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TERPENOIDS—L

TRANSFORMATION PRODUCTS OF COSTUNOLIDE*

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Abstract—Costunolide, containing a ten-membered carbocyclic ring system with the unique distribution of double bonds, undergoes many interesting transformations. The diol prepared by lithium aluminium hydride reduction of costunolide when subjected to metal amine reduction gives a hydrocarbon, $C_{15}H_{26}$, a secondary alcohol, $C_{15}H_{26}O$, and a primary alcohol, $C_{15}H_{26}O$ to which structures, VIII, X and XII have been assigned on the basis of spectral data and their conversions to elemene-type products on pyrolysis and to mono-ethenoid bicyclic products on acid catalysed cyclization. The secondary alcohol X has been converted to D-junenol which constitutes a new synthesis of the alcohol from costunolide. Pyrolysis and acid catalysed cyclization of 12-methoxydihydrocostunolide have also been described.

IN VIEW of the presence of large amount of costunolide (I) in costus root oil,[1] it was felt that the parent hydrocarbon (II) may also be present in the oil. Such a hydrocarbon could be the biogenetic precursor of most of the mono- and bicyclic sesquiterpenic hydrocarbons. In a previous communication,[2] dealing with the hydrocarbon fraction of costus root oil, we had reported the presence of β-elemene (III) together with substantial amounts of β-selinene and aplotaxene, but we were unable to isolate the hydrocarbon (II) from the same fraction. It is obvious that even though such a hydrocarbon may be present in the oil, great care will be required to isolate it, and especially owing to the presence of large amounts of other hydrocarbons, its isolation would be rendered difficult. For effecting a separation of the constituents of the hydrocarbon fraction of costus root oil, we had to unavoidably resort to a suitable combination of fractionation and chromatography, as chromatography alone could not effect the desired separation. Owing to the high temperature used in fractionation (about 200° bath temp.), the hydrocarbon (II), which was probably present in the fraction, would be rearranged pyrolytically[3] to β-elemene (III) which has been found to occur in the same fraction of the oil.

Since we could not isolate the hydrocarbon (II) from the oil as such, we thought of effecting a partial synthesis of the hydrocarbon for which costunolide (I) was a suitable starting material.

Costunolide was reduced by lithium aluminium hydride with a view to get the corresponding diol (IV). The product obtained was purified by chromatography over

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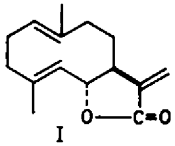
* Contribution No. 653 from the National Chemical Laboratory, Poona-8, India.

[1] A. Paul, A. S. Bawdekar, R. S. Joshi, G. H. Kulkarni, A. S. Rao, G. R. Kelkar and S. C. Bhattacharyya, *Perf. and Ess. Oil Rec.* **51**, 115 (1960); A. S. Rao, G. R. Kelkar and S. C. Bhattacharyya, *Tetrahedron* **9**, 275 (1960).

[2] R. S. Joshi, A. S. Bawdekar, G. H. Kulkarni, A. S. Rao, G. R. Kelkar and S. C. Bhattacharyya, *Perf. and Ess. Oil. Rec.* **52**, 773 (1961).

[3] A. S. Rao, A. Paul, Sadgopal and S. C. Bhattacharyya, *Tetrahedron* **13**, 319 (1961).



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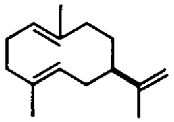

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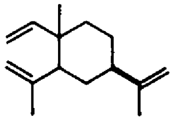

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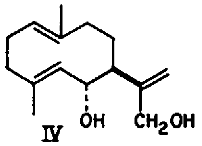

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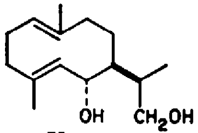

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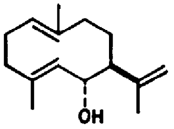

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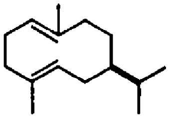

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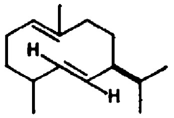

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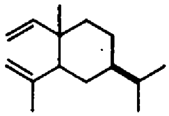

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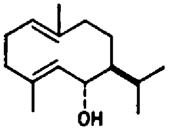

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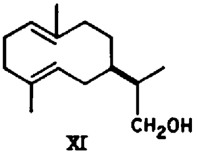

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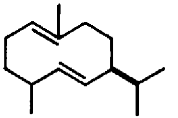

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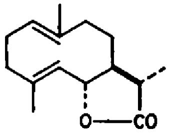

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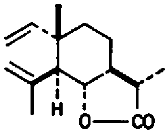

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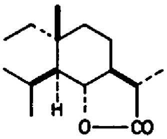

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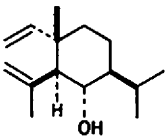

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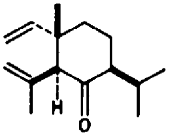

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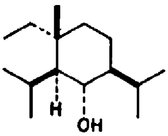

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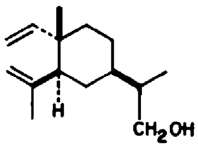

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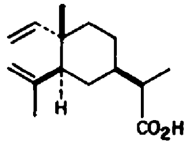

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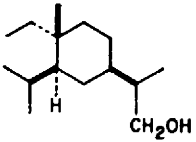
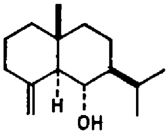


XX & XX a



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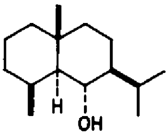

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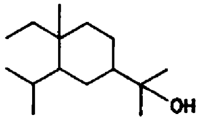

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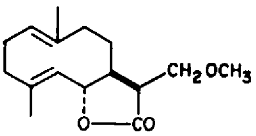

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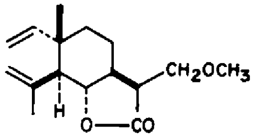

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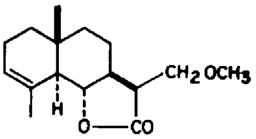

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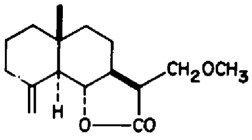
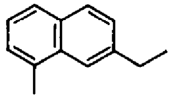
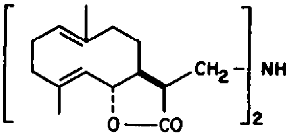


XXVII



XXVIII



XXIX

alumina and found to be a mixture of diols (IV and V) by NMR spectrum and perbenzoic acid titrations which gave the value of 2·2 to 2·3 double bonds. Without making an effort to separate the two diols, the mixture, as such was subjected to metal amine reduction using sodium and liquid ammonia. The diol (IV) contains two allylic hydroxyl groups which are likely to be removed during metal amine reduction to give the hydrocarbon (II), whereas the diol (V) which contains only one allylic hydroxyl group could give only a primary alcohol (XI). Previous references in literature[4] on metal amine reduction of allylic alcohols indicated that allylic alcohols in which a CH_2 group is present in the allylic system undergo hydrogenolysis more easily than those in which it is absent. In the latter case the reaction may not take place or proceeds only in low yields.

During the metal amine reduction of the mixture of diols (IV and V) both type of products, in which one or both allylic hydroxyl groups are eliminated, are formed along with the simultaneous reduction of the methylenic double bond. The products of metal amine reduction of the diol which were separated by chromatography composed of (i) a hydrocarbon, $C_{15}H_{28}$ (VIII); (ii) a secondary alcohol, $C_{15}H_{28}O$ (X); (iii) a primary alcohol (XII); and (iv) the unreacted diol (V). The hydrocarbon (VIII) and the two alcohols (X and XII) were together obtained in about 20% yield on the weight of the original diol mixture. It appears that the reaction involving the elimination of allylic hydroxyl groups in IV takes place only to a limited extent and mostly the dihydro-diol (V) is formed. It also appears that the hydrocarbon (II) and the secondary alcohol (VI) expected to be formed from the diol (IV) by the elimination of two and one allylic hydroxyl groups respectively, are further reduced to the corresponding dihydro products, involving reduction of the methylenic double bond under the influence of the reducing conditions of the reaction. That it is the methylenic double bond that is reduced during the metal amine reduction in all the compounds described is evident from the fact that all the products of metal amine reduction undergo pyrolytic rearrangements (either partly or wholly) to elemene type compounds, which requires the retention of the two originally occurring trisubstituted double bonds intact (or in slightly rearranged position as in VIII and XII). This is reminiscent of the formation of saussurea lactone (XIV) from dihydrocostunolide[3] (XIII). The course of pyrolytic rearrangement was followed by IR spectrum and supplemented by VPC analysis. The absorption due to trisubstituted double bond at 1660 cm^{-1} in the original compounds disappears in the rearranged products with appearance of new peaks at 1640, 890 cm^{-1} due to the methylenic double bond ($>C{=}CH_2$) and at 910 cm^{-1} due to vinyl group ($-CH{=}CH_2$). In addition, they undergo acid catalysed cyclization to monoethenoid bicyclic products in presence of acetic acid alone and in some cases acetic acid and perchloric acid.

The hydrocarbon, $C_{15}H_{26}$, was purified by chromatography and distillation in a good vacuum and could be obtained in pure condition (VPC). Perbenzoic acid titrations showed the presence of only two double bonds, which taken together with the molecular formula $C_{15}H_{26}$ establishes its monocyclic nature. The IR spectrum taken in liquid cell (Fig. 1) showed a peak at 1660 cm^{-1} due to a trisubstituted double bond and doublet at 1380, 1365 cm^{-1} due to isopropyl group. From this it appeared that the hydrocarbon was more probably represented by structure VII and not the structure II. The UV end absorption of the hydrocarbon however was found to be

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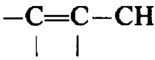
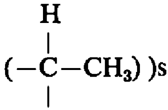
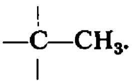
[4] A. J. Birch, *J. Chem. Soc.* 809 (1945); A. J. Birch and A. R. Murray, *J. Chem. Soc.* 1888 (1951).

low (ε 210, 2500) when compared with the end absorption 8800–9000 at 210 mμ) of dihydrocostunolide[1] and 12-methoxydihydrocostunolide.[5] It was therefore felt that the double bonds may not be in the position as indicated by structure VII (the diol mixture and the secondary alcohol X in which the originally occurring trisubstituted double bonds remained intact, show 4500 and 3500 end absorption at 210 mμ respectively). Careful examination of the IR spectrum of the hydrocarbon indicated the presence of a *trans*-disubstituted double bond as evidenced by a peak at 980, 970 cm^{-1} (shoulder). In order to further confirm the presence of disubstituted double bond, the hydrocarbon was partially hydrogenated in alcohol medium using 5% palladium charcoal catalyst to get a product whose IR spectrum did not show any absorption at 980, 970 cm^{-1}. The NMR spectrum of the hydrocarbon (Fig. 4) gave an indication of only one  $-\underset{|}{C}=\underset{|}{C}-CH_3$ group (1·5, 1·55 δ units) and three secondary methyl groups ( $-\overset{\overset{H}{|}}{\underset{|}{C}}-CH_3$))signals at 0·7, 0·75, 0·8, 0·86, 0·91, 1·02, 1·15 δ units). It also indicated the presence of 3-olefinic protons (4·9, 5·1, 5·3, 5·36, 5·6, 5·62 δ units). From these spectral evidences, it was concluded that the hydrocarbon could be better represented by structure VIII than by the structure VII.

The hydrocarbon (VIII) on pyrolysis gave a mixture of two hydrocarbons (70:30 by VPC). The component occurring to the extent of 30% was identified as the starting material by mixed VPC analysis. The IR spectrum of the pyrolysis product (mostly IX) indicated the presence of $>C=CH_2$ and $-CH=CH_2$ groups (890, 1640 and 910 cm^{-1}) and resembled closely to that of β-elemene, except for (i) a doublet at 1380, 1365 cm^{-1}; and (ii) a weak absorption at 980 cm^{-1} arising from the original hydrocarbon. The pyrolysed hydrocarbon mixture was hydrogenated to get the corresponding tetrahydro products. The presence of β-elemane in it as the major product was shown by mixed VPC analysis with the authentic β-elemane. It thus follows that under the conditions used for other compounds, in which the two originally occurring trisubstituted double bonds remained intact, the hydrocarbon could not be completely converted into elemane type product. This further supports the structure VIII for the hydrocarbon, as a compound with structure VII would be expected to be easily converted into dihydro-β-elemene completely.

In presence of acetic acid and perchloric acid the hydrocarbon (VIII), gave a monoethenoid bicyclic hydrocarbon $C_{15}H_{26}$ (catalytic hydrogenation gave one double bond) which could be obtained in 90% purity (VPC). The IR and NMR spectra indicated the presence of a trisubstituted double bond. The NMR spectrum also indicated that all the CH_3 groups are of the type  $-\overset{|}{\underset{|}{C}}-CH_3$. Selenium dehydrogenation of this hydrocarbon failed to give any of the naphthalenic or azulenic hydrocarbons. From this also it would appear that the original hydrocarbon could not be represented by VII as such a structure would have given a hydrocarbon on acid catalysed cyclization capable of giving a naphthalenic hydrocarbon in high yield on selenium dehydrogenation.

The monol (X) and the monol (XII) were both eluted with pet. ether + benzene

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[5] G. H. Kulkarni, A. Paul, A. S. Rao, G. R. Kelkar and S. C. Bhattacharyya, *Tetrahedron* **12**, 178 (1961).

during the chromatography of metal amine reduction product. They were separated by repeated chromatography over alumina and were characterized for their purity by TLC analysis. Perbenzoic acid titrations of monol (X) indicated the presence of two double bonds. It could be completely rearranged pyrolytically to the monol (XV) which has been obtained in pure condition (VPC). The IR (Fig. 1) and the NMR spectra (Fig. 5) are in complete agreement with the structure XV. On CrO_3 oxidation XV gave the corresponding ketone (XVI), the structure of which is supported by the IR, UV and the NMR spectra. Catalytic hydrogenation of XV gave the corresponding tetrahydro product (XVII) which has also been obtained from tetrahydrosaussurea lactone (XIVa) via the hydroxy aldehyde obtained by controlled lithium aluminium hydride reduction of XIVa by Wolf-Kishner reduction.[6,7] This establishes the stereochemistry of compounds XV, XVI and XVII as shown.

Acid catalysed cyclization of X using acetic acid at room temperature gave four products, namely (i) an oxide, (ii) a conjugated hydrocarbon and (iii) two alcohols. The oxide and the conjugated hydrocarbon being obtained in traces were not further studied. The mixture of two alcohols which were present in almost equal proportions (indicated by VPC analysis) were chromatographed on a large ratio of alumina. The fractions eluted earlier were found to be mixtures again, and the fractions eluted later gave a solid on cooling which was purified by vacuum sublimation and crystallization and identified as D-juneol[8] (XXI) by IR spectrum, rotation, m.p. and mixed m.p. with an authentic sample. The mixture of alcohols obtained earlier, on catalytic hydrogenation absorbed one mole of hydrogen and gave dihydrojunenol[8] (XXII) as the main product, identified by IR spectrum, rotation, m.p. and mixed m.p. with an authentic sample.

The primary alcohol (XII) was purified by repeated chromatography over alumina. Its IR spectrum (Fig. 2) showed a peak at 1660 cm^{-1} due to trisubstituted double bond. It also showed peaks at 3400, 1030, due to a primary hydroxyl group. In addition there was a peak at 980 cm^{-1} presumably due to disubstituted double bond. The compound was purified through its acetate. The NMR spectrum of the alcohol (Fig. 4) gave an indication of one $-\underset{|}{C}=\underset{|}{C}-CH_3$ group (1·5 δ units) and two $-\overset{|}{\underset{|}{C}}=CH_3$ groups (0·7, 0·8, 0·9, 0·95, 1·02 and 1·10 δ units). In the olefinic region it showed the presence of 3 olefinic protons. The spectral data thus suggest the structure XII for the alcohol. Perbenzoic acid titrations showed the presence of two double bonds. On pyrolysis, XII was converted to XVIII which was obtained in pure state by the chromatography of its acetate. The IR and NMR spectra (Fig. 4) of the acetate are in complete agreement with the structure XVIII. Chromic oxide oxidation (using Jones reagent)[9] of XVIII gave the corresponding acid (XIX). Catalytic hydrogenation of XVIII gave the corresponding tetrahydro alcohol (XX).

The recovered diol from the products of metal amine reduction of the mixture of diols (IV and V), which essentially contains the dihydro-diol (V), gave a primary

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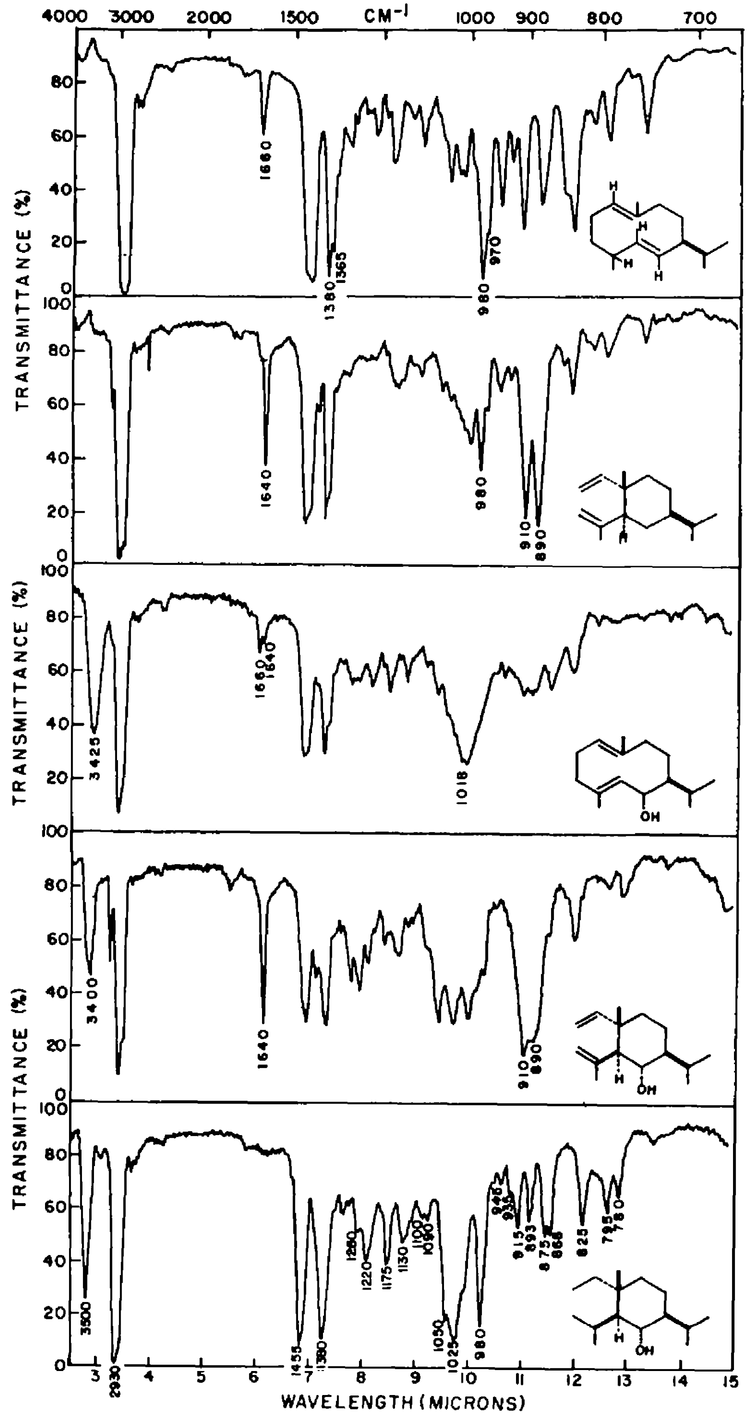
[6] G. E. Arth, *J. Amer. Chem. Soc.* **75**, 2413 (1953); see also E. Lederer, C. Asselineau and S. Bory, *Bull. Soc. Chim., Fr.* 1527 (1955).

[7] A. D. Wagh, S. K. Paknikar and S. C. Bhattacharyya, Unpublished work.

[8] A. M. Shaligram, A. S. Rao, and S. C. Bhattacharyya, *Tetrahedron* **18**, 969 (1962).

[9] K. Bowden, I. M. Heilbron, E. R. H. Jones and B. C. L. Weedon, *J. Chem. Soc.* 39 (1946); A. Bowers, T. G. Halsall and E. R. H. Jones, *J. Chem. Soc.* 2555 (1953).


4000
3000
2000
1500
CM⁻¹
1000
900
800
700
TRANSMITTANCE (%)
0
20
40
60
80
100
1660
1380
1365
980
970
H
H
H
H
1640
980
910
890
H
3425
1660
1640
1018
OH
3400
1640
910
890
H
OH
3500
2930
1455
1380
1260
1220
1175
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1100
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1025
980
946
935
915
893
875
868
825
795
780
H
OH
3
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WAVELENGTH (MICRONS)

FIG. 1

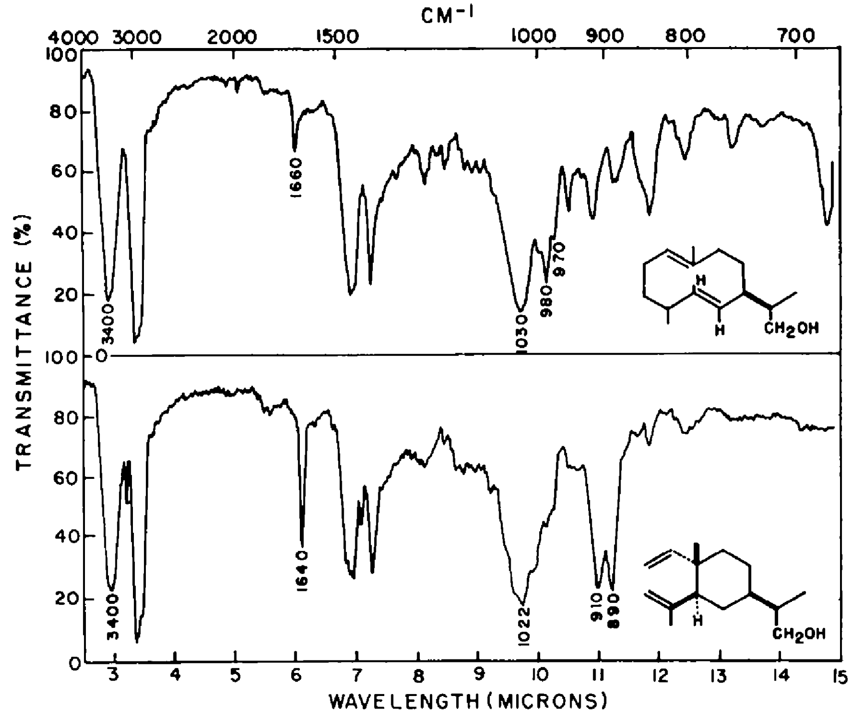

Fig. 2

alcohol, $C_{15}H_{26}O$, when subjected to metal amine reduction for a second time, using an alcoholic solution of the diol. The alcohol $C_{15}H_{26}O$ (XIIa) seemed to be identical in IR spectrum with the primary alcohol (XII), but the two compounds differed in their rotation (−17° and −91° respectively). It appears probable that the two alcohols may be C_{11}-epimers resulting from the two C_{11}-epimeric dihydro-diols (V) which result from the reduction of the methylenic double bond in IV, thus creating a new asymmetric centre. The alcohol (XIIa) could be rearranged to the corresponding alcohol (XVIIIa) which on catalytic hydrogenation gave the tetrahydro product (XXa). The alcohol (XXa) was also obtained from tetrahydroelemol (XXIII) through a series of reactions, by some of our colleagues,[10] and the identity between the two products established by physical constants, IR spectrum and mixed VPC analysis. The conversion of the alcohol (XXa) to tetrahydroelemol would form the subject matter of a future communication.

By treatment with acetic acid and perchloric acid compound (XIIa) has been converted into a mono-ethenoid bicyclic product which on catalytic hydrogenation gave the corresponding dihydro product. Due to paucity of material acid catalysed cyclization products of XIIa could not be completely characterized at present, but will be examined at a future date.

Costunolide containing an α,β-unsaturated lactone grouping undergoes Michael addition reactions. With ammonia in alcoholic solution it forms the ammonia adduct (XXIX) which was purified through its picrate salt. The IR and UV spectra are in complete agreement with the structure XXIX.

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[10] A. D. Wagh, S. K. Paknikar and S. C. Bhattacharyya. Unpublished work.

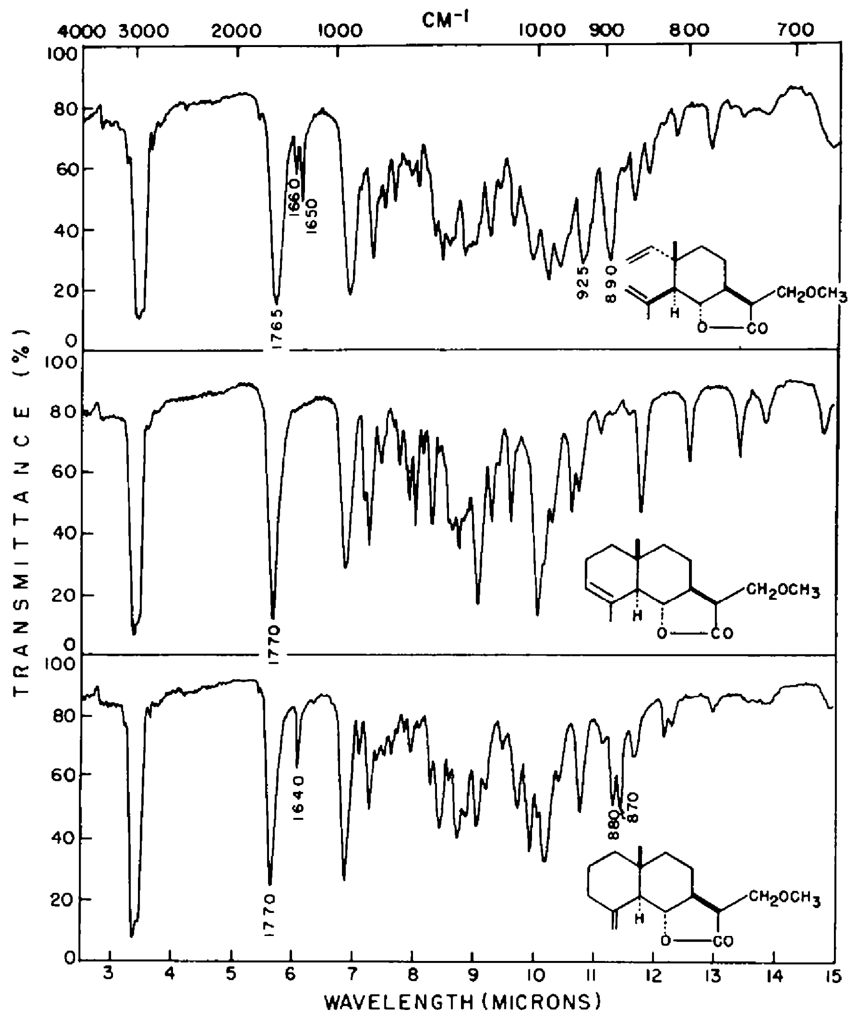

FIG. 3

With methanol in presence of a trace of base at low temperatures costunolide gives 12-methoxydihydrocostunolide (XXIV), m.p. 127°, which has also been isolated from costus root oil and its structure and stereochemistry established.[5] 12-Methoxydihydrocostunolide undergoes pyrolysis and acid catalysed cyclization. When heated under reflux at 230–240° (bath) at 0·5 mm, it is pyrolytically rearranged to give a solid, m.p. 73–74° (XXV). The IR spectrum of this solid indicated clearly the presence of a methylenic double bond (peaks at 890 and 1640 cm^{-1}) but did not give a clear indication of the presence of vinyl group (—CH=CH_2) (peak at 910 cm^{-1} was absent but there was a peak at 925 cm^{-1}). The NMR spectrum (Fig. 6) however indicated the presence of both methylenic and vinyl groups. Catalytic hydrogenation gave the corresponding tetrahydro product, which bears a close resemblence to tetrahydrosaussurea lactone in its IR spectrum.

The acid cyclization of 12-methoxydihydrocostunolide by using acetic acid at room temperature gave a mixture of two lactones (XXVI and XXVII) which were

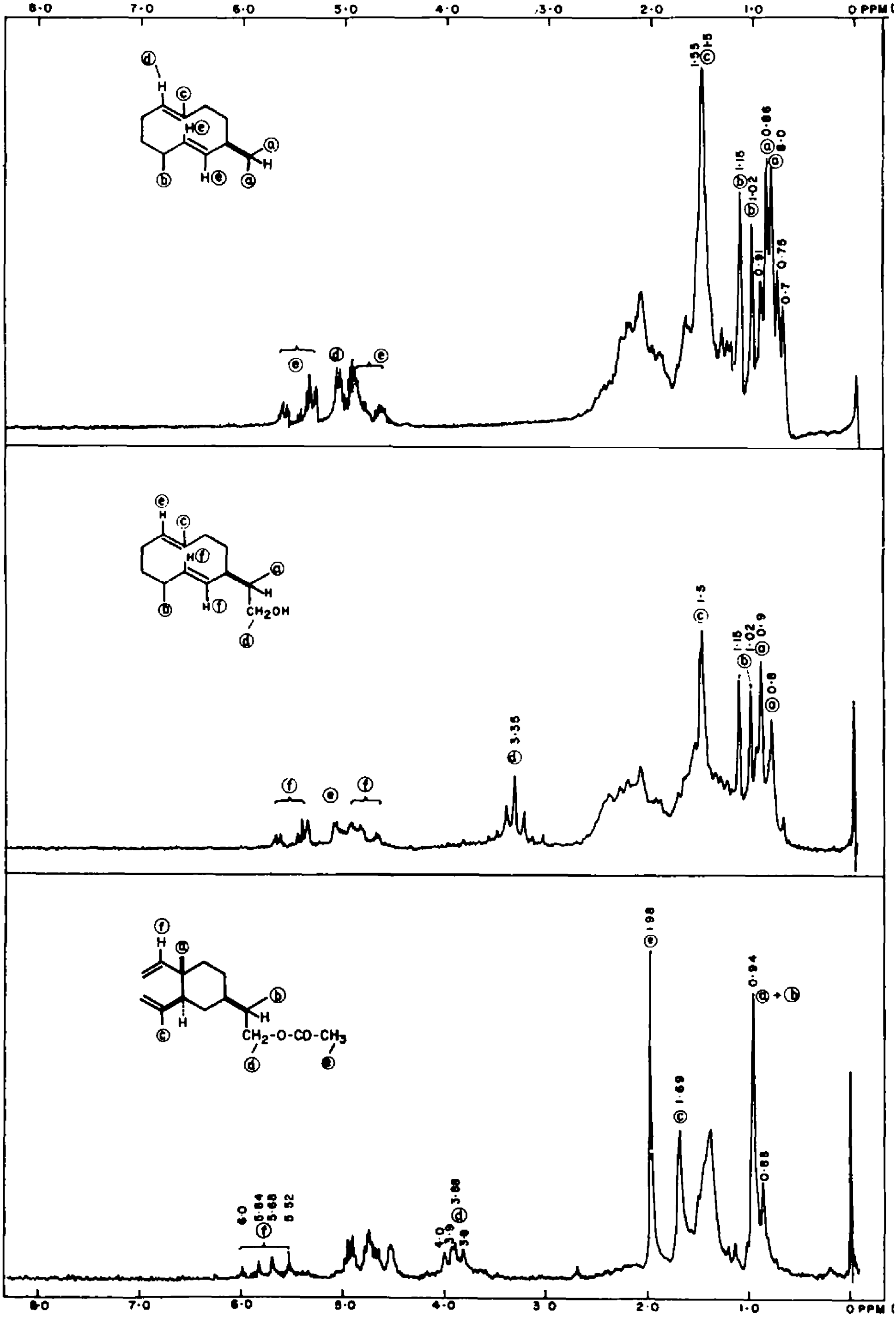
8·0
7·0
6·0
5·0
4·0
3·0
2·0
1·0
0 PPM (δ)
1·55
ⓒ 1·5
ⓐ 0·86
0·8
ⓐ
ⓑ 1·15
ⓑ 1·02
0·91
0·75
0·7
ⓔ
ⓓ
ⓔ
ⓒ 1·5
1·15
1·02
ⓑ
ⓐ 0·9
ⓐ 0·8
ⓓ 3·55
ⓕ
ⓔ
ⓕ
ⓔ 1·98
0·94
ⓐ + ⓑ
ⓒ 1·69
0·88
6·0
5·84
5·68
5·52
ⓕ
4·0
3·9
ⓓ 3·88
3·8
CH₂OH
CH₂-O-CO-CH₃

FIG. 4

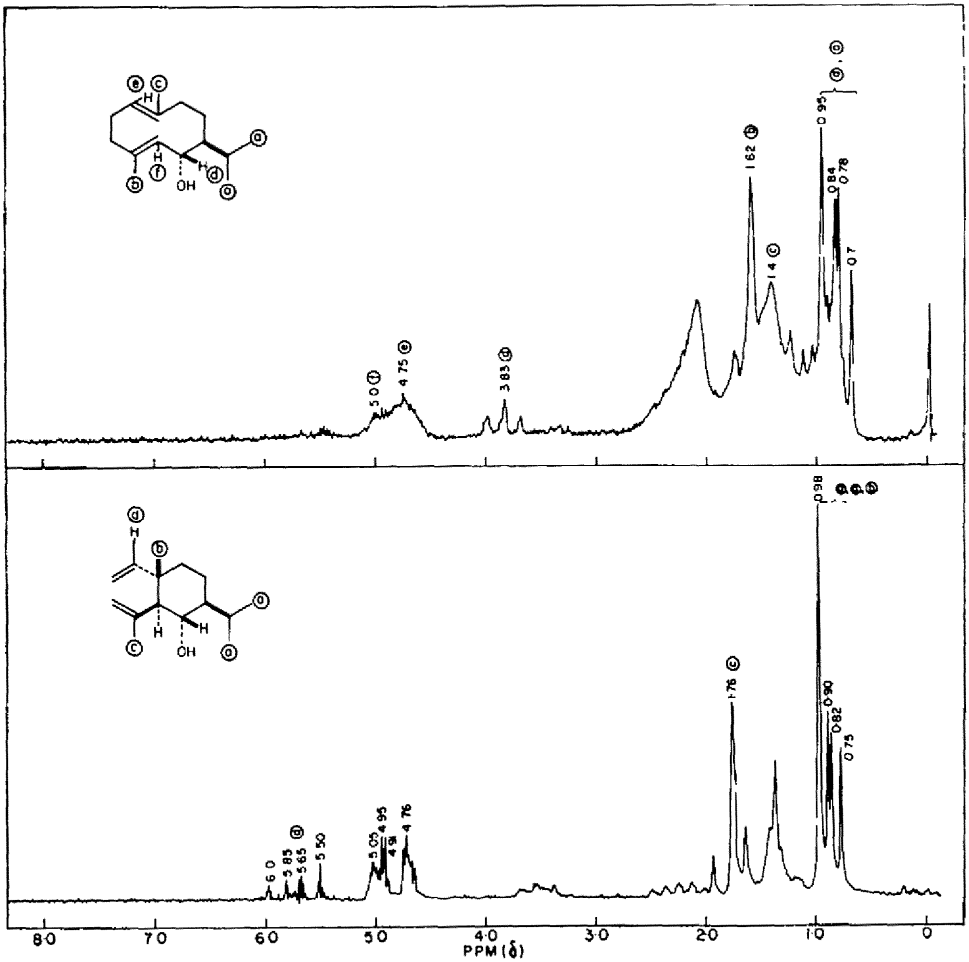

FIG. 5

separated by chromatography and further purified by crystallization. Selenium dehydrogenation of the above two compounds gave 1-methyl-7-ethylnaphthalene (XXVIII), characterized through its TNB derivative.

The two lactones, α-, and β-cyclo-12-methoxydihydrocostunolides were hydrogenated catalytically to the corresponding dihydro products which have been characterized. The IR and NMR (Figs. 3 and 6) spectra are in complete agreement with the structures XXVI and XXVII.

EXPERIMENTAL

All m.ps and b.ps are uncorrected. All b.ps refer to the bath temp. Rotations were measured in chloroform solution. UV spectra were recorded in alcohol solution on Beckman DK-2 ratio recording spectrophotometer by H. Gopinath. IR spectra were determined with Perkin-Elmer Infracord spectrophotometer by K. G. Deshpande. The NMR spectra were taken in carbon tetrachloride solution using tetramethyl silane as internal reference on 60 MC Varian instrument by P. M. Nair and colleagues, and the chemical shifts were measured in δ units. Micro-analysis were carried out by Mr. Pansare and colleagues.

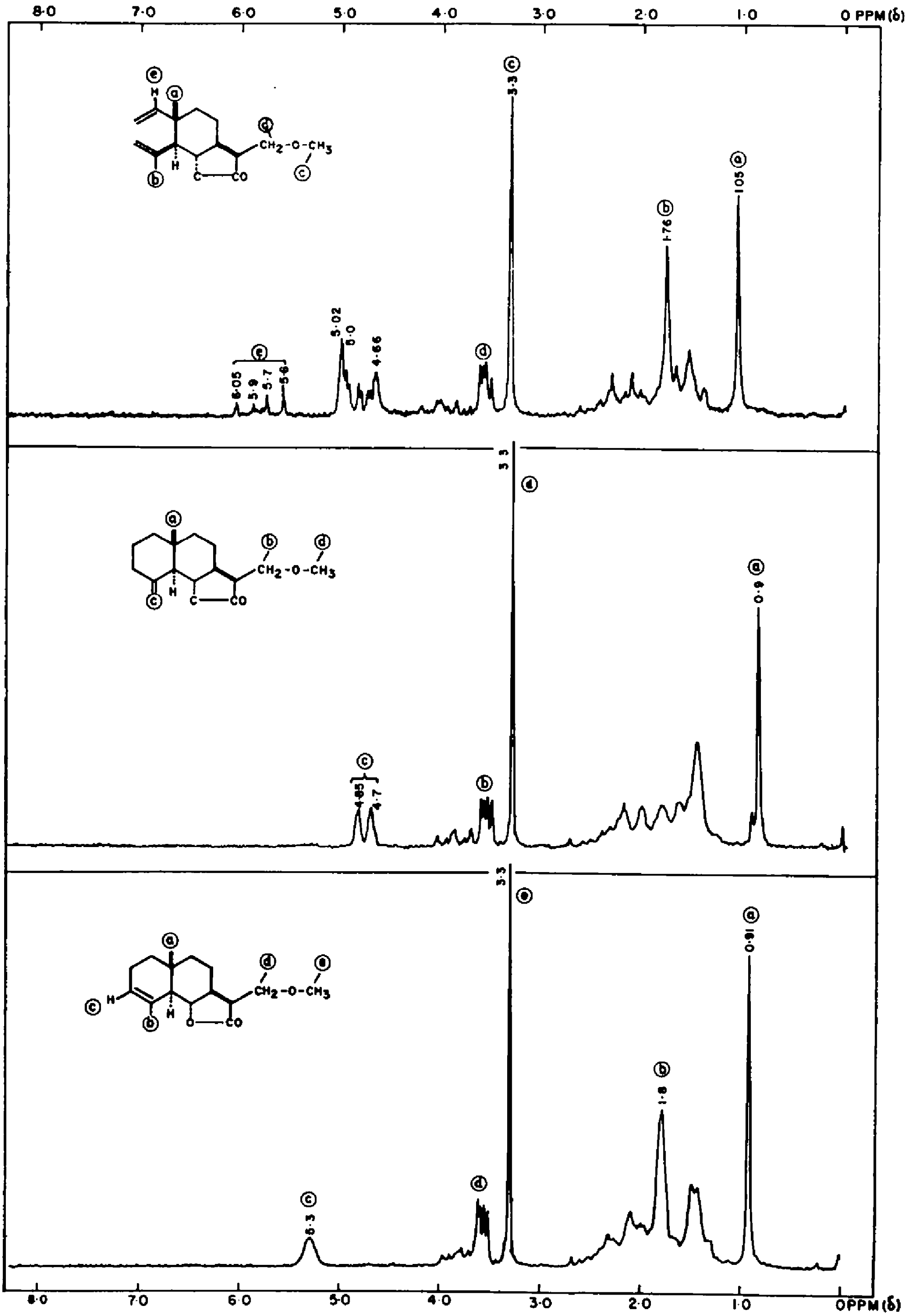
8·0
7·0
6·0
5·0
4·0
3·0
2·0
1·0
0 PPM (δ)
ⓔ
H
ⓐ
ⓓ
CH2-O-CH3
ⓒ
H
ⓑ
C
CO
6·05
5·9
5·7
5·6
ⓔ
5·02
5·0
4·66
ⓓ
3·3
ⓒ
1·76
ⓑ
1·05
ⓐ
ⓐ
ⓑ
ⓓ
CH2-O-CH3
H
ⓒ
C
CO
4·85
4·7
ⓒ
ⓑ
3·3
ⓓ
0·9
ⓐ
ⓐ
ⓓ
ⓔ
CH2-O-CH3
ⓒ
H
H
ⓑ
O
CO
5·3
ⓒ
ⓓ
3·3
ⓔ
1·8
ⓑ
0·91
ⓐ
8·0
7·0
6·0
5·0
4·0
3·0
2·0
1·0
0PPM (δ)

FIG. 6

Unless otherwise stated the IR spectra of solids were taken in Nujol and those of liquids as liquid films.

Lithium aluminium hydride reduction of costunolide (I). Costunolide (24 g; m.p. 106–107°, $(\alpha)_D$ +124°) was reduced with $LiAlH_4$ (10 g) in ether solution initially under cooling and stirring. The reaction mixture was then stirred under reflux (40°) for 24 hr. Excess $LiAlH_4$ was decomposed by alcohol and water. The ether layer containing the diol was washed with water and dried (Na_2SO_4). Removal of ether at 40° gave a thick glassy material (22 g) which was chromatographed on neutral alumina (440 g, grade III). The fraction eluted with pet. ether–benzene contained mostly the unreacted lactone. The fraction eluted with ether contained the diol (15 g) which, however, was not distilled so as to avoid rearrangement, $(\alpha)_D$ +36°, UV end absorption ε 210, 4500 (Found: C, 76·52; H, 10·09. $C_{15}H_{24}O_2$ requires: C, 76·22; H, 10·24%). Perbenzoic acid titrations showed the presence of 2·2 double bond (after 72 hr at −18°). A sample of the diol mixture was pyrolytically rearranged at 220–230° at 2 mm. The rearranged diol, b.p. 185–90°/0·5 mm, $(\alpha)_D$ −17°, n_D^{27} 1·5098 (Found: C, 74·91; H, 10·98. $C_{15}H_{26}O_2$ requires: C, 75·57; H, 11·0%), showed 2·5 double bonds by catalytic hydrogenation indicating thereby that the diol obtained by $LiAlH_4$ reduction was a mixture of IV and V.

Metal amine reduction of the diol mixture (IV and V). In a 2 l. three-necked flask equipped with a mercury sealed stirrer liquid ammonia (500 ml) was drawn. Sodium (20 g) was carefully added during 15–20 min. A solution of the diol (15 g) in ether (150 ml) was added gradually and the mixture stirred for 3 hr. Ammonia was allowed to evaporate and the residue decomposed by dropwise addition of alcohol followed by water. After further dilution with water it was extracted with ether, washed repeatedly with water and dried (Na_2SO_4). After removal of ether, the product was chromatographed on neutral alumina (600 g, gr. III). The pet. ether fraction (1 g) was rechromatographed on neutral alumina (100 g, grade I) and the fraction eluted with pet. ether was distilled to give the hydrocarbon (VIII), b.p. 120°/2 mm, n_D^{26} 1·4885, $(\alpha)_D$ −100°, UV end absorption ε 210, 2500. The IR spectrum (0·05 mm cell) is shown in Fig. 1. Perbenzoic acid titrations showed the presence of two double bonds (1·84 and 1·8 after 96 hr at −18°) (Found: C, 87·2; H, 12·35. $C_{15}H_{26}$ requires: C, 87·3; H, 12·7%).

The fraction of metal amine reduction product (2·5 g), eluted with pet. ether–benzene (1:1), contained two alcohols, one primary and another secondary. These were separated by repeated column chromatography over alumina and found to have the following properties. The alcohols, however, were not distilled to avoid pyrolytic rearrangement.

(a) *Secondary alcohol* (X). $(\alpha)_D$ +14·5°, n_D^{27} 1·4900, UV end absorption, ε 210, 3500, (Found: C, 79·89; H, 11·49. $C_{15}H_{26}O$ requires: C, 81·02; H, 11·79%). Peracid value 1·7 (after 96 hr at −18°).

(b) *Primary alcohol* (XII). $(\alpha)_D$ −91°, n_D^{27} 1·5028, UV end absorption: ε 210, 2200. Peracid value 1·8 (after 96 hr at −18°) (Found: C, 80·76; H, 12·47. $C_{15}H_{26}O$ requires: C, 81·02; H, 11·79%). The IR spectra of these alcohols are shown in Figs. 1 and 2. The fraction of metal amine reduction product, eluted with ether contained mostly the diol (V).

Pyrolysis of the hydrocarbon (VIII). The hydrocarbon (0·5 g) was refluxed for 2 hr at 240–250° at 15 mm. The product was taken in pet. ether and filtered through a column of neutral alumina (50 g, grade I) and the pet. ether eluted portion was again refluxed for 1 hr at 240–250° at 15 mm. The product thus obtained after purification by chromatography and distillation possessed the following properties: b.p. 120–140°/2 mm, n_D^{27} 1·4860, $(\alpha)_D$ −14°. The IR spectrum is shown in Fig. 1. (Found: C, 86·46; H, 12·19. $C_{15}H_{26}$ requires: C, 87·3; H, 12·7%).

The hydrocarbon mixture (0·0664 g) absorbed (15·5 ml) hydrogen at NTP on hydrogenation in acetic acid, using platinum catalyst which corresponded to two double bonds.

Acid catalysed cyclization of the hydrocarbon (VIII). The hydrocarbon (0·4 g) was heated with glacial acetic acid (25 ml) and perchloric acid (1 ml) on a steam bath for 8 hr. It was diluted with water, extracted with ether, the ether layer washed ($NaHCO_3$ aq. followed by water) and dried over Na_2SO_4. After removal of ether the residue was chromatographed on neutral alumina (50 g, grade I) and the pet. ether eluted portion was distilled to give the hydrocarbon (90% pure by VPC), b.p. 110–130°/1 mm, n_D^{22} 1·4920, $(\alpha)_D$ +17° (Found: C, 86·82; H, 12·6. $C_{15}H_{26}$ requires: C, 87·3; H, 12·7%). The IR spectrum showed peaks at 1660 and 815 cm^{-1} due to trisubstituted double bond. The NMR spectrum showed signals at 0·84, 0·93, 0·98 and 1·02 δ units (intensity equal to 12-protons) indicating that all the four $—CH_3$ groups are of the type $—\overset{|}{\underset{|}{C}}—CH_3$. It also showed a signal at 5·2 δ

units due to a proton on a trisubstituted double bond. The hydrocarbon (0·099 g) on hydrogenation in acetic acid in presence of platinum absorbed (11·7 ml) hydrogen at NTP corresponding to the presence of one double bond. Selenium dehydrogenation of the cyclized hydrocarbon failed to give any naphthalenic or azulenic hydrocarbon.

Pyrolysis of the alcohol (X). The alcohol (0·8 g) was refluxed for 1·5 hr at 220–230°/2 mm. The product was chromatographed on neutral alumina (25 g, gr. III) and the fraction eluted with pet. ether–benzene (4:1) was distilled to give (0·5 g) pure XV (VPC) b.p. 130–145°/0·5 mm, n_D^{27} 1·4880, $(\alpha)_D$ −18° (Found: C, 81·16; H, 11·81. $C_{15}H_{26}O$ requires: C, 81·02; H, 11·79%). The IR spectrum showed peaks at 890, 1640, 910 cm^{-1} due to $>C{=}CH_2$ and $-CH{=}CH_2$ (Fig. 1).

Oxidation of the alcohol (XV) *to the ketone* (XVI). The alcohol (0·2 g) was dissolved in acetone (5 ml) and Jones' reagent was added drop by drop till a brown colour persisted. It was kept for 30 min and worked up as usual. The product was purified by chromatography and distillation to give (0·1 g) of the pure ketone (VPC), b.p. 130–140°/0·5 mm, n_D^{27} 1·4845, $(\alpha)_D$ +103°. IR bands at 890, 1640, 910, 1705 cm^{-1} indicated the presence of $>C{=}CH_2$, $-CH{=}CH_2$, and $C{=}O$ groups. The NMR spectrum showed signals at 0·8, 0·84, 0·93, 0·96 δ units (intensity equal to 6 protons) due to isopropyl group; 1·02 σ units (intensity equal to 3 protons) due to a quaternary $-CH_3$; and 1·75, 1·77 δ units (intensity equal to 3 protons) due to $-\underset{|}{C}{=}\underset{|}{C}-CH_3$ group. It also showed signals between 4·7 to 5·05 δ units (intensity equal to 4 protons) and 5·5 to 6·07 δ units (intensity equal to one proton) due to vinyl and unsymmetrical disubstituted double bond. (Found: C, 82·15; H, 11·24. $C_{15}H_{24}O$ requires: C, 81·76; H, 10·98%).

Hydrogenation of the alcohol (XV). The alcohol (0·385 g) was hydrogenated in acetic acid medium using platinum catalyst. The volume of hydrogen absorbed (78·5 ml at NTP) corresponds to two double bonds. The hydrogenated product was worked up in the usual manner and purified by chromatography and distillation to give XVII b.p. 110–130°/0·5 mm, $(\alpha)_D$ +1·4°. (Found: C, 79·29; H, 13·36. $C_{15}H_{30}O$ requires: C, 79·57; H, 13·36%). The liquid solidified on cooling to a low melting solid (m.p. 34–35°) and is identical with the alcohol obtained from tetrahydrosaussurea lactone via the hydroxy aldehyde (obtained by controlled $LiAlH_4$ reduction). The identity was established by mixed VPC, IR spectrum and rotation.

Acid catalysed cyclization of the alcohol (X). The alcohol (1 g) was dissolved in glacial acetic acid (75 ml) and kept at room temp for 4 days. The mixture was then heated for 3 hr on a steam bath and worked up in the usual manner and the product obtained chromatographed on neutral alumina (60 g, gr. II) and eluted as follows:

Chromatogram

Fraction no.	Solvent	Volume in ml	Wt. in g
1	Pet. ether	500	0·25
2	Pet. ether + benzene (4:1)	250	0·1
3	Pet. ether + benzene (1:1)	500	0·4
4	benzene	250	0·15
5	ether	250	trace

Fraction 1 was purified by rechromatography on neutral alumina (30 g, gr. I) and the pet. ether eluted fraction was found from VPC analysis to consist of two compounds (10:90); UV spectrum gave a peak at 248 mμ (ε_{max}. 2300), indicating about 10% of conjugated hydrocarbon; $(\alpha)_D$ −56°. b.p. 120–130°/1 mm. (Found: C, 80·15; H, 10·82%). The elemental analysis indicated that the major product was an oxide.

Fractions 2 and 3 were indicated to be mixtures of alcohols by VPC and IR spectra.

Fraction 4 solidified on cooling. It was sublimed twice, crystallized from pet. ether and sublimed again to give D-junenol, m.p. and mixed m.p. 59–60° $(\alpha)_D$ +53° (Found: C, 80·63; H, 12·14. $C_{15}H_{26}O$ requires: C, 81·02; H, 11·79%).

Fraction 3 (0·2486 g) was hydrogenated in acetic acid medium using platinum catalyst. The volume of hydrogen absorbed (27·0 ml at NTP) indicated the presence of one double bond. The product was worked up in the usual manner and purified by sublimation and crystallization to give a solid m.p. 114–15°, (α)$_D$ ±0° (Found: C, 79·82; H, 12·13. $C_{15}H_{28}O$ requires: C, 80·29; H, 12·57%). From the IR spectrum and mixed m.p. with an authentic sample, (114°), it was identified as dihydrojunenol.

Pyrolysis of the alcohol (XII). The alcohol (1 g) was refluxed at 220–230° at 2 mm for 2 hr. The product was then taken up in pet. ether and chromatographed on neutral alumina (30 g, gr. III). The fraction eluted with pet. ether–benzene (2:1) was distilled to give (XVIII) (purity about 90% by VPC). The IR spectrum (Fig. 2) showed peaks at 890, 1640, and 910 cm^{-1} indicating the presence of $>C=CH_2$ and $-CH=CH_2$. On acetylation with acetic anhydride and pyridine, it gave an acetate which was purified by chromatography and distillation to show a single peak on VPC analysis, b.p. 130–140° at 0·5 mm, (α)$_D$ −32°, n_D^{26} 1·4825. (Found: C, 76·86; H, 10·55. $C_{17}H_{28}O_2$ requires: C, 77·22; H, 10·67%).

Oxidation of alcohol (XVIII) *to the corresponding acid.* The alcohol (0·3 g) was dissolved in acetone (10 ml) and Jones' reagent was added drop by drop till a brown colour persisted. The product was kept for 30 min at room temp and worked up to get a mixture of aldehyde and acid (IR spectrum). The acid was separated by conventional procedure using $NaHCO_3$, b.p. 180–190°/0·5 mm, (α)$_D$ +7°. (Found: C, 76·12; H, 9·99. $C_{15}H_{24}O_2$ requires: C, 76·22; H, 10·24%). IR bands at 1640, 890 cm^{-1} due to $>C=CH_2$ and 910 cm^{-1} due to $-CH=CH_2$ groupings.

Hydrogenation of the alcohol (XVIII) *to* (XX). The alcohol (0·334 g) was hydrogenated in acetic acid medium using platinum catalyst. The volume of hydrogen absorbed (68 ml at NTP) corresponds to two double bonds. The hydrogenated product was worked up in the usual manner, b.p. 130–140°/0·7 mm, n_D^{27} 1·4800. (α)$_D$ −8° (Found: C, 79·49; H, 13·37. $C_{15}H_{30}O$ requires: C, 79·57; H, 13·36%).

Metal amine reduction of the recovered diol (V) *to* (XIIa). The recovered diol (10 g) from the product of metal amine reduction of the diol mixture (IV and V) was subjected to metal amine reduction for a second time in the manner described already using alcoholic solution of the diol. The reaction product on isolation and chromatography over alumina (300 g, gr. III) gave the alcohol (2·5 g), eluted by pet. ether–benzene (1:1) which was not distilled to avoid rearrangement, n_D^{25} 1·5110, (α)$_D$ −17° (Found: C, 79·92; H. 12·3. $C_{15}H_{26}O$ requires: C, 81·02; H, 11·79%).

Pyrolysis of the alcohol (XIIa). The alcohol (1 g) was refluxed for 1·5 hr at 230–240°/3 mm and then distilled to give (XVIIIa) b.p. 140–50°/0·7 mm, n_D^{25} 1·5020, (α)$_D$ −5° (Found: C, 80·9; H, 11·1. $C_{15}H_{26}O$ requires: C, 81·02; H, 11·79%). The alcohol (0·282 g) absorbed hydrogen (58 ml at NTP) when hydrogenated in acetic acid medium using platinum catalyst, corresponding to two double bonds. The hydrogenated product was worked up in the usual manner, b.p. 130–140°/0·5 mm, n_D^{30} 1·4820, (α)$_D$ +1·6° (Found: C, 79·07; H, 13·17. $C_{15}H_{30}O$ requires: C, 79·57; H, 13·36%). This alcohol was identical with the alcohol prepared from tetrahydroelemol. The identity was established by IR spectrum, mixed VPC and physical constants.

Acid catalysed cyclization of the alcohol (XIIa). The alcohol (1·5 g) was dissolved in glacial acetic acid (25 ml) and perchloric acid (1 ml) and kept for a day at room temp. It was then heated for 7 hr on a steam bath and worked up in the usual manner. The product obtained, was chromatographed on alumina (50 g, gr. III). The fraction eluted with pet. ether which was found to be an acetate (IR spectrum) was saponified to the corresponding alcohol, b.p. 140–150°/0·6 mm. (Found: C, 81·3; H, 12·0. $C_{15}H_{26}O$ requires: C, 81·02; H, 11·79%). The alcohol (0·177 g) absorbed hydrogen (18 ml, at NTP) corresponding to the presence of one double bond. The hydrogenated product when worked up in the usual manner had the following properties, b.p. 140–150°/0·6 mm, n_D^{22} 1·4980, (α)$_D$ +9° (Found: C, 81·02; H, 12·36. $C_{15}H_{28}O$ requires: C, 80·29; H, 12·58%).

Pyrolysis of 12-*methoxydihydrocostunolide* (XXIV). 12-Methoxydihydrocostunolide (10 g), m.p. 127°, (α)$_D$ +113°, was heated under reflux for 2 hr at 230–240° (bath) at 0·5 mm. The liquid obtained was dissolved in pet. ether, filtered and the filtrate cooled when the unchanged 12-methoxydihydrocostunolide (XXIV) separated. After removal of solid, the liquid obtained from pet. ether solution was dissolved in methanol and cooled to give crude lactone (2 g), m.p. 66–67° which was crystallized successively from methanol and pet. ether to give the pure lactone, m.p. 73–74° (α)$_D$ +78° (Found: C, 73·2; H. 9·2. OCH_3, 10·9. $C_{16}H_{24}O_3$ requires: C, 72·69; H, 9·16; OCH_3 11·74%). The IR spectrum (Fig. 3) showed peaks at 890, 1640 cm^{-1} due to $>C=CH_2$, but no absorption was observed due to $-CH=CH_2$ at 910 cm^{-1} (instead there was a peak at 925 cm^{-1}). The NMR spectrum (Fig. 6) however indicated the presence of both $>C=CH_2$ and $-CH=CH_2$ groups. 12-Methoxy saussurea lactone (0·96 g) (XXV) absorbed 198 ml hydrogen at NTP, which corresponds to two double bonds.

The hydrogenated product worked up in the usual manner had the following constants, b.p. 195–210°/ 0·5 mm, n_D^{29} 1·4850, $(\alpha)_D$ +35° (Found: C, 72·64; H, 10·32. $C_{16}H_{28}O_3$ requires: C, 71·9; H, 10·52%).

Acid cyclization of 12-*methoxydihydrocostunolide*. 12-Methoxydihydrocostunolide (20 g) was dissolved in glacial acetic acid (200 ml) and kept at room temp for 5 days. It was then worked up in the usual manner and the product obtained was distilled, b.p. 175–85°/0·5 mm and chromatographed on alumina (600 g, gr. III).

Fraction 1 on cooling gave a solid (2·5 g) m.p. 49°. This was purified by chromatography and crystallization from methanol to give (XXVI), m.p. 57° $(\alpha)_D$ +84° (Found: C, 72·8; H, 9·17. $C_{16}H_{24}O_3$ requires: C, 72·69; H, 9·16%). The IR and the NMR spectra are in agreement with the structure (XXVI). Selenium dehydrogenation of XXVI gave 1-methyl-7-ethyl naphthalene characterized as the TNB adduct, m.p. and mixed m.p. 106–107°.

Chromatogram

Fraction no.	Solvent	Volume in ml	Wt. in g
1	Pet. ether	750	7
2	Pet. ether + benzene	500	2
3	Ether	500	0·5
4	Methanol	500	—
5	Acetic acid	500	4

Fraction 5 was purified by distillation and crystallization from methanol to give a solid (XXVII) m.p. 73–74° $(\alpha)_D$ +146° (Found: C, 72·43, H, 9·25. $C_{16}H_{24}O_3$ requires: C, 72·69; H, 9·16%). Selenium dehydrogenation of XXVII gave 1-methyl-7-ethylnaphthalene, characterized as the TNB adduct, m.p. and mixed m.p. 106°.

Compound XXVI (0·6503 g) absorbed 57 ml hydrogen at NTP which corresponds to the presence of one double bond. The hydrogenated product worked up in the usual manner gave a solid m.p. 96° $(\alpha)_D$ +69° (Found: C, 72·0; H, 9·64. $C_{16}H_{26}O_3$ requires: C, 72·14; H, 9·84%). Compound XXVII (0·4653 g) absorbed 41 ml hydrogen at NTP which corresponds to the presence of one double bond. The hydrogenated product on working up gave a solid m.p. 79–80°, $(\alpha)_D$ +56° (Found: C, 72·34; H, 9·8. $C_{16}H_{26}O_3$ requires: C, 72·14; H, 9·84%).

Ammonia adduct of costunolide. Costunolide (10 g) dissolved in alcohol (200 ml) was saturated with ammonia and kept at 0° for 2 days. After dilution with water, it was worked up to give a viscous material (8 g). This was dissolved in benzene and a solution of picric acid in benzene was added to it. A yellow solid immediately separated which was crystallized from methanol, m.p. 203° $(\alpha)_D$ +27° (Found: C, 61·63; H, 6·28; N, 7·9. $C_{36}H_{46}O_{11}N_4$ requires: C, 62·23; H, 6·67; N, 8%). The yellow solid (4 g) was dissolved in chloroform and shaken with 10% NaOH aq. to decompose the picrate. The chloroform layer was washed with water and dried (Na_2SO_4). Removal of chloroform and crystallization of the residue from pet. ether–benzene gave (XXIX), m.p. 153°, $(\alpha)_D$ +87° (Found: C, 75·36; H, 9·36; N, 2·2. $C_{30}H_{43}NO_4$ requires: C, 74·81; H, 9·0; N, 2·91%). UV end absorption, ϵ 210, 15200. The IR spectrum showed a peak at 1660 cm^{-1} due to trisubstituted double bond.