a small amount of pale yellow liquid with an amine-like odor was obtained. This turned brown on exposure to the air, gave a positive ferric chloride test, a negative test for chlorine and a positive test for nitrogen, and with chloroplatinic acid formed a salt melting above 250°. These properties match those reported by Stoermer and Brockerhof[17] for 2-methyl-2H-1,4-benzoxazine (XX).

Anal. Calcd. for $(C_9H_9NO)_2 \cdot 2HCl \cdot PtCl_4$: C, 30.68; H, 2.84; N, 3.98. Found: C, 30.63; H, 3.41; N, 4.03.

Results from a run with a 10-min. reaction time were similar.

Of 4-Chloroxanthone (XXII).—To 1.7 g. of XXII in 100 cc. of ether and 100 cc. of ammonia a solution of potassium amide (from 1.1 g. of potassium metal) was added. Reaction time was 30 min. By standard procedures, 3-aminoxanthone, m.p. 233–234° (lit. 232° for 3-aminoxanthone,[36] 199–200° for 4-aminoxanthone[37]), was isolated in 26% yield.

(36) F. Ullmann and C. Wagner, *Ann.*, **355**, 395 (1907).

(37) S. Akagi and T. Iwashige, *J. Pharm. Soc. Japan*, **74**, 610 (1954); *Chem. Abstr.*, **48**, 10742 (1954).

Experiments Directed toward the Total Synthesis of Terpenes. IV. The Synthesis of (±)-Sandaracopimaradiene and (±)-Pimaradiene[1,2]

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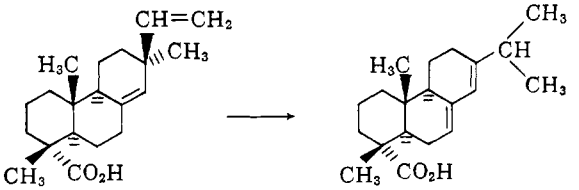
Two synthetic sequences for the conversion of (±)-14-podocarpanone (11) to (±)-sandaracopimaradiene (2) and (±)-pimaradiene (3) are described. The first route involves the methylation of (±)-13-ethylidene-14-podocarpanone (23), while a second, milder pathway proceeds through (±)-13-podocarpen-13-carboxaldehyde (31).

The synthetic challenge presented by the diterpenoid resin acids, such as abietic acid and the pimaric acids, while similar to that of the steroids, has been overlooked until recently because of the lack of any significant therapeutic effect associated with the diterpenes. The solution to the synthetic problems associated with the steroids has not only brought about renewed interest[3] in the resin acids, but also laid an experimental foundation of incalculable value to one rising to the challenge of these acids. As a part of this resurgence of interest in the diterpenes, we began an integrated program directed toward elaborating methods suitable to the total synthesis of the pimaric acids. The pimaric acids, rather than the more common abietic acid, were chosen as a goal since it appeared reasonable to expect that acid catalyzed rearrangement of these acids would ultimately lead to abietic acid. That such was indeed the case was later shown by Wenkert and co-workers[6a] when they effected the isomerization of (+)-pimaric acid to (−)-abietic acid by treatment with sulfuric acid.

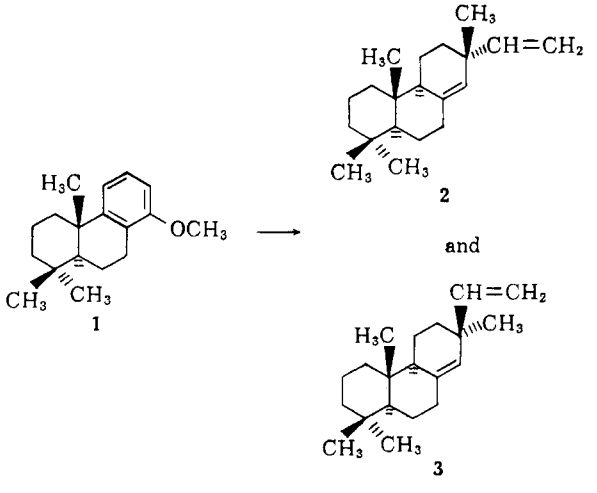


(+)-Pimaric acid (−)-Abietic acid

As a result, a total synthesis of the synthetically more complex pimaric acid would represent a formal total synthesis of abietic acid.

Much as has been done by previous workers,[3] our program was divided into two main phases: one directed toward the construction of a tricyclic acid possessing the appropriate substituents on the *trans*-fused A and B rings and an aromatic C-ring[4]; coupled with this, a program was initiated to investigate methods suitable for the conversion of a model aromatic system to a compound having the ring C substitution pattern of the pimaric acids. In this manner, the procedures developed in the latter phase would be available for application to the intermediate that resulted from the former phase, and hence lead to a scheme for the total synthesis of the pimaric acids.

The work described herein is concerned with the methods that we were able to develop for the construction of the ring C substitution pattern of the pimaric acids. The first choice to be made was that of an appropriate model for this work, and while in principle a simple monocyclic system could serve as such a model, we chose instead the tricyclic ether 1.[5] The rationale behind this choice was that a tricyclic model, lacking only the asymmetry at C-4, would more closely approximate the tricyclic acid resulting from the other phase of the program. An equally important factor was that a stereorational route for the conversion of the ether 1 to the dienes 2 and 3 offered the opportunity to test the earlier stereochemical assignments[6] of the pimaric acids



(1) For a preliminary report of this work, see R. E. Ireland and R. W. Schiess, *Tetrahedron Letters*, No. **25**, 37 (1960).

(2) This investigation was supported by the National Science Foundation through a research grant (G-5912).

(3) For a recent review, see N. A. J. Rogers and J. A. Barltrop, *Quart. Rev.*, **16**, 117 (1962).

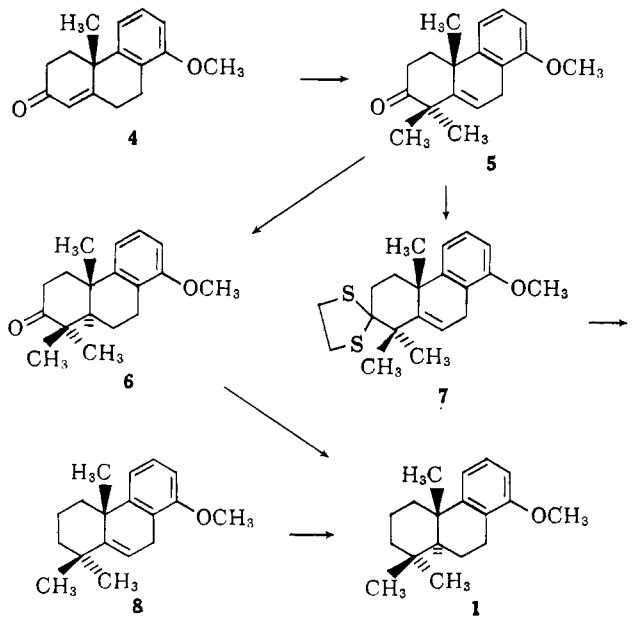
(4) R. E. Ireland and R. C. Kierstead, *J. Org. Chem.*, **27**, 703 (1962).

(5) Steroid numbering is used throughout, and although formulas of only one enantiomer are drawn, they are taken to represent a racemate except where indicated.

(6) (a) E. Wenkert and J. W. Chamberlin, *J. Am. Chem. Soc.*, **81**, 688 (1959); (b) O. E. Edwards and R. Howe, *Can. J. Chem.*, **37**, 760 (1959); (c) B. Green, A. Harris, and W. B. Whalley, *J. Chem. Soc.*, 4715 (1958).

by comparison with the derived pimaradienes. Of added interest at the outset of this work was that the diterpenoid hydrocarbon rimuene was proposed to have the sandaracopimaradiene structure **2**.[7] Hence, by employing the tricyclic ether **1** for our model experiments, we were in a position to test this proposal.

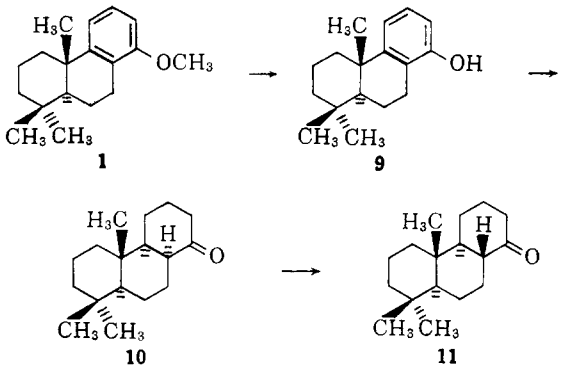
For the ether **1** to serve an efficient model, it must be readily available in large quantities, a condition that was readily satisfied by the application of methods found earlier by those concerned with the construction of polycyclic intermediates for steroid total synthesis. In particular, large quantities of the tricyclic ketone **4** were prepared from 5-methoxy-2-tetralone, following the excellent procedure described by Robinson and co-workers.[8] Introduction of the *gem*-dimethyl system at C-4 was cleanly accomplished in 75% yield according



to the conditions of Woodward and co-workers[9] by treatment of the ketone **4** with excess potassium *t*-butoxide and methyl iodide.

In our hands the obvious and more direct path from the ketone **5** to the ether **1**—namely, catalytic hydrogenation of the 5,6-double bond and reductive removal of the 3-ketone—proved unsatisfactory.[10] Thus, while the saturated ketone **6** was obtained in 50% yield by reduction over 10% palladium on carbon, its isolation in pure form required chromatography and was not readily amenable to large scales. This result, coupled with only a 60% yield of the ether **1** on Wolff–Kishner reduction[11] of the saturated ketone **5**, made us look for another route. A better sequence for effecting the conversion of the ketone **5** to the desired ether **1** was found in the desulfurization of the dithioketal **7**. This ketal was prepared in 97% yield by the elegant procedure of Fieser,[12] and on desulfurization with W-2 Raney nickel[13] in alcohol solution, the olefin **8** resulted in an 81% yield. Finally, catalytic hydrogenation over 10% palladium on carbon afforded a 95% yield of the desired ether **1**. The high yields obtained in these easy steps made this sequence quite attractive. In this manner, the ketone **5** could be converted to the ether **1** in an over-all 81% yield by a method that required the minimum of time and was readily adapted to the large scales necessary.

Our supply of the ether **1** assured, we turned our attention to the modification of the aromatic ring. We had specifically chosen to work with a model with a C-14 oxygen function, for when the aromatic ring was saturated, we could expect to obtain the more stable B/C-ring fusion through enolization of a C-14-keto function. The more stable B/C ring fusion, however, is determined by the orientation of the C-9 hydrogen. Thus, if C-9 hydrogen is α-oriented, the desired B/C-*trans* fusion is more stable than the B/C-*cis* juncture (*trans-anti-trans* > *trans-anti-cis*), but if the C-9 hydrogen were β-oriented, the more stable fusion is that where the rings are *cis*-locked (*trans-syn-cis* > *trans-syn-trans*). It was possible to assure the introduction of a C-9α-oriented hydrogen through the agency of chemical reduction where the more stable *anti* backbone would be expected, but this would require the use of forcing metal–ammonia reduction conditions[14] where the yields are not high. Therefore, it seemed more profitable to investigate the catalytic reduction of the aromatic ring.



To this end the free phenol **9** was prepared in 90% yield from the ether **1** by treatment with hydrobromic–hydriodic acid in glacial acetic acid. Reduction of this phenol over ruthenium in alcohol solution[15] occurred rapidly and afforded a saturated alcohol, which without purification was oxidized with Jones reagent[16] in cold acetone. The crystalline ketone that resulted in a 95% crude yield from this treatment melted at 65–67° when analytically pure (40% yield). When this ketone was chromatographed on alumina, a new ketone, melting at 73–73.5° was obtained in 90% yield. Similarly, if the saturated alcohol were oxidized with Jones reagent[16] and the crude product purified by filtration through

(7) L. H. Briggs, B. F. Cain, B. R. Davis, and J. K. Wilmhurst, *Tetrahedron Letters*, No. **8**, 13 (1959). The authors are indebted to Professor Briggs for providing us with a sample of rimuene.

(8) J. W. Cornforth and R. Robinson, *J. Chem. Soc.*, 1855 (1949).

(9) R. B. Woodward, A. A. Patchett, D. H. R. Barton, D. A. J. Ives, and R. B. Kelly, *J. Chem. Soc.*, 1131 (1957).

(10) This route proved a satisfactory sequence for R. B. Turner and P. E. Shaw [*Tetrahedron Letters*, No. **18**, 24 (1960)] who also prepared the ether **1** as well as the ketone **11**. However, in view of the different experimental conditions employed by these workers, our synthesis is included here.

(11) Huang-Minlon, *J. Am. Chem. Soc.*, **68**, 2487 (1946).

(12) L. F. Fieser, *ibid.*, **76**, 1945 (1954).

(13) R. Mozingo, "Organic Syntheses," Coll. Vol. III, John Wiley and Sons, Inc., New York, N. Y., 1955, p. 181.

(14) W. S. Johnson, B. Bannister, and R. Pappo, *J. Am. Chem. Soc.*, **78**, 6331 (1956).

(15) W. S. Johnson, E. G. Rogier, and J. Ackerman, *ibid.*, **78**, 6322 (1956).

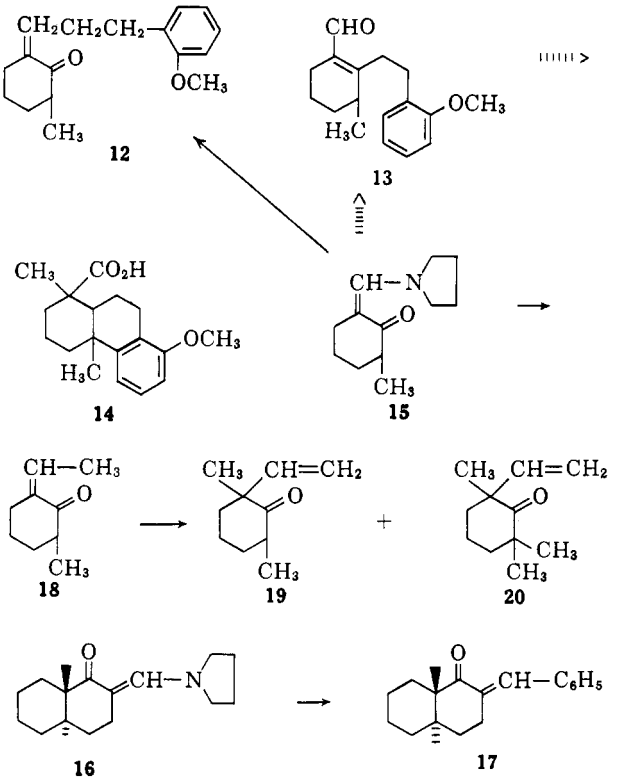
(16) K. Bowden, I. M. Heilbron, E. R. H. Jones, and B. C. L. Weedon, *J. Chem. Soc.*, 39 (1946); see also, C. Djerassi, R. R. Engle, and A. Bowers, *J. Org. Chem.*, **21**, 1547 (1956).

alumina, the 73° ketone was obtained in 86% over-all yield from the phenol **9**.

The behavior of the two ketones obtained in this sequence suggests that the C-9 hydrogen has been introduced in the α-orientation and that the 67° ketone is the less stable *trans-anti-cis* ketone **10** which is isomerized by the basic alumina to the more stable *trans-anti-trans* ketone **11**.

Firstly, the observation that the 5,6-double bond in such tricyclic systems is saturated solely by attack of the α-face of the molecule[17] provides good precedence for saturation of the aromatic system taking a similar steric course. A more compelling argument was found on comparison of the solution infrared spectra of the two ketones **10** and **11**. While these spectra were similar, there were significant differences in the 900–1400-cm.$^{-1}$ region which precluded these two ketones being polymorphic forms of the same substance. On theoretical groups, one can also argue that had saturation of the aromatic ring occurred by β-addition of hydrogen, the resulting *trans-syn-cis* ketone[18] would be the more stable of the pair and would not have undergone isomerization on alumina.[19] Therefore, the assignment of the desired *trans-anti-trans* structure **11**[10] to the 73° ketone appeared to be on firm ground, and we proceeded further with the synthetic scheme.

At this point we called on some experience gained from our work on the first phase of the general resin acid synthesis. The plan envisioned for the construction of the necessary tricyclic acid involved the addition of 2-(*o*-methoxyphenyl)ethylmagnesium bromide to a derivative of 2-hydroxymethylene-6-methylcyclohexanone to generate the aldehyde **13**, which could be methylated, oxidized and cyclized to afford the desired acid **14**. The derivative we chose was the pyrrolidine eneamine **15**,[20] which proved more stable and more readily prepared on a large scale than the more familiar isopropyl ether.[21] However, unlike the isopropyl ether, we found that the addition of the organometallic reagent (either the magnesium or the lithium reagent) did not take place in the desired 1,2-sense to generate the aldehyde **13** after acid hydrolysis, but rather in the 1,4-sense[22] and thereby afforded the unsaturated ketone **12**. This conclusion is based on the observations that the infrared spectrum of this material lacked a band attributable to an aldehydic hydrogen at 2750 cm.$^{-1}$ and



the substance also failed to deposit metallic silver from Tollens reagent. Also indicative of the presence of a cisoid α,β-unsaturated ketone system was a maximum in the ultraviolet spectrum at 245 mμ (ϵ 7600). Further confirmation of the 1,4-mode of addition of organometallic derivatives to the pyrrolidinomethylene ketones was found when 2-benzylidene-1-decalone (**17**)[23] was obtained in 95% yield by treatment of the eneamine ketone **16** with phenylmagnesium bromide.

Even though these results left much to be desired from the standpoint of preparing the acid **14**, they opened up an excellent avenue for the production of alkylidene ketones—compounds that are not readily available by direct condensation of aliphatic aldehydes and ketones. Thus, when the pyrrolidinomethylene ketone **15** was treated with methylmagnesium bromide, a 54% yield of the ethylidene ketone **18** resulted.

Taking advantage of the ready availability of the ethylidene ketone **18**, we investigated the alkylation reaction with methyl iodide and potassium *t*-butoxide. When the ketone **18** was methylated using the standard reaction conditions,[9] only a very low yield of monomeric product was formed. The obvious conclusion to be drawn from such a result is that the base establishes an equilibrium between the ketone and its enolate and that polymerization *via* Michael-type addition of the enolate to un-ionized ketone takes place before (or more rapidly than) methylation. To overcome this difficulty, we employed a large excess (36-fold) of potassium *t*-butoxide on the premise that if all the ketone could be enolized, the enolate itself would not undergo polymerization. It was gratifying to find that this was indeed the case since, when the ketone **18** was methylated under these conditions, there resulted a 75% yield of a mixture of the ketones **19** and **20**. There was very little of the monomethylated product formed because of the large excess of reagents; it was possible, however, to isolate

(17) G. Stork and J. W. Schulenberg, *J. Am. Chem. Soc.*, **84**, 284 (1962).

(18) R. F. Church and R. E. Ireland, *J. Org. Chem.*, **27**, 17 (1962).

(19) This argument relies on the assumption that hydrogenation of the ring occurs completely during one adsorption on the catalyst and thereby introduces all of the hydrogens from the same side and generates a B/C-*cis* ring fusion. If a multiadsorption process were involved then, barring the steric requirements of the molecule, a B/C-*trans* fusion could theoretically be produced. The 9α,8β-B/C *trans* system would lead to the stable *trans-anti-trans* ketone—a condition we did not observe. However, the 9β,8α-B/C *trans* system would lead to the base labile *trans-syn-trans* ketone on oxidation. If such were the case, then the isomerization of the initially formed ketone on alumina would be from a *trans-syn-trans* ketone to a *trans-syn-cis* one. This latter situation is very unlikely, for even if the hydrogenation were to be a step-wise process, the fewer double bonds remaining in ring C, the more attack of the α-face should be favored by the puckering of the ring. Secondly, the product of the reduction appears to be stereochemically quite homogeneous—a result that would not be expected of a stepwise reduction, for there would certainly be some of the C-9 hydrogen introduced in the α-orientation even by a step-wise process. Finally, the authentic *trans-syn-cis* ketone has recently been prepared[18] in these laboratories and was shown to differ from the stable 73° ketone described here by comparison of their infrared spectra and depression of the mixture melting point.

(20) G. Stork and H. K. Landesman, *J. Am. Chem. Soc.*, **78**, 5128 (1956).

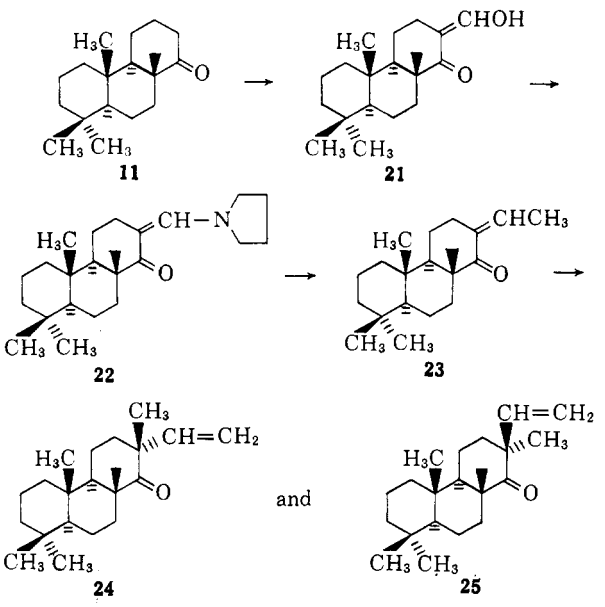
(21) W. S. Johnson and H. Posvic, *ibid.*, **69**, 1361 (1947).

(22) C. Jutz, *Ber.*, **91**, 1867 (1958).

(23) W. S. Johnson, *J. Am. Chem. Soc.*, **65**, 1317 (1943).

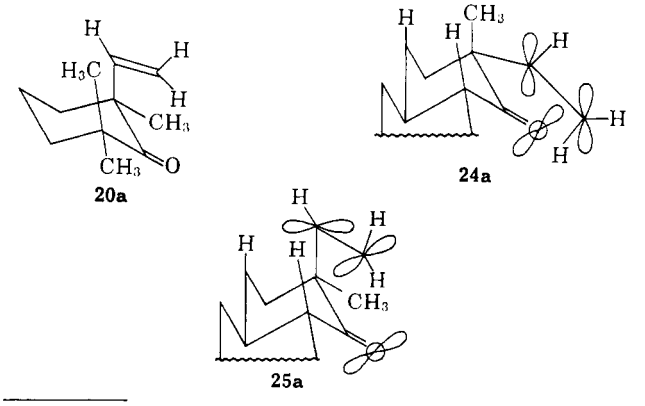
the pure trimethyl ketone **20** by distillation. That the methylation had occurred on the α-carbon with shift of the double bond out of conjugation was shown both by the characteristic bands of the vinyl group at 3.24, 5.48, 6.18, 10.08, and 10.94 μ in the infrared spectrum of the product and by the absence of the conjugated ketone chromophoric system in the ultraviolet spectrum [λ_{max}^{alc} 301 mμ (ϵ 75)].

Although these methylation conditions were sufficiently vigorous to methylate both the α and the α' positions of the ethylidene ketone **18**, we felt that were they applied to (±)-13-ethylidene-14-podocarpanone (**23**), there would be a good chance of observing only methylation at the 13-position in view of the difficulty previous workers have had in effecting angular methylation.[23,24] To this end, (±)-14-podocarpanone (**11**) was converted to its hydroxymethylene[21] derivative **21** and thence to the pyrrolidinomethylene ketone **22**



in an over-all 83% yield by azeotropic removal of water from a benzene solution of the hydroxymethylene ketone **21** and pyrrolidine. Treatment of the eneamine **22** with methylmagnesium bromide in benzene–ether solution, followed by hydrolysis of the reaction mixture with 10% aqueous hydrochloric acid led to a 94% yield of the ethylidene ketone **23**. On methylation of the ketone **23** in the presence of a 130-fold excess of potassium *t*-butoxide, there was obtained a 71% yield of crude, monomeric product, the ultraviolet spectrum of which indicated that *ca.* 8% of the conjugated ketone still remained. By a process of crystallization and chromatography, we were able to isolate from this crude distillate a 9% yield of the pure equatorially methylated ketone **25**, m.p. 78–80°, and a 32% yield of the pure axially methylated ketone **24**, m.p. 69–70°. These crucial stereochemical assignments are based on the following reason processes. In the absence of major steric requirements, one would expect that methylation of the enolate of the ketone **23** to be governed by stereoelectronic control whereby the predominate product should be that resulting from axial attack.[25] Thus on theoretical grounds, one would expect that the ketone formed in preponderant yield from our methylation would be that having structure **24** [β-(axial)methyl]. If we assume that no selective loss of one ketone occurred during our fractionation of the crude product, then the 70° ketone, obtained in 32% yield, must have the structure **24**. Further, we observed that the 70° ketone was more strongly adsorbed on Florisil than its epimer. This would tend to indicate that the polar substituents on the 70° ketone are more exposed than those on the epimeric 80° ketone, and therefore suggests that the 70° ketone possesses the α-(equatorial)-vinyl grouping as required by structure **24**.

More rigorous evidence for this stereochemical assignment was found in an analysis of the ultraviolet spectra of the two ketones. In alcohol solution the 70° ketone exhibited a maximum at 292 mμ (ϵ 51), while the 80° ketone had its maximum at 294 mμ (ϵ 104). These values indicate, first of all, that the ketones are not methylated at C-8, for the maxima of both occur at significantly lower wave length than either tetramethylcyclohexanone [λ_{max}^{alc} 300 (ϵ 24)] or 2,2,6-trimethyl-6-vinylcyclohexanone (**20**) [λ_{max}^{alc} 301 (ϵ 75)], both of which are known to be $\alpha,\alpha,\alpha',\alpha'$-tetrasubstituted cyclohexanones. Secondly, the bathochromic shift observed between the two ketones indicates that the vinyl grouping in the 80° ketone is in a position to interact with the carbonyl group, while that in the 70° ketone is not. Molecular models of the two possible structures **24** and **25** show that while there is free rotation about the C-4 vinyl grouping bond, the more stable conformations are those indicated in structures **24a** and **25a**. It can be seen that only in structure **25a** can there be any interaction between the π_c orbital of the vinyl group and the nonbonding p_n-orbital of the carbonyl oxygen. Such an interaction should lead to a p_n-π_c^* transition of the type discussed by Labhart and Wagniere[26] and hence a bathochromic displacement of the carbonyl absorption should be observed in the spectrum of the ketone with structure **25a**. Because of the free rotation about the C-13 vinyl grouping bond, this interaction would not be expected to be as great in magnitude as some of the cases mentioned by these[26] and other authors.[27] That this change in the ultraviolet absorption of the two ketones was not due solely to solvent interaction was shown by their spectra in cyclohexane where the 80° ketone absorbed at 295 mμ (ϵ 98) and the 70° ketone at 294 mμ (ϵ 45). It is also interesting to



(24) J. W. Cook and C. A. Lawrence, *J. Chem. Soc.*, 817 (1937); A. J. Birch and R. Robinson, *ibid.*, 501 (1944).

(25) M. E. Kuehne, *J. Am. Chem. Soc.*, **83**, 1492 (1961); W. S. Johnson, D. S. Allen, Jr., R. R. Hindersin, G. N. Sausen, and R. Pappo, *ibid.*, **84**, 2181 (1962).

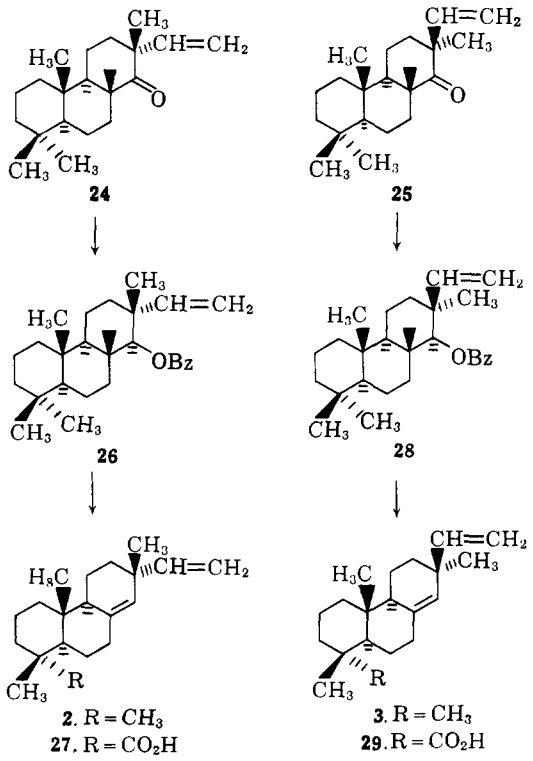
(26) H. Labhart and N. S. Wagniere, *Helv. Chim. Acta*, **42**, 2219 (1959).

(27) S. Winstein, L. deVries, and R. Orloski, *J. Am. Chem. Soc.*, **83**, 2020 (1961), and references cited therein.

note that the ultraviolet absorption of the vinyl cyclohexanone **20** is more intense than the analogous saturated 2,2,6,6-tetramethylcyclohexanone—a result that suggests the presence of the conformation **20a**. A similar effect has been observed by Cookson[28] for α,α-diphenylcyclohexanone, where one phenyl group must occupy an axial conformation. On the basis of this analysis and the circumstantial evidence cited above, we have assigned structure **25** to the 80° ketone and structure **24** to the 70° ketone.

The infrared spectra of the two epimeric vinyl ketones **24** and **25** also show a small, but noticeable shift in the position of the principle vinyl absorption band. This strong band occurs at 10.96 μ in the spectrum of the α-(equatorial) vinyl ketone **24**, whereas, this band was found to occur at 10.88 μ in the spectrum of the β-(axial) vinyl ketone **25**. We have found[29] throughout our work that this relationship between the conformation of the vinyl group and position of this band is quite diagnostic. For instance, methyl sandaracopimarate, methyl isopimarate and the corresponding sandaracopimaraidene and isopimaradiene all have an equatorial vinyl substituent and all show a strong band at 10.96–10.98 μ, whereas methyl pimarate and pimaradiene with axial vinyl groups absorb at 10.86–10.88 μ.

The final problem to be overcome in our quest for a route to the pimaradienes was the conversion of the C-14 ketone to a $\Delta^{8(14)}$ double bond. The first step in this process was the reduction of the ketones **24** and **25** to their corresponding alcohols by treatment with sodium in alcohol solution. In view of the homoallylic character of these alcohols, it was felt that in effecting their elimination, a nonionic process was necessary to prevent skeletal rearrangements. Therefore, the individual alcohols were not purified themselves but converted directly to their benzoates with benzoyl chloride in pyridine solution. In this fashion the ketone **24** led to the benzoate **26** in 81% yield and its epimer **25** afforded a 75% yield of the benzoate **28**. In each case the mode of reduction dictates that the C-14 oxygen bond be equatorial and hence *cis* to the C-8 hydrogen. Advantage was then taken of the concerted character of the pyrolytic ester elimination reaction to remove the elements of benzoic acid and generate the desired dienes. Thus, when the benzoate **26** was sublimed through a glass wool packed chamber heated at 430°, there was obtained a 79% yield of the diene **2**, while the same treatment of the benzoate **28** afforded an 82% yield of the diene **3**. Each diene was purified by filtration through an alumina column in pentane solution and shown to consist of only one component to the extent of at least 90% by gas-liquid chromatography. An important condition of the latter criterion of purity was that a mixture of the two dienes was readily resolved into its components under the same gas-liquid chromatographic conditions; the diene with the axial vinyl grouping **3** was retained on the column 0.89 as long as the equatorial vinyl diene **2**.



At this point it became important to compare the properties of our synthetic dienes **2** and **3** of known structure and stereochemistry with their optically active counterparts derivable from sandaracopimaric and pimaric acids, respectively. The conversion of these acids[30] to their dienes followed the classical reaction sequence: $RCO_2H \rightarrow RCH_2OH \rightarrow RCHO \rightarrow RCH{=}NNHCONH_2 \rightarrow RCH_3$. In each case, although the aldehydes, sandaracopimaral and pimaral, were isolated and characterized once, it was found more expedient to isolate them from the oxidation with Jones reagent[16] as their semicarbazones, for the free aldehydes were relatively unstable. Application of the Huang–Minlon modification[11] of the Wolff–Kishner reduction to these semicarbazones directly proved a very satisfactory method for preparing the desired optically active dienes (−**2**) and (+**3**).[31] Thus sandaracopimaric acid (**27**) afforded a 56% over-all yield of sandaracopimarodiene (−**2**), m.p. 41–42°, $[\alpha]D$ −12°, and pimaric acid (**29**) gave a 66% over-all yield of pimaradiene (+**3**), m.p. 24–26°, $[\alpha]D$ +99°. That no skeletal rearrangement had taken place during this degradation and that these dienes were indeed stereochemically and structurally the same as their parent acids was shown by the persistence at every stage of two characteristic skeletal vibrations at 854 cm.$^{-1}$ and 865 cm.$^{-1}$ in the infrared spectra of the intermediates, as well as the acids and the dienes themselves. The 800–900-cm.$^{-1}$ region of the infrared spectrum seems to be quite sensitive to the basic skeleton of the hydrophenananthrene system, for the pattern of bands in this region is insensitive to the type and stereochemistry of the substitution—*i.e.*, α or β-CO_2R, CHO, CH_2OH, CH_3 do not change the pattern—but is quite sensitive to both the position of the substituents on the periphery of the ring system, the stereochemistry of the backbone—*i.e.*, the *trans-syn*-$\Delta^{8(14)}$ system[18] absorbs at 860 cm.$^{-1}$ only—and the position of the nuclear double bond—*i.e.*, the *trans-anti*-Δ^7 system (iso-

(28) R. C. Cookson and N. S. Wariyar, *J. Chem. Soc.*, 2302 (1956).
(29) See also, H. H. Bruun, *Acta Chem. Scand.*, **10**, 577 (1956).
(30) The authors are greatly indebted to Dr. O. E. Edwards for supplying us with generous quantities of these acids.
(31) The salient features of this degradation sequence are recorded in the experimental section, where they differ from earlier methods and may be of general use. The experimental procedures for the earlier stages have already been recorded by other workers.[32,40]
(32) R. E. Ireland and J. Newbould, *J. Org. Chem.*, **27**, 1931 (1962).

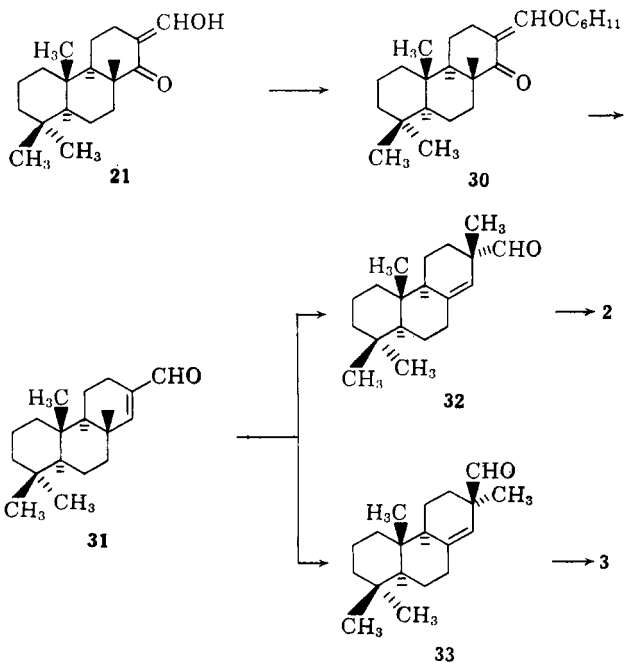
pimaric) exhibits three bands at 820 cm.$^{-1}$, 835 cm.$^{-1}$ and 860 cm.$^{-1}$.[32]

Comparison of the infrared spectra of the synthetic dienes **2** and **3** with sandaracopimaradiene (−**2**) and pimaradiene (+**3**) revealed their respective identities. Identical retention times were also obtained on gas-liquid chromatography between the synthetic dienes and their respective optically active counterparts. This identity between synthetic material of well founded structure and stereochemistry and the natural compounds provides good confirmation of the stereochemical assignments made by earlier workers.[6]

It was of interest to note that the infrared spectrum and gas-liquid chromatographic mobility of the diterpene rimuene,[2] proposed to have the sandaracopimaradiene structure, were quite different. Needless to say, the melting point of a mixture of rimuene (m.p. 54–55°) and sandaracopimaradiene (m.p. 41–42°) was depressed to room temperature. This represented the first clear-cut evidence that the structural proposal for rimuene was in error and is responsible for a reinvestigation of the chemistry of this diterpene.

Despite the success of the above synthesis of the ring C-substitution pattern of the pimaric acids, the final pyrolytic decomposition was considered a weak point in the synthetic scheme. Were it necessary to apply this sequence to the tricyclic acid **14** that was the goal of the first phase of our program, we felt that this last step would be fraught with experimental difficulties. Thus, in order to circumvent this step, we investigated another route to the dienes **2** and **3** from the ketone **11**.

As mentioned above, the earlier work of others had shown that the products from the alkoxymethylene ketones and organometallic reagents as well as hydrides led principally to 1,2-addition.[33] Acid-catalyzed allylic rearrangement[34] of the primary reaction product then formed an α,β-unsaturated aldehyde. With this precedence before us, we converted the ketone **11** to the cyclohexoxymethylene ketone **30** in 72% over-all yield



by azeotropic removal of water from a benzene: *p*-toluenesulfonic acid solution of the hydroxymethylene derivative **21** and cyclohexanol. On reduction with methanolic sodium borohydride and then treatment with aqueous mineral acid, there resulted a 66% yield of the α,β-unsaturated aldehyde **31**.

Again in order to effect methylation of this conjugated carbonyl system, we had to resort to large excesses of base. However, in the case of the aldehyde, polymerization was not the main problem, for when insufficient base was used, unchanged aldehyde was recovered. The aldehyde appeared to be less readily enolized than the ethylidene ketone. When a 60-fold excess of potassium *t*-butoxide was employed, there was obtained a 77% yield of colorless, volatile, semicrystalline distillate that showed only a band for a saturated aldehyde in the infrared spectrum. By a process of careful chromatography, we were able to isolate first a 16% yield of the aldehyde **33**, m.p. 56–59°, and then a 28% yield of the epimer **32**, m.p. 76–78°. The chromatography was followed with the aid of gas-liquid chromatography under conditions such that the two aldehydes were easily resolved. The resultant crystalline aldehydes were shown to be substantially free from any impurities by this same technique.

It was a simple matter to complete our second route to the pimaradienes by treatment of the respective aldehydes **32** and **33** with methyl triphenylphosphonium bromide[35] in the presence of potassium *t*-butoxide. In this manner the aldehyde **32** afforded an 87% yield of the diene **2**, identical with that prepared by the former route and that from natural sandaracopimaric acid **27**. Similarly, the aldehyde **33** afforded a 96% yield of the epimeric diene **3**, identical with pimaradiene. The dienes prepared by this route were sufficiently free of contaminants to crystallize (no more than a trace of impurity is necessary to prevent the crystallization of the (±)-dienes). Thus we were able to add the final, aesthetically satisfying physical constant to those already recorded for the synthetic dienes **2** and **3** when it was found that (±)-sandaracopimaradiene melted at 22–25° while (±)-pimaradiene melted at 28–31°, and a mixture of the two remained an oil even at 0°.

Experimental[36]

7-Keto-1-methoxy-8,8,13-trimethyl-5,6,7,8,10,13-hexahydrophenanthrene (5).—The procedure used is essentially that of Woodward.[9] To a solution of 20 g. (0.513 g.-atom) of potassium in 640 ml. of dry *t*-butyl alcohol in a nitrogen atmosphere at room temperature was added all at once a solution of 41.5 g. (0.172 mole) of the unsaturated ketone **4** in 75 ml. of dry benzene. After stirring for 5 min. at room temperature, the red-orange solution was thoroughly chilled with an ice–water bath, and 64

(33) R. B. Woodward and W. M. McLamore, *J. Am. Chem. Soc.*, **71**, 379 (1949); P. Seifert and H. Schinz, *Helv. Chim. Acta*, **34**, 728 (1951).

(34) M. Stiles and A. Longroy, *Tetrahedron Letters*, 337 (1961).

(35) G. Wittig and V. Schöllkopf, *Ber.*, **87**, 1318 (1954).

(36) Unless specified otherwise, the term "petroleum ether" refers to reagent grade material boiling in the range 30–60°. All gas-liquid chromatograms were obtained on a Barber–Coleman Model 10 gas-liquid chromatography unit using a 6-ft. column packed with 15% diethylene glycol succinate on Chromosorb W. Melting points were determined on a Kofler Hot Stage and are corrected for stem exposure. Analyses were performed by Spang Microanalytical Laboratory, Ann Arbor, Mich. Infrared spectra that are recorded in microns were measured on a Perkin–Elmer Infracord Model 137 and those recorded in reciprocal centimeters were measured on a Perkin–Elmer Model 237 Spectrometer. Strong bands are marked (s); all others reported are of moderate intensity unless otherwise specified. Ultraviolet spectra were determined on a Cary Recording Spectrophotometer (Model 11 MS). Florisil refers to the product of the Floridin Company, Tallahassee, Florida, 60/100 mesh. A portion of the starting ketone **4** was supplied by HI Laboratories, 7878 Whitmore Lake Road, Whitmore Lake, Mich.

ml. of methyl iodide added all at once. A white precipitate began forming almost immediately, and the reaction mixture became warm. The mixture was stirred overnight while the ice melted, and then 400 ml. of water was added and most of the *t*-butyl alcohol removed by distillation at reduced pressure. The solid product, isolated from the aqueous liquor by ether extraction, was crystallized from ethyl alcohol and afforded 34.5 g. (75%) of the ketone **5**, m.p. 112–114.5°, which gave a bright yellow precipitate with 2,4-dinitrophenylhydrazine reagent. The analytical sample, obtained after several further crystallizations from the same solvent, melted at 115–116° with softening at 108° (reported,[10] m.p. 109.5–110.5°). A mixture of this material and the starting unsaturated ketone **4** melted over the range 93–100°.

Anal. Calcd. for $C_{18}H_{22}O_2$: C, 79.96; H, 8.20. Found: C, 79.86; H, 8.11.

Infrared: $\tilde{\nu}_{max}^{HCCl_3}$ 1710 cm.$^{-1}$ (s) (> C=O, satd.); 1678 cm.$^{-1}$ (w) (> C = C <); 1260 cm.$^{-1}$ (s) (C—O—C).

7-Keto-1-methoxy-8,8,13-trimethyl-5,6,7,8,9,10,13,14-*trans*-octahydrophenanthrene (6).—A solution of 2.0 g. (7.4 mmoles) of the ketone **5** in 25 ml. of glacial acetic acid containing 200 mg. of suspended 10% palladium-on-carbon was stirred in a hydrogen atmosphere for 12 hr. during which time 209 ml. of hydrogen was absorbed (196 ml. of hydrogen calculated for 1 mol. equiv.). After removal of the catalyst by filtration and the acetic acid by distillation at reduced pressure, the residue was crystallized from ethyl alcohol and afforded 1.3 g. of an oily solid. This material was purified by elution from 80 g. of alumina (Fisher) with 1000 ml. of 20% ether:petroleum ether and crystallization from methanol. In this manner there was obtained 1.0 g. (50%) of saturated ketone **6** m.p. 93–96°. The analytical sample, m.p. 95.5–96.5° (reported,[10] m.p. 90–93°), was obtained after two further crystallizations from the same solvent.

Anal. Calcd. for $C_{18}H_{24}O_2$: C, 79.37; H, 8.88. Found: C, 79.26; H, 8.86.

Infrared: $\tilde{\nu}_{max}^{HCCl_3}$ 1710 cm.$^{-1}$ (s) (>C=O, satd.); 1260 cm.$^{-1}$ (s) (C—O—C).

7,7-Ethylenedithio-1-methoxy-8,8,13-trimethyl-5,6,7,8,10,13-hexahydrophenanthrene (7).—According to the procedure of Fieser,[12] a solution of 5.4 g. (0.02 mole) of the ketone **5** and 2.7 ml. of ethanedithiol in 25 ml. of glacial acetic acid was treated with 2.7 ml. of freshly distilled boron trifluoride etherate. After standing several minutes at room temperature, the solution was scratched to induce crystallization of the thioketal and then cooled for 2 hr. in a cold water bath (*ca.* 20°). Filtration of the mixture and washing the filter cake with methanol afforded 6.7 g. (97%) of the thioketal **7**, m.p. 175–177° with softening at 171°. The analytical sample, obtained after crystallization from acetone, was fine needles and melted at 177–178° with softening at 173°.

Anal. Calcd. for $C_{20}H_{26}OS_2$: C, 69.31; H, 7.56; S, 18.51. Found: C, 69.37; H, 7.58; S, 18.71.

The corresponding **propylenethioketal**, prepared in the same fashion in 87% yield from 39 g. (0.144 mole) of the ketone **5** and 20 ml. of 1,3-propanedithiol in 180 ml. of glacial acetic acid containing 20 ml. of boron trifluoride etherate, melted at 168–171°. The analytical sample, obtained after three crystallizations from acetone, was fine needles and melted at 171–172°.

Anal. Calcd. for $C_{21}H_{28}OS_2$: C, 69.95; H, 7.83; S, 17.79. Found: C, 69.99; H, 7.96; S, 17.70.

1-Methoxy-8,8,13-trimethyl-5,6,7,8,10,13-hexahydrophenanthrene (8).—To a well stirred suspension of 20 teaspoonfuls of W-2 Raney nickel[13] in 1 l. of absolute ethanol was added 17.0 g. (0.049 mole) of the ethylenethioketal **7**, and the mixture was stirred and refluxed overnight. After removal of the nickel by filtration, the solvent was evaporated at reduced pressure and the residue crystallized from ethyl alcohol. In this manner there was obtained 10.2 g. (81%) of the olefin **8**, m.p. 91–93°, as lustrous plates. The analytical sample, m.p. 93–94°, was obtained after two further crystallizations from the same solvent.

Anal. Calcd. for $C_{18}H_{24}O$: C, 84.32; H, 9.44. Found: C, 84.27; H, 9.53.

Infrared: $\tilde{\nu}_{max}^{HCCl_3}$ 1678 cm.$^{-1}$ (w) (> C=C <); 1250 cm.$^{-1}$ (s) (C—O—C).

1-Methoxy-8,8,13-trimethyl-*trans*-5,6,7,8,9,10,13,14-octahydrophenanthrene (1). (a) By Hydrogenation of the Olefin 8.—A mixture of 10.0 g. (0.04 mole) of the olefin **8** and 1.0 g. of 10% palladium-on-carbon in 100 ml. of cyclohexane and 150 ml. of glacial acetic acid was shaken overnight in a Parr hydrogenation apparatus at an initial pressure of 40 p.s.i. of hydrogen. After this time a drop of 4 p.s.i. was observed and the up-take of hydrogen ceased. After removal of the catalyst, the solution was diluted with water and the product isolated by ether extraction. Evaporation of the ether at reduced pressure and crystallization of the residue from ethyl alcohol afforded 9.8 g. (95%) of the saturated derivative **1**, m.p. 119.5–120.5° with softening at 117° (reported,[10] m.p. 114–115°). The melting point was not raised by further crystallization from alcohol.

Anal. Calcd. for $C_{18}H_{26}O$: C, 83.67; H, 10.14. Found: C, 83.64; H, 10.15.

Infrared: $\tilde{\nu}_{max}^{HCCl_3}$ 1255 cm.$^{-1}$ (s) (C—O—C).

The same saturated derivative **1**, m.p. 118.5–119.5° with softening at 114°, was obtained in 60% yield on reduction of 1.08 g. (4 mmoles) of the saturated ketone **6** with 1.0 ml. of hydrazine hydrate and 5.0 g. of potassium hydroxide in 20 ml. of diethylene glycol according to the Huang-Minlon modification[11] of the Wolff-Kishner reduction.

(b) Directly from the Ketone 5.—When 20 g. (0.074 mole) of the ketone **5** was converted to the propylenethioketal with 11.2 ml. of 1,3-propanedithiol in 100 ml. of glacial acetic acid containing 11.2 ml. of boron trifluoride etherate, there was obtained 25 g. of crude thioketal. This crude product was desulfurized with 30 teaspoonfuls of W-2 Raney nickel[13] in 1500 ml. of ethanol. The residue, obtained after removal of the catalyst by filtration and the solvent by distillation at reduced pressure, was hydrogenated as above over 20 g. of 10% palladium on carbon in 100 ml. of cyclohexane and 150 ml. of glacial acetic acid. After the same work-up as described in part **a**, there was obtained 15.4 g. (81%) of the octahydrophenanthrene **1**, m.p. 118.5–119.5°, after one crystallization from ethyl alcohol.

1-Hydroxy-8,8,13-trimethyl-*trans*-5,6,7,8,9,10,13,14-octahydrophenanthrene (9).—A solution of 15.5 g. (0.06 mole) of the ether **1** in 200 ml. of glacial acetic acid and 200 ml. of 48% aqueous hydrobromic acid containing 20 ml. of aqueous hydriodic acid (sp. gr. 1.5 g./cc.) was stirred and refluxed in a nitrogen atmosphere for 12 hr. After cooling, the reaction mixture was diluted with 250 ml. of water, and the precipitated phenol isolated by ether extraction. The residue, obtained after evaporation of the ether at reduced pressure, was crystallized from petroleum ether (90–100°) and afforded 13.1 g. (90%) of the phenol **9**, m.p. 152.5–154° (reported,[10] m.p. 146–148°). The melting point was not raised by further crystallization from methylcyclohexane or benzene:petroleum ether.

Anal. Calcd. for $C_{17}H_{24}O$: C, 83.55; H, 9.90. Found: C, 83.60; H, 9.86.

Infrared: $\tilde{\nu}_{max}^{Nujol}$ 3300 cm.$^{-1}$ (s) (O—H).

(±)-14-Podocarpanone (11).—According to the method developed by Johnson,[14] 6.24 g. (0.0256 mole) of the phenol **9** and 0.62 g. of ruthenium oxide in 70 ml. of ethanol were shaken under 1500 p.s.i. of hydrogen pressure at 50° for 8 hr. After cooling, the catalyst was removed by filtration and five such charges—a total of 31.2 g. (0.128 mole) of phenol—were combined, and the solvent removed at reduced pressure. The resulting crude alcohol was dissolved in 500 ml. of acetone, cooled to 0°, and oxidized with 35 ml. of Jones reagent.[15] The acetone solution was decanted from the precipitated salts and evaporated at reduced pressure. Cold water was added to the salts and this mixture combined with residue from the acetone portion. The crude ketone **10**, isolated from these aqueous liquors by ether extraction, amounted to 30 g. On chromatography of this material on 750 g. of alumina (Fisher), there was eluted 27.4 g. (86%) of the pure ketone **11**, m.p. 71–73°, with 4 l. of 2% benzene:petroleum ether. The analytical sample, m.p. 73–73.5°, was obtained after two crystallizations from methanol (reported,[10] m.p. 67–68°).

Anal. Calcd. for $C_{17}H_{28}O$: C, 82.20; H, 11.36. Found: C, 82.37; H, 11.48.

Infrared: $\tilde{\nu}_{max}^{HCCl_3}$ 1701 cm.$^{-1}$ (s) (>C=O), 1148 cm.$^{-1}$ (w) and 1124 cm.$^{-1}$ (w).

In another experiment, 1.00 g. (0.004 mole) of crude oily alcohol from reduction was oxidized with 1.0 ml. of Jones reagent in 50 ml. of acetone at 0°. The reaction mixture was diluted with 250 ml. of water, and the ketone **10** isolated by ether extraction. When the crude crystalline product, amounting to 0.96 g. (95%), m.p. 60–65°, was crystallized two times from methanol, there resulted 0.40 g. (40%) of the pure *trans-anti-cis* ketone **10**, m.p. 65–67°. Exposure of 0.30 g. of this material in petroleum ether solution to 10 g. of alumina (Fisher), and then elution with 250 ml. of benzene afforded 0.27 g. (90% recovery) of the *trans-anti-trans* ketone **11**, m.p. 72–73°.

Anal. Calcd. for $C_{17}H_{28}O$: C, 82.20; H, 11.36. Found: C, 82.33; H, 11.37.

Infrared: $\nu_{max}^{HCCl_3}$ 1703 cm.$^{-1}$ (s) (>C=O); 1175 cm.$^{-1}$ (w), 1151 cm.$^{-1}$ (w) and 1115 cm.$^{-1}$ (w).

2-Methyl-6-pyrrolidinomethylenecyclohexanone (15).—A solution of 73 g. (0.52 mole) of 2-methyl-6-hydroxymethylenecyclohexanone and 39 g. (0.52 mole) of pyrrolidine in 500 ml. of benzene was refluxed for 4 hr. under a Dean–Stark water separator. At the end of this period, there had collected 9.9 ml. of water. After the benzene was removed at reduced pressure, distillation of the residue afforded 95 g. (94%) of the pyrrolidinomethylene ketone **15**, b.p. 125–128° (0.12 mm.). Redistillation of this material gave the analytical sample, which boiled at 124–125° (0.05 mm.) ($n^{24.5}$°D 1.5812 on supercooled liquid, m.p. 47–50°).

Anal. Calcd. for $C_{12}H_{19}NO$: C, 74.56; H, 9.91; N, 7.25. Found: C, 74.60; H, 9.82; N, 7.21.

Infrared: λ_{max}^{film} 6.10 μ (>C=O); 6.48, 6.55 μ (s) (conj. C=C).

2β-(*o*-Methoxyphenyl)propylidene-6-methylcyclohexanone (12).—To the Grignard reagent prepared in 200 ml. of dry ether from 87 g. (0.405 mole) of 2-(*o*-methoxyphenyl)ethyl bromide and 11.1 g. (0.453 g.-atom) of magnesium was added 78.5 g. (0.406 mole) of the eneamine **15** in 150 ml. of dry ether, and the mixture was decomposed by the addition of 300 ml. of 2 *N* aqueous hydrochloric acid, and the product isolated from the ethereal layer after it was washed with water, saturated brine, dried (Na_2SO_4), and evaporated. Distillation of the resulting brown oil afforded 80.3 g. (77%) of the ketone **12**, b.p. 152–155° (0.3 mm.), n^{25}°D 1.5457. The analytical sample, obtained after redistillation, boiled at 130–131° (0.05 mm.), n^{25}°D 1.5452. This material failed to give any evidence of oxidation when treated with Tollens reagent.

Anal. Calcd. for $C_{17}H_{22}O_2$: C, 79.03; H, 8.58. Found: C, 79.10; H, 8.58.

Ultraviolet: λ_{max}^{alc} 245 mμ (ϵ 7600). **Infrared:** λ_{max}^{film} 5.92 μ (s) (>C=O).

The 2,4-dinitrophenylhydrazone melted at 170–171.5° after three recrystallizations from ethyl acetate:methanol.

Anal. Calcd. for $C_{23}H_{26}N_4O_5$: C, 63.00; H, 5.98; N, 12.78. Found: C, 62.78; H, 5.86; N, 12.62.

2-Ethylidene-6-methylcyclohexanone (18).—To 200 ml. of a 0.78 *M* ethereal methylmagnesium bromide solution was added 27 g. (0.14 mole) of the eneamine **15** in 50 ml. of ether, and the reaction mixture stirred for 2 hr. After the addition of 150 ml. of 2 *N* aqueous hydrochloric acid, the ketone **18** was isolated from the ethereal extracts. Distillation of the light orange residue (14.2 g.; 74%) afforded 10.4 g. (54%), b.p. 129–131° (76 mm.), λn^{23}°D 1.4832. The analytical sample, obtained by redistillation, boiled at 63.5° (2.5 mm.), n^{23}°D 1.4841.

Anal. Calcd. for $C_9H_{14}O$: C, 78.21; H, 10.21. Found: C, 77.90; H, 10.16.

Ultraviolet: λ_{max}^{alc} 241 (ϵ 6950). **Infrared:** λ_{max}^{film} 5.92 μ (s) (>C=O); 6.18 μ (C=C).

The 2,4-dinitrophenylhydrazone melted at 156–157° after three recrystallizations from methanol.

Anal. Calcd. for $C_{15}H_{18}N_4O_4$: C, 56.59; H, 5.70; N, 17.60. Found: C, 56.66; H, 5.65; N, 17.67.

2-Pyrrolidinomethylene-1-decalone (16).—A solution of 57.0 g. (0.315 mole) of 2-hydroxymethylene-1-decalone[21] and 41.0 ml. (35.5 g. 0.5 mole) of pyrrolidine in 300 ml. of benzene was refluxed under a Dean–Stark water separator for 4 hr.; at the end of this period *ca.* 6 ml. of water had collected. The benzene was removed at reduced pressure, and the light tan, crystalline residue crystallized from petroleum ether (b.p. 60–75°). In this manner there was obtained 60 g. (82%) of the eneamine **16**, m.p. 96–98°. The analytical sample, obtained as colorless leaflets after two further crystallizations from the same solvent, melted at 97–98°.

Anal. Calcd. for $C_{15}H_{23}NO$: C, 77.20; H, 9.93; N, 6.00. Found: C, 77.10; H, 9.96; N, 5.85.

Infrared: $\lambda_{max}^{HCCl_3}$ 6.10 μ (s) (>C=O); 6.50 μ (s) and 6.58 μ (s) (conj. > C=C <).

2-Benzylidene-1-decalone (17).—To a solution of phenylmagnesium bromide [prepared from 1.50 g. (0.062 g.-atom) of magnesium and 6.3 ml. (9.42 g.; 0.06 mole) of bromobenzene] in 150 ml. of ether was added a solution of 10.0 g. (0.041 mole) of the eneamine **16** in 50 ml. of dry tetrahydrofuran. After the reaction had been stirred for 3 hr. at room temperature, 50 ml. of 5% aqueous hydrochloric acid was added and the product isolated by ether extraction. The crystalline residue obtained after removal of the ether was crystallized once from methanol and once from petroleum ether (b.p. 30–60°). In this manner there was obtained 8.2 g. (84%) of the benzylidene derivative **17**, m.p. 91–93 (reported,[23] m.p. 91–92°).

Methylation of 2-Ethylidene-6-methylcyclohexanone (18).—To a cooled solution of 30.7 g. (0.785 g.-atom) of potassium in 1000 ml. of dry *t*-butyl alcohol was added over a 20-min. period at room temperature in a nitrogen atmosphere a solution of 3.02 g. (0.022 mole) of the ethylidene ketone **18** in 50 ml. (114 g.; 0.8 mole) of methyl iodide. The cooling bath was removed after 10 min., and the reaction mixture stirred for an additional 14 hr. The neutral reaction mixture was filtered and the *t*-butyl alcohol removed by distillation at atmospheric pressure. Distillation of the residue, obtained after the usual work-up, afforded 2.53 g. (69%) of colorless, liquid boiling at 58–62° (4.5 mm.). Redistillation of this material afforded an analytically pure specimen of the ketone **20**, b.p. 52–53° (3.0 mm.).

Anal. Calcd. for $C_{11}H_{18}O$: C, 79.46; H, 10.92. Found: C, 79.45; H, 11.03.

Ultraviolet: λ_{max}^{alc} 301 mμ (ϵ, 75). **Infrared:** λ_{max}^{film} 3.24 μ (vinyl hydrogen); 5.92 μ (s) (> C=O); 6.18 μ (> C=C <); 5.48 μ (w), 10.08 μ, 10.94 μ (s) (—CH=CH_2 grouping).

In other experiments under substantially the same conditions but where only a three to fourfold excess of base was employed, the yields of volatile material were from 25–35% and analysis by ultraviolet spectrum and gas-liquid chromatography indicated the presence of three major components: starting α,β-unsaturated ketone **18**, the trimethyl ketone **20**, and another material, presumed to be ketone **19**. The latter, however, was never obtained in a pure condition.

(±)-13-Pyrrolidinomethylene-14-podocarpanone (22).—To an ice-cooled suspension of 8.9 g. (0.165 mole) of commercial sodium methoxide in 150 ml. of dry benzene under a nitrogen atmosphere was slowly added a solution of 10.5 g. (0.043 mole) of the ketone **11** and 18.5 g. (0.25 mole) of ethyl formate in 50 ml. of dry benzene. After the reaction mixture had stirred overnight at room temperature, 75 ml. of water was added and the basic aqueous layer separated. The benzene layer was diluted with ether and extracted twice with 25-ml. portions of 5% aqueous sodium hydroxide. The combined basic solutions were washed with ether, cooled by addition of crushed ice, layered with *ca.* 75 ml. of ether, and acidified to Congo Red with ice cooled concentrated hydrochloric acid. The ethereal solution was separated, washed with water and saturated brine, and then dried (Na_2SO_4). Evaporation of most of the ether afforded 12.5 g. of the hydroxymethylene derivative **21** as alight yellow solid [λ_{max}^{film} 6.12 μ (s) and 6.34 μ (s) (β-ketoaldehyde)] that still retained some solvent.

This material, a sample of which imparted a dark green coloration to a 1% alcoholic ferric chloride solution, was not further purified but dissolved in 150 ml. of benzene and treated with 4.25 ml. (3.6 g.; 0.05 mole) of pyrrolidine. This mixture was refluxed under a Dean–Stark water separator for 2 hr. in a nitrogen atmosphere. When the benzene was removed at reduced pressure and the residue (13.50 g.) crystallized from *n*-hexane, there was obtained 9.84 g. (73%) of light tan solid, m.p. 152–154°. Concentration of the mother liquors afforded another 1.43 g. (10%) of only slightly less pure material, m.p. 150–153° with softening at 148°. The analytical sample, obtained as colorless needles after five crystallizations from *n*-hexane, melted at 154–156°.

Anal. Calcd. for $C_{22}H_{35}NO$: C, 80.19; H, 10.70; N, 4.25. Found: C, 80.17; H, 10.65; N, 4.20.

Infrared: $\lambda_{max}^{HCCl_3}$ 6.10 μ (s) (conj. >C=O); 6.50 μ (s) and 6.58 μ (s) (conj. >C=C<).

(±)-13-Ethylidene-14-podocarpanone (23).—To a solution of methylmagnesium bromide [from 0.72 g. (0.03 g.-atom) of magnesium and excess gaseous methyl bromide] in 50 ml. of dry ether was added 2.407 g. (0.0073 mole) of the pyrrolidinomethylene ketone **22** in 25 ml. of dry benzene and the reaction mixture stirred for 1 hr. under a nitrogen atmosphere at room temperature. The Grignard complex was decomposed by adding 25 ml. of 10% aqueous hydrochloric acid. The ethereal layer separated, washed several times with water, saturated brine, and dried (Na_2SO_4). Evaporation of the ether at reduced pressure afforded 1.991 g. of crude unsaturated ketone as a yellow oil that rapidly crystallized on standing at room temperature. Evaporative distillation of this material at 130°/0.05 mm. afforded 1.882 g. (94%) of colorless, crystalline distillate, m.p. 70–72°. The analytical sample, obtained after crystallization three times from *n*-pentane, one time from ether and finally once

from *n*-pentane (all crystallizations effected by cooling to −70°), melted at 76–76.5°.

Anal. Calcd. for $C_{19}H_{30}O$: C, 83.15; H, 11.02. Found: C, 82.99; H, 10.96.

Ultraviolet: λ_{max}^{alc} 243 mμ (ε 7070). **Infrared:** λ_{max}^{film} 5.98 μ (s) (>C=O); 6.20 μ (s) (> C=C <).

The **2,4-dinitrophenylhydrazone** melted at 208–210° after crystallization from ethyl acetate.

Anal. Calcd. for $C_{25}H_{34}N_4O_4$: C, 66.05; H, 7.54; N, 12.33. Found: C, 66.11; H, 7.57; N, 12.27.

(±)-13α-Methyl-13β-vinyl-14-podocarpanone (25) and (±)-13β-Methyl-13α-vinyl-14-podocarpanone (24).—To a cooled (20°), stirred solution of 75 g. (1.93 g.-atoms) of potassium in 2500 ml. of dry *t*-butyl alcohol in a nitrogen atmosphere was added a solution of 4.104 g. (0.015 mole) of the ethylidene ketone **23** in 40 ml. of dry ether. After the orange-red reaction mixture had been stirred for 4 min., 125 ml. of methyl iodide was added over a period of 6 min. during which time a heavy white precipitate formed. The mixture was stirred for 1 hr. in the ice bath, and then 25 ml. more of methyl iodide was added and the suspension stirred overnight at room temperature. The snow white, neutral reaction mixture was filtered through Celite and concentrated to *ca.* 50 ml. Water was added, and the organic material isolated by ether extraction. The residue, obtained on evaporation of the ether, was evaporatively distilled at 190°/0.02 mm. In this manner there was obtained 3.067 g. (71%) of a thick, yellow, oily distillate, the ultraviolet spectrum of which indicated the presence of *ca.* 8% starting ethylidene ketone **23** [λ_{max}^{alc} 244 (ε 575)].

Crystallization of the distillate from 12 ml. of *n*-pentane at −70° afforded 1.561 g. of solid, m.p. 35–48°, and left 1.505 g. (**I**) as oily mother liquor. Recrystallization of the solid material from the same solvent gave 1.198 g. (**II**) of solid, m.p. 48–54°, and left 0.350 g. (**III**) as oily mother liquor. The fractions **I**, **II**, and **III** were chromatographed on Florisil as follows:

Fraction I.—Chromatography on 163 g. of Florisil afforded 235 mg. of the ketone **25**, eluted with 750 ml. of 25% benzene:petroleum ether, and 266 mg. of the ketone **24**, eluted with 1250 ml. of 50% benzene:petroleum ether. An intermediate fraction, eluted with 750 ml. of 50% benzene:petroleum ether and amounting to 34 mg. (8%), was the starting ethylidene ketone **23**.

Fraction II.—Chromatography on 110 g. of Florisil afforded 86 mg. of the ketone **25**, eluted with 400 ml. of 25% benzene:petroleum ether, and 946 mg. of the ketone **24**, eluted with 1900 ml. of 50% benzene:petroleum ether.

Fraction III.—Chromatography on 45 g. of Florisil afforded 84 mg. of the ketone **25**, eluted with 300 ml. of 25% benzene:petroleum ether and 171 mg. of the ketone **24**, eluted with 300 ml. of 50% benzene:petroleum ether.

Therefore, the total amount of the ketone **25** obtained was 405 mg. (9%), m.p. 74–77°, and that of the ketone **24** was 1.383 g. (32%), m.p. 66–69°.

The analytical sample of the ketone **25**, m.p. 78–80°, was obtained after four crystallizations from *n*-pentane at −70° and two from methanol at −10°.

Anal. Calcd. for $C_{20}H_{32}O$: C, 83.26; H, 11.18. Found: C, 83.33; H, 11.18.

Ultraviolet: λ_{max}^{alc} 294 mμ (ε 104); $\lambda_{max}^{cyclohexane}$ 295 mμ (ε 98). **Infrared:** λ_{max}^{Nujol} 5.85 μ (s) (>C=O); 3.19 μ (w) (vinyl H); 6.12 μ (>C=C<); 5.44 μ (w), 10.08 μ (s) (—CH=CH_2).

The analytical sample of the ketone **24**, m.p. 69–70°, was obtained after two crystallizations from *n*-pentane at −70°.

Anal. Calcd. for $C_{20}H_{32}O$: C, 83.26; H, 11.18. Found: C, 83.14; H, 11.08.

Ultraviolet: λ_{max}^{alc} 292 mμ (ε 51); $\lambda_{max}^{cyclohexane}$ 294 mμ (ε 45). **Infrared:** λ_{max}^{Nujol} 5.85 μ (s) (>C=O); 3.20 μ (w) (vinyl H); 6.11 μ (>C=C<); 5.48 μ (w), 10.08 μ, 10.96 μ (—CH=CH_2).

(±)-14β-Benzoyloxy-13β-methyl-13α-vinylpodocarpane (26).—To a solution of 477 mg. (1.65 mmoles) of the ketone **24** in 50 ml. of ethanol was added 4 g. (0.174 g.-atom) of sodium, and the mixture refluxed under a nitrogen atmosphere until all the sodium had been consumed (*ca.* 2 hr.). Water was added, and the product isolated by extraction with 1:1 ether:petroleum ether; after the usual washing sequence, the ethereal solution was dried (Na_2SO_4), filtered, and evaporated. The residue so obtained amounted to 495 mg. of crude alcohol, which crystallized on standing.

The crude alcohol was dissolved in 3 ml. of dry pyridine, cooled to 0° and treated with 0.5 ml. of benzoyl chloride. After standing for 24 hr. at room temperature, the reaction mixture was poured into ice-water, and the precipitated benzoate isolated by ether extraction. A rough purification of the ester was effected by adsorption on 60 g. of Florisil in petroleum ether. Elution with 400 ml. of 30% benzene:petroleum ether afforded 640 mg. of solid material, which on crystallization from methanol gave 530 mg. (81%) of the pure benzoate **26**, m.p. 124–125°. The analytical sample, obtained after four crystallizations from methanol, melted at 125–126°.

Anal. Calcd. for $C_{27}H_{38}O_2$: C, 82.19; H, 9.71. Found: C, 82.01; H, 9.76.

Infrared: $\lambda_{max}^{HCCl_3}$ 5.88 μ (s) (>C=O); 6.12 μ (w) (>C=C<); 6.25 μ (w), 6.34 μ (w), 14.11 μ (s) (monosubst. phenyl).

(±)-14β-Benzoyloxy-13α-methyl-13β-vinylpodocarpane (28).—In a fashion similar to that described above for the benzoate **26** 3140 mg. (0.485 mmole) of the ketone **25** was reduced with 3.5 g. (0.152 g.-atom) of sodium in 35 ml. of ethanol.) The crude, solid alcohol obtained (144 mg.) was benzoylated in 1 ml. of pyridine with 0.1 ml. of benzoyl chloride. The resulting crude benzoate, after elution from 25 g. of Florisil with 300 ml. of 30% benzene:petroleum ether, amounted to 169 mg. Crystallization of this material from ether:ethanol at −20° afforded 137 mg. (75%) of the benzoate **28**, m.p. 82–84°. The melting point of this material was not raised by two further crystallizations from the same solvent pair.

Anal. Calcd. for $C_{27}H_{38}O_2$: C, 82.18; H, 9.71. Found: C, 82.15; H, 9.81.

Infrared: $\lambda_{max}^{HCCl_3}$ 5.87 μ (s) (>C=O); 6.11 μ (w) (>C=C<); 6.25 μ (w), 6.34 μ (w), 14.11 μ (s) (monosubst. phenyl).

(±)-13-Cyclohexoxymethylene-14-podocarpanone (30).—To a well stirred suspension of 8.1 g. (0.15 mole) of commercial sodium methoxide in 150 ml. of dry benzene under a nitrogen atmosphere was added dropwise with cooling a solution of 7.7 g. (0.031 mole) of the ketone **11** and 20 ml. of ethyl formate in 50 ml. of dry benzene. After stirring overnight at room temperature, the reaction mixture was worked up as described above, and the crude, solid hydroxymethylene derivative **21** (8.55 g.) used directly in the etherification experiment.

A solution of the hydroxymethylene derivative, 3.8 ml. (3.5 g.; 0.035 mole) of cyclohexanol and 10 mg. of *p*-toluenesulfonic acid monohydrate in 200 ml. of benzene was refluxed in a nitrogen atmosphere under a Dean–Stark water separator filled with Drierite. After 10 hr. the reaction mixture was cooled, washed successively with 5% aqueous sodium hydroxide and water, and then dried (Na_2SO_4). After filtration of the drying agent, the benzene was removed from the filtrate at reduced pressure, and the solid residue crystallized from methanol. In this manner there was obtained 6.43 g. (72%) of the enol ether **30**, m.p. 120–121°, as colorless plates. The analytical sample, obtained after two further crystallizations from the same solvent, showed the same melting point.

Anal. Calcd. for $C_{24}H_{38}O_2$: C, 80.39; H, 10.68. Found: C, 80.21; H, 10.80.

Infrared: $\lambda_{max}^{HCCl_3}$ 3.18 μ (vinyl H); 6.00 μ (conj. >C=O); 6.35 μ (s) (conj. >C=C<); 9.45 μ (s) (C—O—C).

(±)-13-Podocarpene-13-carboxaldehyde (31).—To a solution of 4.03 g. (0.011 mole) of the enol ether **30** in 130 ml. of methanol was added a solution of 0.76 g. (0.02 mole) of sodium borohydride in 6 ml. of 0.1 *N* aqueous sodium hydroxide, and the reaction mixture stirred and refluxed for 2 hr. The solution was concentrated to approximately 50% of the original volume, water was added, and the product isolated by ether extraction. The dry ether extracts were concentrated to 75 ml. and stirred for 2 hr. at room temperature in a nitrogen atmosphere with 75 ml. of 3 *N* aqueous hydrochloric acid. After the usual work-up, there was obtained 3.8 g. of an oily, yellow crystalline mass which was evaporatively distilled at 120° (0.05 mm.) (bath temp.). The distillate on crystallization from methanol at −20° afforded 1.64 g. (56%) of the aldehyde **31**, m.p. 81–83°. Chromatography of the mother liquor (1.23 g.) on 100 g. of Florisil afforded 334 mg. of the aldehyde **31** by elution with 750 ml. of benzene; crystallization of this material from methanol at −20° gave 295 mg. (10%) of the pure aldehyde **31**, m.p. 81–83°. Thus, the total yield of aldehyde **31** was 1.935 g. (66%). The analytical sample, obtained on one further crystallization from the same solvent, still melted at 81–83°.

Anal. Calcd. for $C_{18}H_{28}O$: C, 83.02; H, 10.84. Found: C, 83.18; H, 10.83.

Infrared: $\lambda_{max}^{HCCl_3}$ 3.66 μ (—C*H*O); 5.99 μ (s) (conj. >C=O); 6.11 μ (conj. >C=C<).

The **2,4-dinitrophenylhydrazone** melted at 254–255° after three recrystallizations from ethyl acetate.

Anal. Calcd. for $C_{24}H_{32}N_4O_4$: C, 65.43; H, 7.32; N, 12.72. Found: C, 65.58; H, 7.47; N, 12.55.

(±)-13α-Methyl-$\Delta^{8(14)}$-podocarpene-13β-carboxaldehyde (33) and (±)-13β-Methyl-$\Delta^{8(14)}$-podocarpene-13α-carboxaldehyde (32). —A slurry of potassium *t*-butoxide in *t*-butyl alcohol was prepared by dissolving 20 g. (0.51 mole) of potassium in 400 ml. of dry *t*-butyl alcohol and then removing 100 ml. of alcohol by distillation under a nitrogen atmosphere with vigorous stirring. To this slurry was added 2.171 g. (8.35 mmoles) of the α,β-unsaturated aldehyde **31** in 20 ml. of dry benzene, and the deep orange reaction mixture was stirred and refluxed in a nitrogen atmosphere for exactly 5 min. The mixture was then cooled in an ice bath for 4 min., and then 40 ml. of methyl iodide was added all at once. The mixture refluxed vigorously for *ca.* 30. sec. and turned from a deep orange to a pale yellow color while a white precipitate formed. Stirring was continued for 1 hr. in the ice bath and then for 12 hr. at room temperature. The snow white reaction mixture was filtered through Celite, concentrated to *ca.* 50 ml. at reduced pressure on the steam bath, water added, and the products isolated by ether extraction. Evaporative distillation at 150° (0.05 mm.) of the residue (2.3 g.) obtained after removal of the solvent afforded 1.749 g. (77%) of colorless, semicrystalline distillate which was chromatographed on 200 g. of Florisil. After a small initial forerun eluted with petroleum ether, elution was continued with 13% benzene: petroleum ether with the following results:

Fraction	Weight, mg.	Vol. of solvent, ml.	G.l.c. analysis at 196°
A	272	1000	86% (33) 4% (32) 10% (impurity)
B	773	2500	40% (33) 57% (32) 3% (impurity)
C	500	1000 13% benzene: petroleum ether 2000 40% benzene: petroleum ether	2% (33) 98% (32)

Rechromatography of fraction B on 170 g. of Florisil employing the same solvent pattern as above gave the following results;

Fraction	Weight, mg.	Vol. of solvent, ml.	G.l.c. analysis at 196°
A[1]	121	600	93% (33) 2% (32) 5% (impurity)
B[1]	471	2800	40% (33) 60% (32)
C[1]	184	1500 40% benzene: petroleum ether	2% (33) 98% (32)

When fractions A and A[1] [393 mg. (17%)] were combined and evaporatively distilled at 140° (0.05 mm.) (bath temp.), there resulted 354 mg. (16%) of the aldehyde **33** as a colorless, crystalline distillate, m.p. 56–59°. Crystallization of this material from 2 ml. of pentane at −70° and then 2 ml. of methanol at −15° afforded 221 mg. (10%) of the analytically pure aldehyde **33** as fine plates, m.p. 58–60°.

Anal. Calcd. for $C_{19}H_{30}O$: C, 83.15; H, 11.02. Found: C, 83.30; H, 11.15.

Infrared: $\lambda_{max}^{HCCl_3}$ 3.67 μ (—C*H*O); 5.86 μ (s) (satd. >C=O); 6.05 μ (>C=C<).

The **semicarbazone**, prepared by the method of Fieser,[37] melted at 195–200° dec. after two crystallizations from methanol.

Anal. Calcd. for $C_{20}H_{33}N_3O$: C, 72.46; H, 10.03; N, 12.68. Found: C, 72.35; H, 10.06; N, 12.59.

The **2,4-dinitrophenylhydrazine**, prepared by the method of Shriner, Fuson, and Curtin, melted at 185–187° after three crystallizations from ethyl acetate:methanol.

Anal. Calcd. for $C_{25}H_{34}N_4O_4$: C, 66.06; H, 7.54; N, 12.33 Found: C, 66.01; H, 7.61; N, 12.28.

When fractions C and C[1] [684 mg. (30%)] were combined and evaporatively distilled at 140° (0.05 mm.) (bath temp.), there resulted 635 mg. (28%) of the aldehyde **32** as a colorless, crystalline distillate, m.p. 76–78°. Crystallization of this material from 5 ml. of methanol at −15° afforded 500 mg. (22%) of this analytically pure aldehyde **32** as fine needles, m.p. 77–80°.

Anal. Calcd. for $C_{19}H_{30}O$: C, 83.15; H, 11.02. Found: C, 83.22; H, 11.02.

Infrared: $\lambda_{max}^{HCCl_3}$ 3.69 μ (—C*H*O); 5.85 μ (s) (satd. >C=O); 6.05 μ (>C=C<).

The **semicarbazone**, prepared by the method of Fieser,[37] melted at 226–228° after two crystallizations from isopropyl alcohol.

Anal. Calcd. for $C_{20}H_{33}N_3O$: C, 72.46; H, 10.03; N, 12.68. Found: C, 72.66; H, 9.96; N, 12.55.

The **2,4-dinitrophenylhydrazone**, prepared by the method of Shriner, Fuson, and Curtin, melted at 210–212° after four crystallizations from ethyl acetate:methanol.

Anal. Calcd. for $C_{25}H_{34}N_4O_4$: C, 66.06; H, 7.54; N, 12.33. Found: C, 66.16; H, 7.57; N, 12.22.

(±)-Sandaracopimaradiene (2). (a) **By Pyrolysis of the Benzoate (26).**—The benzoate **26** (64 mg., 0.16 mmole) was evaporatively distilled at 200° (0.05 mm.) (bath temp.) through a 2-ft. column packed with Pyrex glass wool and heated to 420–440°. The pyrolyzate that condensed (a mixture of solid and liquid amounting to 63 mg.) was dissolved in petroleum ether and adsorbed on 2 g. of Woelm alumina (Activity I). Elution with 20 ml. of petroleum ether afforded 35 mg. (79%) of the (±)-diene **2** as a colorless oil which was evaporatively distilled at 70–80° (0.05 mm) (bath temp.) to afford the analytical sample. Gas–liquid chromatography of this material at 150° indicated the presence of a single component to the extent of 95%. The infrared spectrum of this (±)-diene was indistinguishable from that of the (−)-diene (**−2**).

Anal. Calcd. for $C_{20}H_{32}$: C, 88.17; H, 11.83. Found: C, 88.21; H, 11.81.

Infrared[38]: ν_{max}^{film} 3078 cm.$^{-1}$ (vinyl H); 1822 cm.$^{-1}$ (w), 1636 cm.$^{-1}$, 995 cm.$^{-1}$ and 907 cm.$^{-1}$ (—CH=CH_2 grouping); 1658 cm.$^{-1}$ (w) and 817 cm.$^{-1}$ (w) (trisubst. >C=C<); 854 cm.$^{-1}$ and 865 cm.$^{-1}$ (skeletal vibrations).

(b) **From the Aldehyde 32.**—To a solution of 1.017 g. (2.84 mmoles) of triphenylmethylphosphonium bromide in 15 ml. of anhydrous ether was added 2.8 ml. of a 0.95 *N* solution of potassium *t*-butoxide in *t*-butyl alcohol, and the mixture stirred for 1 hr. under a nitrogen atmosphere. Then a solution of 187 mg. (0.68 mmole) of the aldehyde **32** in 5 ml. of petroleum ether was added, and the reaction mixture stirred for 5 hr. The yellow mixture was treated with water and the organic material isolated by petroleum ether extraction. The semisolid residue (triphenylphosphonium oxide plus diene) obtained on evaporation of solvents was chromatographed on 6 g. of Woelm alumina (Activity I). Elution with 100 ml. of petroleum ether afforded 181 mg. of diene, which on evaporative distillation at 120–130° (0.05 mm.) (bath temp.) amounted to 162 mg. (87%) of pure (±)-sandaracopimaradiene (**2**). This material was homogeneous on gas-liquid chromatography under the same conditions described above in part (a), and could be crystallized from acetone at −20° whereupon the crystalline (±)-sandaracopimaradiene (**2**) showed a melting point of 22–25°. The infrared spectrum of the (±)-diene **2** prepared here was identical to that prepared in part **a** and to the (−)-diene **−2** prepared from sandaracopimaric acid (**27**).

Anal. Calcd. for $C_{20}H_{32}$: C, 88.17; H, 11.83. Found: C, 88.21; H, 11.78.

(−)-Sandaracopimaradiene (−2).—A mixture of 220 mg. (0.64 mmole) of the sandaracopimaral semicarbazone in 8 ml. of diethylene glycol was heated with stirring under a nitrogen atmosphere to 100° whereupon the mixture became homogeneous. Solid potasiusm hydroxide (2.6 g.) was cautiously added, and the temperature gradually raised to 205°. At 170–180° evolution of gas was observed. After heating at 205° for 3 hr., the reaction mixture was cooled, diluted with water, and the product isolated by petroleum ether extraction in the usual manner. When the residue obtained on evaporation of the solvent was chromato-

(37) L. F. Fieser, "Experiments in Organic Chemistry," 3rd ed., D. C. Heath and Company, Boston, Mass., p. 85.

(38) Recorded on a Beckman IR-7 instrument through the courtesy of the Parke–Davis and Company spectrographic laboratory.

graphed on 5 g. of Woelm alumina (Activity I), there was obtained 135 mg. (78%) of the (−)-diene (−**2**), m.p. 39–41°, by elution with 50 ml. of petroleum ether. Crystallization of this material from ethyl alcohol afforded 126 mg. (73%) of the pure (−)-sandaracopimaradiene (−**2**), m.p. 41–42°, $[\alpha]^{25}D$ −12° (*c*, 224 mg./100 ml., $HCCl_3$). Gas-liquid chromatography of this material at 150° showed only one component with the same retention time as that of the (±)-diene **2**; the infrared spectrum of this (−)-diene −**2** was identical to that of the (±)-diene **2**.

Anal. Calcd. for $C_{20}H_{32}$: C, 88.17; H, 11.83. Found: C, 87.97; H, 11.68.

(±)-**Pimaradiene** (**3**). (a) **By Pyrolysis of the Benzoate 28.**—Pyrolysis of 83 mg. (0.21 mmole) of the benzoate **28** under the same conditions as described above for the benzoate **26** afforded 54 mg. (93%) of semisolid, crude pyrolyzate. Chromatography of this material on 3 g. of Woelm alumina (Activity I) gave 47 mg. (82%) of the (±)-diene **3** as a colorless oil on elution with 30 ml. of petroleum ether. The analytical sample was obtained by evaporative distillation at 100° (0.05 mm.) (bath temp.). Gas-liquid chromatography of this material at 148° indicated the presence of a single component to the extent of 90% plus 10% of a less mobile material (possibly conjugated diene). The infrared spectrum of this (±)-diene **3** was identical to that of the (+)-diene +**3** obtained from pimaric acid (**29**).

Anal. Calcd. for $C_{20}H_{32}$: C, 88.17; H, 11.83. Found: C, 88.26; H, 11.84.

Infrared: ν_{max}^{film} 3080 cm.$^{-1}$ (vinyl H); 1832 cm.$^{-1}$ (w), 1638 cm.$^{-1}$, 995 cm.$^{-1}$ and 913 cm.$^{-1}$ (—CH=CH_2 grouping); 1660 cm.$^{-1}$ (w) and 818 cm.$^{-1}$. (w) (trisubst. > C=C<); 854 cm.$^{-1}$ and 856 cm.$^{-1}$ (skeletal vibrations).

(b) **From the Aldehyde 33.**—In exactly the same manner as described above, a solution of 207 mg. (0.76 mmole) of the aldehyde **33** in 5 ml. of petroleum ether was added to an etheral solution of methylenetriphenylphosphorane [prepared from 1.115 g. (3.10 mmoles) of triphenylmethylphosphonium bromide in 15 ml. of ether and 3.2 ml. of a 1.05 *N* solution of potassium *t*-butoxide in *t*-butyl alcohol] and the mixture stirred for 6 hr. at room temperature under a nitrogen atmosphere. Isolation of the product was accomplished by petroleum ether extraction and chromatography of the organic material on 7 g. of Woelm alumina (Activity I) afforded 218 mg. of colorless oil, eluted with 100 ml. of petroleum ether. Evaporative distillation of this material at 120° (0.05 mm.) (bath temp.) gave 203 mg. (99%) of pure (±)-pimaradiene (**3**), m.p. 28–31°. Gas-liquid chromatography of this material at 148° indicated the presence of a single component to the extent of 96% plus 4% of a less mobile impurity with the same retention time as (±)-sandaracopimaradiene (arising from a slight contamination of the starting aldehyde **33** by its epimer). The infrared spectrum of this material was identical to that of (+)-pimaradiene (+**3**) and the (±)-pimaradiene (**3**) prepared by pyrolysis.

Anal. Calcd. for $C_{20}H_{32}$: C, 88.17; H, 11.83. Found: C, 88.10; H, 11.75.

The melting point of a mixture of this material and (±)-sandaracopimaradiene (**2**), m.p. 22–25°, was depressed below 0°.

(+)-**Pimaradiene** (+**3**).—In the same fashion as that described above for the preparation of (−)-sandaracopimaradiene (−**2**), 400 mg. (1.16 mmoles) of the pimaral semicarbazone was decomposed by heating under nitrogen with 5.0 g. of potassium hydroxide in 15 ml. of diethylene glycol. Chromatography of the resulting hydrocarbon on 10 g. of Woelm alumina (Activity I) afforded 278 mg. (88%) of (+)-pimaradiene (+**3**) m.p. 24–26°, $[\alpha]^{25}D$ +99° (*c*, 510 mg./100 ml. $HCCl_3$) eluted with 70 ml. of petroleum ether as a clear, colorless oil at room temperature. Gas-liquid chromatography of this material at 148° showed the presence of only one component with the same retention time as (±)-pimaradiene (**3**). The infrared spectra of the (+)-pimaradiene (+**3**) and the (±)-pimaradiene (**3**) were identical.

Anal. Calcd. for $C_{20}H_{32}$: C, 88.17; H, 11.83. Found: C, 87.97; H, 11.83.

Sandaracopimarol.—A solution of 900 mg. (2.85 mmoles) of methyl sandaracopimarate,[39] m.p. 64–65.5°, and 50 ml. of dry ether was reduced with 2.5 ml. of saturated, ethereal lithium aluminum hydride (1.2 *M*) and worked up using 0.23 ml. of water and 0.18 ml. of 10% aqueous sodium hydroxide. After removal of the ether at reduced pressure on the steam bath, evaporative distillation of the residue at 135° (0.02 mm.) afforded 776 mg. (93%) of a glass.

Anal. Calcd. for $C_{20}H_{30}O$: C, 83.27; H, 11.18. Found: C, 83.04; H, 11.16.

Infrared: λ_{max}^{film} 2.94 μ (s) (—OH); 3.20 μ (w) (vinyl H); 5.48 μ (w), 6.12 μ, 10.02 μ and 11.98 μ (—CH=CH_2 grouping); 6.04 μ (w) and 12.2 μ (w) (trisubst. >C=C<); 11.55 μ and 11.70 μ (skeletal vibrations).

Sandaracopimaral Semicarbazone.—A solution of 620 mg. (2.15 mmoles) of sandaracopimarol in 40 ml. of acetone was oxidized with 0.6 ml. of Jones reagent[16] and worked-up by addition of water and extraction with ether. The crude aldehyde crystallized on trituration with petroleum ether at −70°, and after two crystallizations of the solid from methanol, there resulted 377 mg. (62%) of **sandaracopimaral**, m.p. 49–50°.

Anal. Calcd. for $C_{20}H_{30}O$: C, 83.86; H, 10.56. Found: C, 83.75; H, 10.68.

Infrared: λ_{max}^{film} 3.69 μ (s) (—C*H*O); 5.80 μ (s) (>C=O); 5.48 μ (w), 6.12 μ, 10.02 μ and 11.99 μ (—CH=CH_2) grouping); 6.02 μ (w) and 12.18 μ (w) (trisubst. >C=C<); 11.55 μ and 11.72 μ (skeletal vibrations).

Sandaracopimaral Semicarbazone, m.p. 218–220° with softening at 215° from methanol, was prepared from 286 mg. (1.0 mmole) of sandaracopimaral, m.p. 48–50°, in 94% yield by using the method of Fieser.[37]

Anal. Calcd. for $C_{21}H_{33}N_3O$: C, 73.42; H, 9.68. Found: C, 73.40; H, 9.70.

Pimaral Semicarbazone.—A solution of 1.0 g. (3.16 mmoles) of methyl pimarate, m.p. 66–67.5° (reported,[6b] m.p. 69°) in 50 ml. of dry ether was reduced with 2.75 ml. of a saturated, ethereal solution of lithium aluminum hydride (1.2 *M*). After the addition of 0.25 ml. of water and then 0.20 ml. of 10% aqueous sodium hydroxide, the precipitated salts were removed by filtration, and the ether evaporated at reduced pressure on the steam bath. The crude **pimarol** was not further purified but dissolved in 30 ml. of acetone and oxidized at 0–5° with 0.8 ml. of Jones reagent.[16] After addition of water to the reaction mixture, the **pimaral** was isolated by ether extraction and characterized by its infrared spectrum (λ_{max}^{film} 3.20 μ (w) (vinyl H); 3.70 μ (w) (—C*H*O); 5.82 μ (s) (>C=O); 6.13 μ (w) (>C=C<); 10.05 μ and 10.92 μ (s) (—CH=CH_2); 11.58 μ and 11.72 μ (skeletal vibrations). When the crude aldehyde was converted directly to the semicarbazone by the method of Fieser,[37] there resulted 750 mg. (75%) of pimaral semicarbazone, m.p. 213–216° dec. (reported, m.p. 205–210°[41] and 223–225°[40]) after two crystallizations from methanol. This material was submitted for combustion analysis because of the apparent discrepancy in the observed melting point and those previously reported.

Anal. Calcd. for $C_{21}H_{33}N_3O$: C, 73.42; H, 9.68. Found: C, 73.49; H, 9.76.

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