidehydroabietic acid (**4**).[1] This procedure gave, however, a mixture of 32% of **2**, 41% of 19-norabieta-4(18),8,11,13-tetraene (**5**), and 27% of 19-norabieta-3,8,11,13-tetraene (**6**). Repetition of the decarboxylation in the podocarpic acid series gave, in contrast to the original report,[4,5] a mixture containing 32% of the analog of **2** and 38 and 25% of the analogs of **5**

(1) Part VI: J. W. Huffman, *J. Org. Chem.*, **35**, 3154 (1970).
(2) J. W. Huffman, *ibid.*, **35**, 478 (1970).
(3) C. R. Bennett, R. C. Cambie, R. A. Franich, and T. J. Fullerton, *Aust. J. Chem.*, **22**, 1711 (1969).
(4) C. R. Bennett and R. C. Cambie, *Tetrahedron*, **23**, 927 (1967).
(5) R. C. Cambie and W. A. Denny, *Aust. J. Chem.*, **22**, 1699 (1969), subsequently reported similar data, correcting their original report (ref 4).