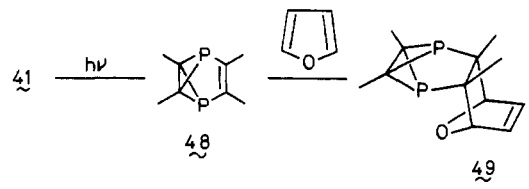
Scheme XIII



Treatment of 41 with an excess of sulfur gave the thiadiphosphanorbornadiene (45), while 0.5 equiv of sulfur gave thiadiphosphole (47) and 39. Thus, sulfur was trapped by 41 to give 45 which has the character of a dienophile and reacted with an excess of 41 to give adduct 46. This adduct (46) has a partial dihydronorbornadiene structure and seems to have been cleaved to 47 and 39 (Scheme XII).

Finally, we show in Scheme XIII the first example of a benzvalene analogue containing a heteroatom in the ring. Irradiation of 41 with a high-pressure mercury lamp gave diphosphabenzvalene (48),[45] which showed the presence of two kinds of trifluoromethyl in its ^{19}F NMR spectrum (one a doublet, the other a triplet, by P–F coupling) and a single kind of phosphorus in its ^{31}P NMR spectrum. Compound 48 reacted with furan to give an adduct (49), just as benzvalene (1) did.

(45) Kobayashi, Y.; Fujino, S., Hamana, H.; Kumadaki, I.; Hanzawa, Y. *J. Am. Chem. Soc.* 1977, *99*, 8511.

A curious feature of these phoshorus compounds is that planar trivalent phosphorus compounds (41, 43, and 47) are very sensitive to air, while bicyclic cage compounds (39, 44, 45, 48, 49) are stable to air. This offers an interesting problem to theoretical chemists.

Concluding Remarks

In this Account, we have shown many examples in which trifluoromethyl groups stabilize otherwise unstable ring systems. This stabilization may be due in part to steric effects. However, this cannot be the sole factor responsible, as mentioned before. Some changes in hybridization on carbon atoms due to the high electronegativity of fluorine atoms, and some p–π repulsion might make important contributions in some cases. We are now planning to examine steric effects by means of force-field calculations, and electronic effects by MO calculations.[46]

(46) After the submission of this paper, Greenberg et al. reported theoretical calculation of the perfluoroalkyl effect. (Greenberg, A.; Liebman, J. F.; Van Vechten, D. *Tetrahedron* **1980**, *36*, 1161). According to their calculations, a trifluoromethyl group does not stabilize strained compounds. They were concerned with energy differences between unsubstituted and trifluoromethylated compounds. We use the word "stabilized" when a strained ring system is formed from the parent aromatic compound. Our concern is with the small energy difference between the strained ring system and the aromatic compound with trifluoromethyl groups and the fast formation and slow decomposition of strained ring systems with trifluoromethyl groups. Slow decomposition may be partly due to the "siphoning" of vibrational energy into perfluoroalkyl groups, as mentioned by Greenberg et al.

Aspects of Longifolene Chemistry. An Example of Another Facet of Natural Products Chemistry

SUKH DEV

Malti-Chem Research Centre, Nandesari, Vadodara, India

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There are several facets of natural product chemistry: structure elucidation, synthesis, biostudies, and transformations. Classically, structure elucidation was the prime motivation for the study of a natural product, whether biologically active or just an academic curiosity. Degradation, transformations, synthesis—all formed an integral part of this exercise. However, with the introduction of spectroscopic techniques, the role of chemical reactions in structure determination has become minimal. Increasingly, complex organic structures are being elucidated by X-ray crystallography, a technique which essentially bypasses the organic chemist! These advances constitute a watershed in the development of chemistry of natural products and have enabled chemists to direct efforts to aspects of natural products chemistry considered unassailable until recently. On the other hand, the classical approach involving chemical transformations had, in the past, generated a fund of interesting and unexpected results, often of fundamental importance. This is because many complex natural products have such built-in stereoelectronic features that their chemical transformations, not too infrequently, led to unanticipated results.[1] It is suggested that chemical transformations of easily available, novel, complex organic molecules deserve to be investigated so that the excitement of the unexpected is not completely lost!

Longifolene, $C_{15}H_{24}$, is a tricyclic olefin and occurs to the extent of 5–10% in the Indian turpentine oil, which is produced commercially from the oleoresin of Himalayan pine, *Pinus longifolia* Roxb. Its structure (1) was established[2] in 1953, but still over 25-years later, it continues to attract attention as a novel substrate for

Sukh Dev is Research Director of Malti-Chem Research Centre, Nandesari, Baroda, India. He was born in Chakwal, which is now in Pakistan, in 1923. He studied at D. A. V. College, Lahore, for his M.Sc. degree and at Indian Institute of Science, Bangalore, for the Ph.D. and D.Sc. From 1969 until he joined Malti-Chem in 1974, he was Head of the Division of Organic Chemistry at the National Chemical Laboratory, Poona. His research interests include natural products chemistry, nonbenzenoid aromatic systems, organic reactions, and the development of new technology.

(1) Viewed with hindsight, such results offer little difficulty in rationalization!

(2) R. H. Moffett and D. Rogers, *Chem. Ind. (London)*, 916 (1953); P. Naffa and G. Ourisson, *ibid.*, 917 (1953).

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transformations, generating interesting chemistry. This Account[3] has been written to highlight some recent results of this aspect of chemistry of longifolene,[4] as an example of another facet of natural products chemistry.

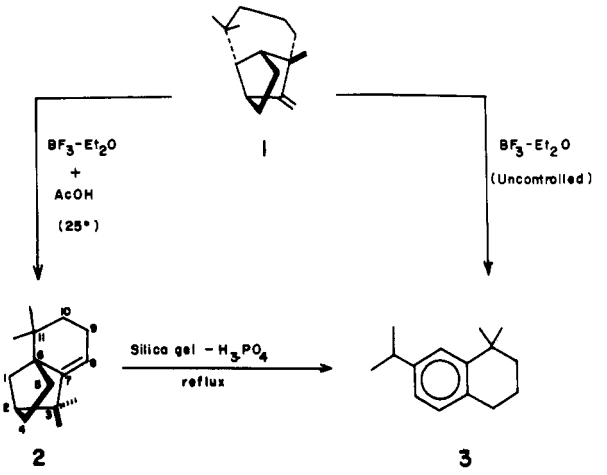
Acid-Catalyzed Rearrangement

Under acid catalysis, longifolene undergoes a variety of rearrangements depending on the reaction conditions and the reagent. Two of these (Scheme I) are of special interest, as deep-seated skeletal rearrangements are involved. Thus, (+)-longifolene (1) on exposure to strong protic (e.g., H_2SO_4) or Lewis acids (e.g., BF_3·Et_2O) rearranges in an excellent yield to an isomeric tricyclic hydrocarbon, (−)-isolongifolene (2), the structure of which has been established unequivocally by degradation[5,6] and synthesis.[7] It was also established that isolongifolene, thus obtained, is racemized to varying degrees.[5] However, if this reaction with acids is carried out under more severe conditions, or if isolongifolene is further treated under these conditions, then a tetralin characterized as 3 results as the major product.[8]

This rearrangement of longifolene to isolongifolene with concomitant partial racemization was rationalized[5,9] by a series of 1,2 shifts (Scheme II). Racemization of (−)-isolongifolene is explained by initial racemization (via 4 ⇌ 5) of longifolene prior to skeletal reorganization, as it is difficult to visualize a suitable mode for the racemization of isolongifolene once it has been generated. The remaining steps were considered unexceptional: formation of the bridgehead carbocation (6) has earlier analogy.[10] Subsequently, Berson et al.,[11] on the basis of their extensive studies on methylnorbornyl cations, pointed out that the proposed endo,endo methyl shift (4 → 6) should be energetically unfavorable. He therefore proposed a modified scheme (Scheme III) wherein the more precedented exo,exo (11 → 12) shift is involved. Still later, McMurry[12] suggested the intermediacy of longicyclene[13] (13) in order to evolve a simplified version (Scheme IV) of Scheme III.

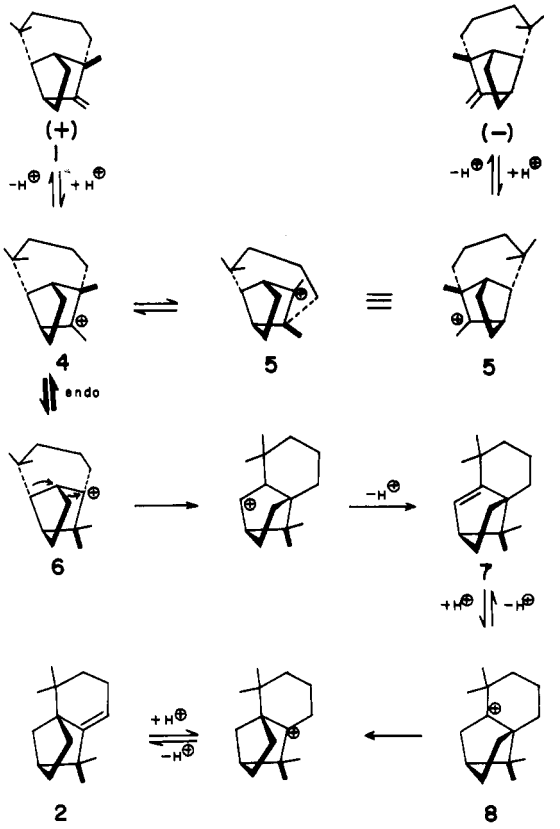
Some years ago we undertook work to clarify the above situation, and our salient findings are summarized below.[14,15]

Scheme I



2 3

Scheme II



4 5 5 6 7 2 8

To elucidate the mechanism of rearrangement of longifolene to isolongifolene, it is important to first distinguish between Scheme II and Scheme III since Scheme IV raises the general question of possible intermediates which may lie on the reaction pathway, and this is best dealt with after distinguishing between Schemes II and III. It was soon realized that a clear-cut answer to this question should be forthcoming if one would subject longifolene-*4,4,5,5-d*$_4$ (14) to this rearrangement, as the two routes would lead to isolongifolene-d_4 having different deuterium substitution patterns (Scheme V) which it should be possible to discern. Thus, synthesis of longifolene-*4,4,5,5-d*$_4$ (14) became the immediate objective.

(3) Essentially based on the Award Address, the Earnest Guenther Award in the Chemistry of Essential Oils and Related Products, 179th National Meeting of the American Chemical Society, March 1980, Houston, TX.

(4) A fuller account of the chemistry of longifolene is under publication elsewhere: Sukh Dev, *Forschr. Chem. Org. Naturstoff.*, in press.

(5) R. Ranganathan, U. R. Nayak, T. S. Santhanakrishnan, and Sukh Dev, *Tetrahedron*, **26**, 621 (1970).

(6) T. S. Santhanakrishnan, U. R. Nayak, and Sukh Dev, *Tetrahedron*, **26**, 641 (1970).

(7) R. R. Sobti and Sukh Dev, *Tetrahedron*, **26**, 649 (1970).

(8) S. C. Bisarya, U. R. Nayak, and Sukh Dev, *Tetrahedron Lett.*, 2323 (1969).

(9) G. Ourisson, *Proc. Chem. Soc. London*, 274 (1964).

(10) See, e.g., J. S. Clunie and J. M. Robertson, *Proc. Chem. Soc. London*, 82 (1980).

(11) J. A. Berson, J. H. Hammons, A. W. McRowe, R. G. Bergman, A. Remanick, and D. Houston, *J. Am. Chem. Soc.*, **89**, 2590 (1967).

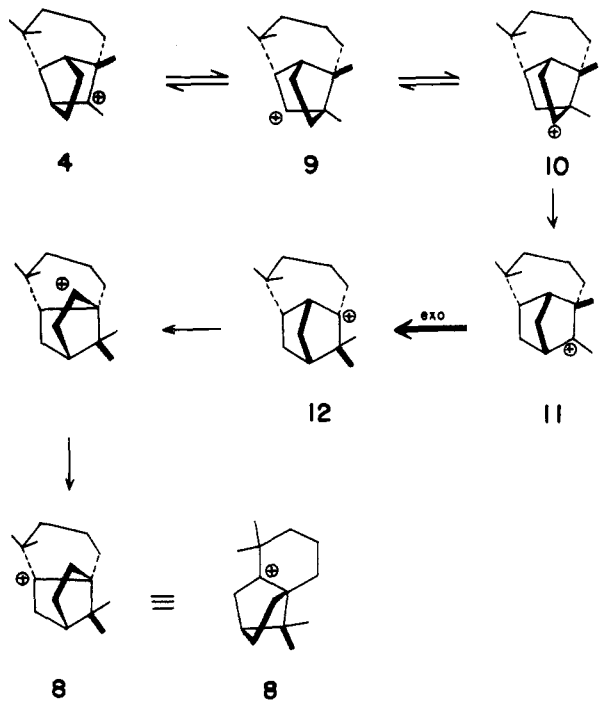
(12) J. E. McMurry, *J. Org. Chem.*, **36**, 2826 (1971).

(13) U. R. Nayak and Sukh Dev, *Tetrahedron*, **24**, 4099 (1968).

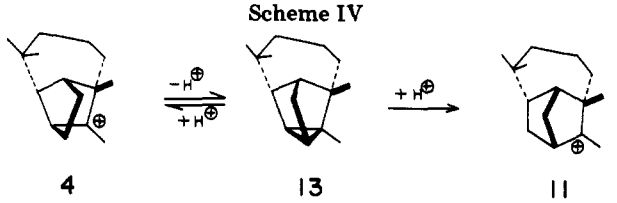
(14) J. S. Yadav, U. R. Nayak, and Sukh Dev, *Tetrahedron*, **36**, 309 (1980).

(15) J. S. Yadav, R. Soman, R. R. Sobti, U. R. Nayak, and Sukh Dev, *Tetrahedron*, **36** (1980).

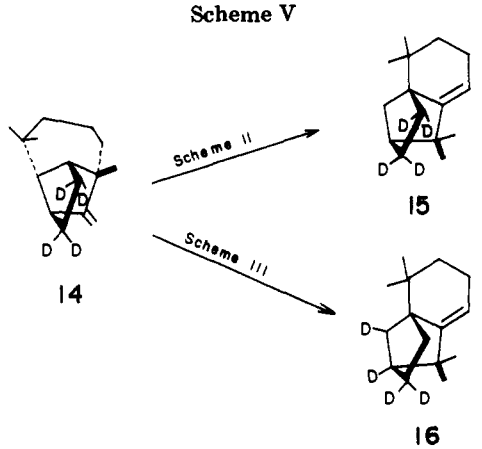
Scheme III



Scheme IV



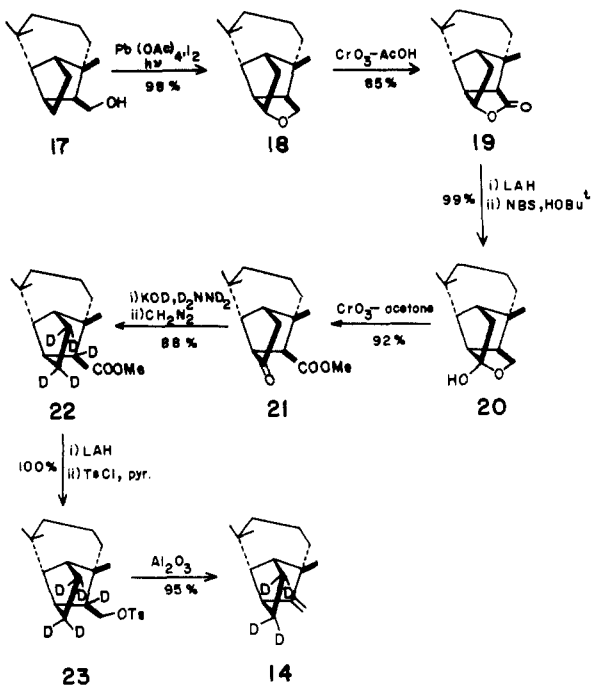
Scheme V



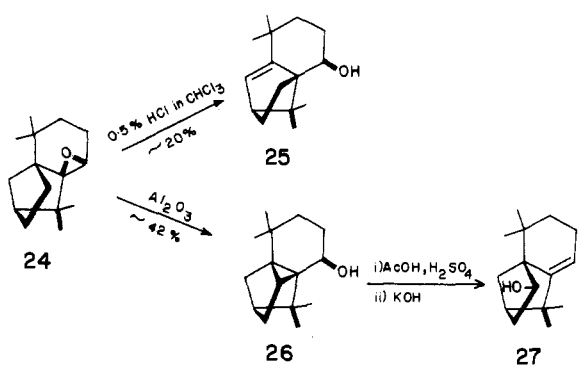
Any method for introducing deuterium at C-4 and C-5 in longifolene would first require suitable functionalization, such as introduction of a CO group, at either of these positions in longifolene. Ether **18**, which had been prepared earlier by Patnekar and Bhattacharyya[16] and Lhomme and Ourisson[17] by the action of lead tetraacetate on 3-isolongifolol (**17**), appeared ideal for further elaboration into the required product. The first prerequisite, however, was to obtain ether **18** in more satisfactory yields, as both groups of previous workers could obtain **18** in yields of only 20–30%. By using $Pb(OAc)_4$/iodine/$h\nu$, rather than $Pb(OAc)_4$ alone, and by suitable modifications of the reaction conditions,

(16) S. G. Patnekar and S. C. Bhattacharyya, *Tetrahedron*, **23**, 919 (1967).
(17) J. Lhomme and G. Ourisson, *Tetrahedron*, **24**, 3177 (1968).

Scheme VI



Scheme VII



we succeeded in getting **18** in almost quantitative yields. Further elaboration of **18** was carried out as outlined in Scheme VI.

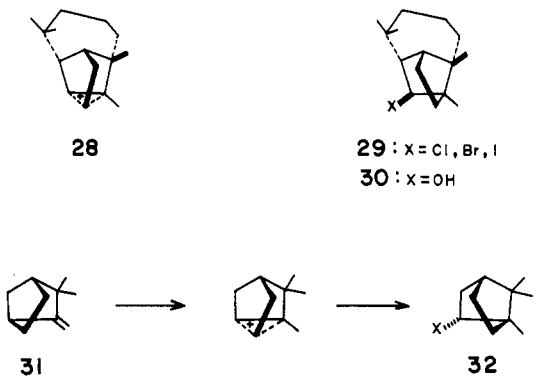
The transformation **21** → **22**, which is crucial to our purpose, could be most conveniently carried out by Wolff–Kisher reduction, using KOD, $D_2NND_2{\cdot}D_2O$, and diethylene glycol-*O*-d_2. The product (as Me ester) showed by mass spectrometry an average deuterium content of 4.34/molecule (relative % deuterated species: D_3, 8; D_4, 49; D_5, 43). The additional deuterium is principally due to the anticipated incorporation at C-3 and some random substitution.[18] This additional deuteration is not of any consequence for the purpose at hand, since it was essentially lost at the last elimination step. The target **14** showed an average deuterium content of 3.5 D/molecule (relative % deuterated species: D_1, 1; D_2, 7; D_3, 35; D_4, 49; D_5, 9).

Exposure of **14** to $BF_3{\cdot}Et_2O$ gave isolongifolene-d_4 in which the deuterium atoms must now be located unequivocally in order to distinguish between the alternatives **15** and **16**. We had earlier discovered two reactions of isolongifolene epoxide[19,20] (**24**), as shown in Scheme

(18) See, e.g., A. Nickon, J. L. Lambert, J. E. Oliver, D. F. Corey, and J. Morgan, *J. Am. Chem. Soc.*, **98**, 2593 (1976).
(19) T. S. Santhanakrishnan, R. R. Sobti, U. R. Nayak, and Sukh Dev, *Tetrahedron*, **26**, 657 (1970).

VII, which appeared elegantly suited to our objective. The alcohol **25** and the homoallylic alcohol **27**, derivable from the cyclopropyl carbinol **26** by acid-catalyzed rearrangement,[14,21] are eminently suitable for spectroscopic distinction between the two deuterium distribution possibilities. These reactions were next applied to isolongifolene-d_4, and the deuterated products corresponding to **25**, **27**, and the ketone derived from **27** were examined by ^{1}H NMR and mass spectrometry. Without going into any further details, it will suffice here to say that the results clearly ruled out structure **15** for isolongifolene-d_4 and *any* participation of endo pathway as envisaged in Scheme II and provide full support for the gross features of the alternative exo,exo mechanism (Scheme III) proposed by Berson et al.

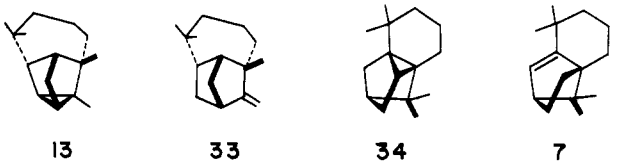
A strong preference for exo,exo 3,2-hydride/Me migration for bicyclo[2.2.1]heptane systems, in general, is now well established,[22,23] though at least two cases of endo,endo migration arising from certain special structural features have been recorded.[24,25] However, the theoretical basis for this preference is still a subject of controversy.[22a] The most widely advanced[22b] explanation for this stereospecificity, advocated initially by Berson,[11] rests on the intermediacy of a nonclassical ion, a concept which has been under active scrutiny and considerable controversy during the past several years.[26] However, in longifolene chemistry, the bridged ion such as **28** is considered unimportant,[9] since the addition of



hydrogen halides to longifolene results in longibornyl halides **29** and not longiisobornyl halide, expected on analogy with the reactions of camphene (**31**, **32**); hydration[27] also results in substitution from the endo face giving longiborneol (**30**).

In analogy with this stereochemical outcome from reactions involving external nucleophiles, one would have expected at least some participation of the endo-migration route (Scheme II) toward isolongifolene development. Since this is not so, rationalization was sought in some other possible contributory factors. Examination of Schemes II and III shows that in ion **6** (Scheme II) the charge is located at the bridgehead of the bicyclo[4.2.1]nonane part of the system, while in the corresponding ion **12** of Scheme III, the vacant p orbital would be at the bridgehead of the somewhat more flexible bicyclo[4.3.1]decane system. Indeed molecular models (Dreiding) reveal that whereas a planar trigonal carbon at the bridgehead, as required for **12** is readily incorporated without any serious deformation of the constituent bicyclo[2.2.1]heptane system, a similar exercise for **6** is not possible without severely distorting its bicyclo[2.2.1]heptane component. Thus ion **6** is considered to be less stable relative to **12** and this energy difference may provide a tangible barrier to the pathway depicted in Scheme II. It is true that bridgehead carbocations on bicyclo[3.2.1]octane systems have been invoked to rationalize certain rearrangements in the caryophyllene[28] and thujopsene[29] series, but in our present consideration of ions **6** and **12**, we are concerned with the thermodynamic energy difference.

We may now turn to the second question, namely, the possible occurrence of neutral intermediates, which may lie on the reaction pathway from longifolene to isolongifolene, and specifically the suggestion of McMurry[12] implicating longicyclene (**13**) via cation **11**. An inspection of Scheme III reveals that if one considers the possibility of equilibration of the tertiary carbocations with the corresponding olefin (1,2 elimination) or cyclopropane (1,3 elimination),[30] there are then, besides longicyclene (**13**), at least three more compounds (**7**, **33**, **34**), which may conceivably lie on the reaction pathway.



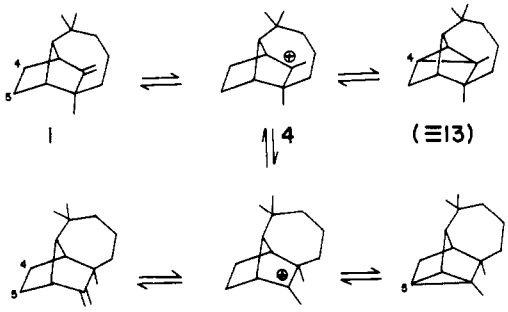
If one isomerizes longifolene in the presence of a deuterio acid, then additional deuterium would get incorporated at certain specific sites, which in turn would reveal if **13**, **34**, and/or **7** are reaction intermediates. Specifically, the absence of any deuterium at C-1/C-2 in isolongifolene (**2**) would render McMurry's suggestion untenable. It may be noted that intermediacy of **33** cannot be probed by this method.

Exposure of longifolene to BF_3·Et_2O–AcOD (30 °C, 20 min) yielded deuterated isolongifolene, which was shown[15] to have its entire deuterium (average deuterium content ~3.1 D/molecule) restricted to the two methyls on C-3, thus clearly precluding the involvement of longicyclene and/or other possible intermediates considered earlier.

However, it had been found earlier[13] that longicyclene/longifolene on being exposed to cupric acetate in refluxing acetic acid (22 h) gets converted into a similar mixture consisting of some 51% longifolene, 20%

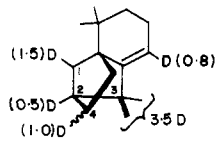
(20) J. A. McMillan, I. C. Paul, U. R. Nayak, and Sukh Dev, *Tetrahedron Lett.*, 419 (1974).
(21) E. H. Eschinasi, G. W. Shaffer, and A. P. Bartels, *Tetrahedron Lett.*, 3523 (1970).
(22) See, e.g., (a) J. A. Berson in "Molecular Rearrangements", Vol. I, P. de Mayo, Ed., Interscience, New York, 1963, p 111; (b) G. D. Sargent in "Carbonium Ions", Vol. III, G. A. Olah and P. von R. Schleyer, Eds., Wiley-Interscience, New York, 1972, p 1114.
(23) C. W. David, B. W. Everling, R. J. Kilian, J. B. Stothers, and W. R. Vaughan, *J. Am. Chem. Soc.*, **95**, 1265 (1973).
(24) A. W. Bushell and P. Wilder, *J. Am. Chem. Soc.*, **89**, 5721 (1967); P. Wilder and W. C. Hsieh, *J. Org. Chem.*, **36**, 2552 (1971).
(25) S. Rengaraju and K. D. Berlin, *Tetrahedron*, **27**, 2399 (1971).
(26) For a recent summary, see: (a) G. A. Olah, *Acc. Chem. Res.*, **9**, 41 (1976); (b) H. C. Brown, *Tetrahedron*, **32**, 179 (1976).
(27) U. R. Nayak and Sukh Dev, *Tetrahedron*, **8**, 42 (1960); J. R. Prahlad, U. R. Nayak, and Sukh Dev, *ibid.*, **26**, 663 (1970).
(28) W. Parker, R. A. Raphael, and J. S. Roberts, *J. Chem. Soc. C* 2634 (1969).
(29) W. G. Dauben and L. E. Friedrich, *J. Org. Chem.*, **37**, 241 (1972).
(30) J. T. Keating and P. S. Skell in "Carbonium Ions", Vol. II, G. A. Olah and P. von R. Schleyer, Eds., Wiley-Interscience, New York, 1970, pp 595, 629.

Scheme VIII



longicyclene, and 15% isolongifolene (balance being acetates[27]). Obviously, under the reaction conditions, longifolene and longicyclene are equilibrated, with some quantity of the material being irreversibly transformed into isolongifolene. This equilibration would imply that, under certain conditions, longicyclene can be implicated as an intermediate, though not an obligatory one, in the rearrangement of longifolene to isolongifolene. Direct evidence in support of this was forthcoming as follows.

Exposure of longifolene to D_3PO_4–dioxane at reflux, conditions under which longifolene to isolongifolene isomerization is exceptionally sluggish (requiring 96 h for completion), furnished deuterated isolongifolene having species containing up to 12 D atoms and a total average 7.33 D/molecule. This clearly indicates new equilibration of intermediate carbocations with the corresponding olefin/cyclopropane. A study of the mass spectral fragmentation of the product along with an analysis of the spectral characteristics (^1H NMR, mass) of its derivatives corresponding to **25** and **27** helped in elucidating the location of the D label in the product; this information is summarized[15] in **35**. This result is



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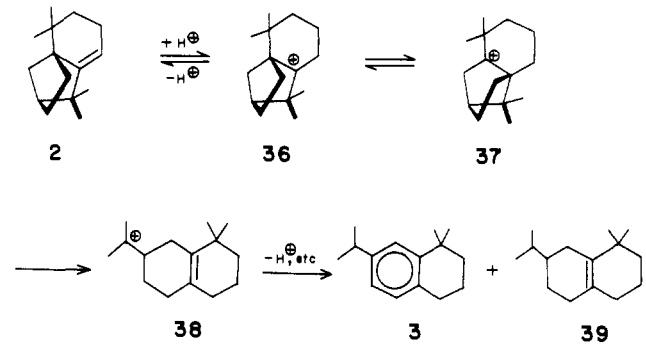
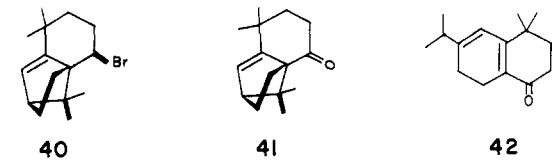
best rationalized in terms of involvement of antipodal longicyclenes (Scheme VIII), resulting in additional deuteration at C-4 and C-5 in the longifolene skeleton, which ultimately shows up as deuterium at C-1, C-2, and C-4 in the isolongifolene nucleus. These results also require that cleavage of the cyclopropane ring in longicyclene leads preferentially to longifolyl cation **4** rather than to the cation **11** (Scheme IV). More direct evidence in support of this contention has been forthcoming from the results[15] of the rearrangement of longicyclene with BF_3-Et_2O–AcOD, but these will not be further discussed here.

Isolongifolene is still a high-energy molecule by virtue of the presence of the strained bicyclo[2.2.1]heptane system; hence it is not surprising that the molecule reorganizes further under appropriate conditions.[8] Thus, isolongifolene (or longifolene; Scheme I) on being refluxed in the presence of silica gel–phosphoric acid gives besides a polymer (25–30%) the tetralin **3** and the octalin **39**.[31] A possible pathway for this rearrangement is depicted in Scheme IX.

Scheme IX



As a corollary to the mechanism shown in Scheme IX, one would expect facilitation of the rearrangement in structures in which the change **37** to **36** is inhibited. This is fully borne out[31] by the rearrangement of 8-bromoneoisolongifolene (**40**)[32] and the ketone **41**.[19]



8-Bromoneoisolongifolene on dissolution in 90% H_2SO_4 at 0 °C rapidly generates hydrogen bromide to finally furnish tetralin **3** in good yield. Similarly, ketone **41** on exposure to 90% H_2SO_4 at 0 °C readily rearranged to the anticipated dienone **42**.

Steric Diversion

Conceivably, in an addition reaction of an olefin, if the more substituted end of the ethylenic linkage is sterically shielded such that the approach of a nucleophile or a radical is essentially blocked, the resulting product cannot be expected to be the result of a simple addition reaction but would always be complicated by the intervention of other pathways such as elimination/rearrangement.[33] Another consequence of such steric crowding would be that, even if a simple addition does occur in favorable cases such as oxirane ring formation or is made to occur under special reaction conditions, the product due to steric compression would be specially prone to reactions in which there is a change from sp^3 to sp^2 hybridization at the new fully substituted carbon[34,35] in the transition state.

Thus, sterically crowded situations can divert the "normal" reaction pathway, and the term *steric diversion* has been proposed[36] to describe this switchover from the "normal" route. In both longifolene (**1**) and isolongifolene (**2**), the ethylenic linkage is well shielded and steric crowding at the more substituted end of the olefinic bond is at least as severe as in *unsym*-dineopentylethylene. Hence, it is not surprising that the chemistry of longifolene/isolongifolene is replete with examples of "abnormal products", more appropriately called sterically diverted products. We present two

(31) S. C. Bisarya, U. R. Nayak, Sukh Dev, B. S. Pandey, J. S. Yadav, and H. P. S. Chawla, *J. Indian Chem. Soc.* **55**, 1138 (1978).

(32) J. S. Yadav, H. P. S. Chawla, and Sukh Dev, *Tetrahedron*, **34**, 475 (1978).

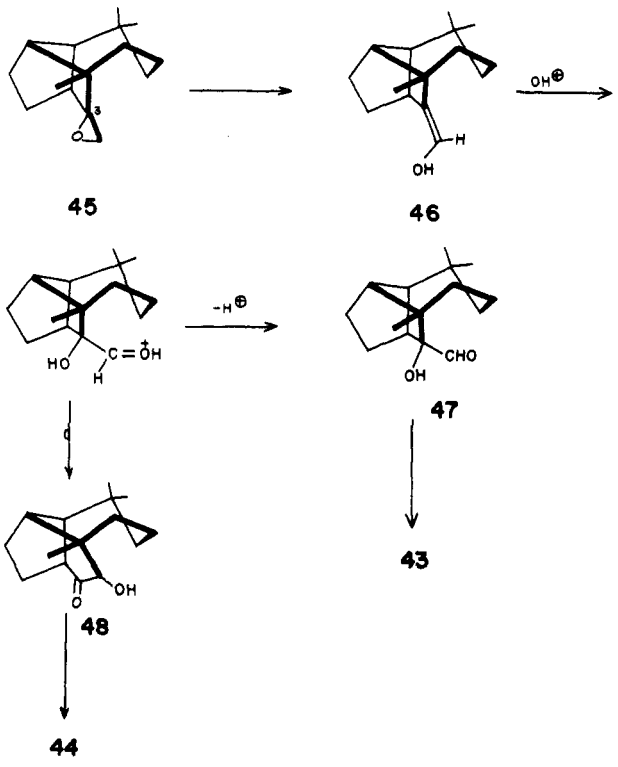
(33) See, e.g., S. Marmor and J. G. Maroshi, *J. Org. Chem.*, **31**, 4278 (1966).

(34) H. C. Brown, *J. Chem. Soc.*, 1248 (1956).

(35) T. T. Tidwell, *Tetrahedron*, **34**, 1855 (1978).

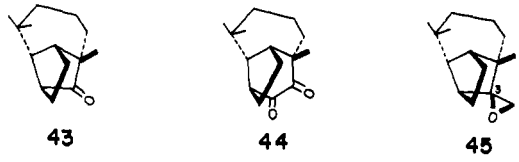
(36) J. S. Yadav, H. P. S. Chawla, Sukh Dev, A. S. C. Prakasa Rao, and U. R. Nayak, *Tetrahedron*, **33**, 2441 (1977).

Scheme X



examples, one each from longifolene and isolongifolene chemistry:

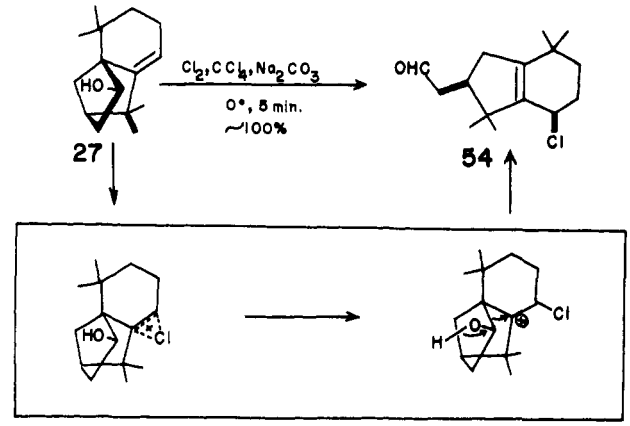
Naffa and Ourisson[37] found that longifolene, which has only one olefinic linkage, consumes almost 2 mol equiv of perbenzoic acid (in $CHCl_3$ at ~0 °C), generating completely unexpected products, the norketone longicamphenilone (**43**, 68%) and the ring-expanded dione **44**, and none of the anticipated epoxide. In a later



investigation, it was demonstrated[38] that longifolene epoxide, which was assigned the endo structure **45**, is indeed the primary product of epoxidation, provided the reaction is carried out in benzene solution. It was further shown that the epoxide slowly consumed 1 mole equiv of perbenzoic acid (in $CHCl_3$, ~0 °C) to furnish a mixture of compounds, qualitatively similar to the products of uncontrolled oxidation of longifolene by perbenzoic acid.

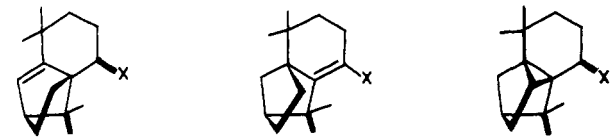
The above results were rationalized (Scheme X) in terms of the key suggestion[38] that the propensity of longifolene epoxide to further peracid attack has its origin in the steric compression at C-3 in the epoxide, which is relieved by its isomerization to the enol **46**. Thus α-hydroxy aldehyde **47** becomes the key intermediate in these transformations. Until recently, however, all attempts to isolate **47** or even obtain evidence for its presence were unsuccessful. It has now been demonstrated[39] that, by using a mixture of carefully purified chloroform and ethanol, oxidation of

Scheme XI



longifolene with 2 mol equiv of perbenzoic acid gives, in good yield, the elusive 3-hydroxylongifolaldehyde, which has been shown to possess the stereochemistry **47**. As expected, **47** readily furnished the C_{14}-ketone **43** on further peracid oxidation and smoothly rearranged to the ketol **48**, the precursor for the dione **44**, on a short exposure to *p*-toluenesulfonic acid in chloroform (at 25 °C).

In isolongifolene chemistry, electrophilic addition to the olefinic bond is an example of steric diversion. Addition of halogens (Cl_2, Br_2) and pseudohalogens (ICl, halogen azides, nitrosyl chloride) to isolongifolene does not result in any "normal" addition products due to severe steric hindrance to the approach of the counterion at C-7. The intially formed halonium ion undergoes elimination/rearrangement to furnish[36] one or more of the products **49**, **50**, **51**. Thus, exposure of



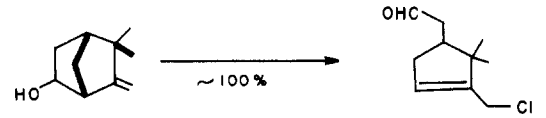
isolongifolene to 1 mol equiv of chlorine gives **49** (55%) and **51** (45%; X = Cl); bromine on the other hand, leads mostly to **49** (95%; X = Br), while ICl gives over 90% of the elimination product **50** (X = I). These results have been rationalized in terms of the bridging capacity[40] of halogens. With 2 mol equiv of bromine, isolongifolene gives chiefly **52** (X = Br), whereas 2 mol equiv of chlorine leads to the products **52** (X = Cl) and **53** in a ratio of 1:12.

Fragmentation of Homoallylic Alcohol

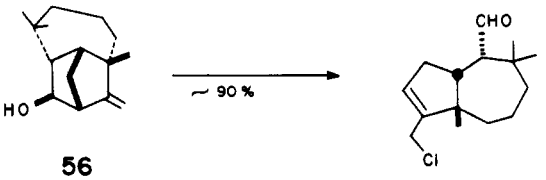
In pursuit of another objective, the action of halogens on the homoallylic alcohol **27**, readily available from isolongifolene epoxide (**24**), was investigated. It was found[41] that the reaction with chlorine, under buffered

(37) P. Naffa and G. Ourisson, *Bull. Soc. Chim. Fr.*, 1115 (1954).
(38) U. R. Nayak and Sukh Dev, *Tetrahedron*, **19**, 2269 (1963).
(39) A. P. Joshi, U. R. Nayak, and Sukh Dev, *Tetrahedron*, **32**, 1423 (1976).
(40) P. Freeman, *Chem. Rev.*, **75**, 439 (1975).
(41) J. S. Yadav, H. P. S. Chawla, and Sukh Dev, *Tetrahedron Lett.*, 201 (1977).

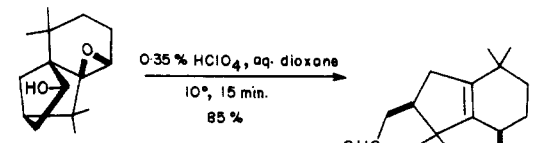
conditions at ~0 °C, resulted in a facile, quantitative fragmentation to an aldehyde, readily recognized as **54**. Scheme XI depicts a possible pathway. Extension of this reaction to two other homoallylic alcohols (**55**, **56**) which were on hand resulted in similar clean fragmentations. It was further found that the fragmentation of this system (e.g., **55**) would occur under the influence of other usual electrophiles (acids, halogens, pseudohalogens, mercuric acetate). Oxiranes, such as **57**, also



55 **58**



56



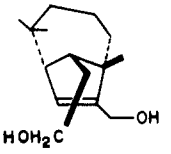
57

underwent facile transformation to the corresponding hydroxy aldehydes under mild acid catalysis. The configuration of the hydroxyl group appears to be inconsequential, as the epimers of alcohols **27** and **55** fragmented with equal facility to the corresponding chloro aldehydes **54** and **58**, respectively.

This cleavage reaction differs from Grob fragmentation[42] in generating allylic halides, alcohols etc., instead of olefins and, in appropriate cases, this can be of distinct value for further synthetic operations. To illustrate this, the application of this fragmentation reaction to the synthesis[43] of (−)-secolongifolenediol (**59**), the optical antipode of a metabolite[44] of the fungus *Helminthosporium sativum* will be discussed.

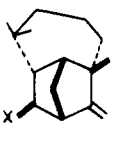
(42) See, e.g., C. A. Grob and P. W. Schiess, *Angew. Chem., Int. Ed. Engl.*, **6**, 1 (1967).
(43) J. S. Yadav, H. P. S. Chawla, and Sukh Dev, *Tetrahedron Lett.*, 1749 (1977).
(44) F. Dorn and D. Arigoni, *Experientia*, **30**, 851 (1974).

The homoallylic alcohol pertinent to the synthesis of **59** is 4-hydroxylongifolene (**60**). This intermediate was

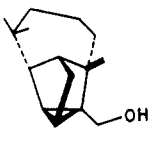


59

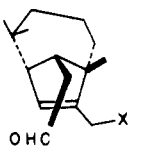
60: X = OH
61: X = Br



62: X = Br
56: X = OH



63



64: X = Cl
65: X = OH

prepared as follows: Exploiting the cleavage[45] of a cyclopropane ring with *N*-bromosuccinimide (NBS), longicyclene was exposed to NBS in refluxing $CHCl_3$, to get a product (100%) consisting essentially of the two homoallylic bromides **61** and **62** (4:1). Hydrolysis of the bromide mixture in aqueous dioxane (100 °C) under buffered conditions (Li_2CO_3) furnished a product in which the required **60** was present only to the extent of 15%, the major product (75%) being the known[46] pseudolongifolol (**63**)! However, additional amounts of the required 4-hydroxylongifolene (**60**) could be obtained by carrying out acid-catalyzed isomerization of pseudolongifolol, which resulted in a mixture of **60**, **56**, and **63** (2:3:5). The mixtures were separated by chromatography over $AgNO_3$ on silica gel.

Alcohol **60**, when exposed to 1 mol equiv of Cl_2 (5% solution in CCl_4) at 0 °C (5 min), in the presence of Li_2CO_3, was nearly quantitatively converted into the anticipated chloro aldehyde **64**. This on hydrolysis furnished in 90% yield the hydroxy aldehyde **65**. $NaBH_4$ reduction of **65** gave in excellent yield the desired secolongifolenediol (**59**).

The work I have described has been possible with the dedicated efforts of my students and colleagues whose names appear in the references. I take this opportunity to express my gratitude to them.

(45) M. Gaitonde, P. A. Vatakencherry, and Sukh Dev, *Tetrahedron Lett.*, 2007 (1964).
(46) G. Mehta, U. R. Nayak, and Sukh Dev, *Tetrahedron*, **24**, 4105 (1968).