Regioselective Intramolecular Base-Induced Synthesis of α,β-Unsaturated Acyldecalins from Decalones via Carbon Homologation with TosMIC. Synthesis of (±)-6-Eudesmen-4α-ol and (±)-Vetiselinene

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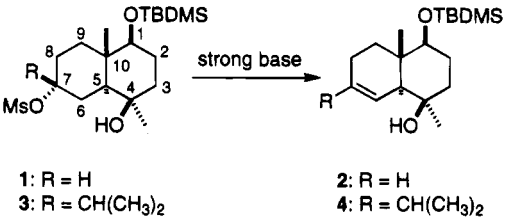
Reaction of decalones **6a–e** with TosMIC gives adducts **7a–e** which can be methylated concomitant with regioselective migration of the double bond to an endocyclic position. The regioselectivity of the double bond migration is determined by the presence or absence of a free hydroxyl group at C(4). Base-catalyzed methylation of TosMIC adducts **7b–d**, possessing a free hydroxyl group at C(4), and subsequent acid-catalyzed hydrolysis led preferentially to the C(6)–C(7) double bond isomers **10b–d**, respectively. An intramolecular deprotonation of H-6 is considered to be responsible for this regioselectivity. If the hydroxyl group at C(4) is absent or protected as in **7a** and **7e**, respectively, the C(7)–C(8) double bond isomers **9a** and **9c** are obtained via an intermolecular abstraction of a sterically less shielded proton at C(8). The usefulness of this methodology is illustrated by the total synthesis of (±)-6-eudesmen-4α-ol (**18**) and (±)-vetiselinene (**22**).

Introduction

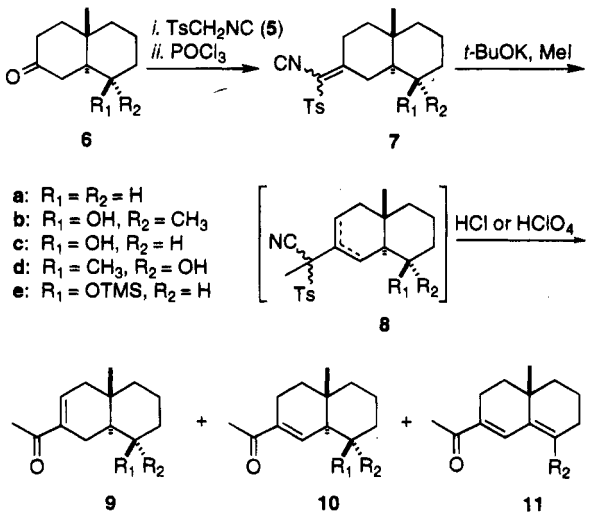
From our previous work on the total synthesis of sesquiterpenes,[1] it is known that a strategically positioned hydroxyl group plays a crucial role in the regioselective elimination of the sulfonate ester group in rigid *trans*-perhydronaphthalene-1,4-diol monosulfonate esters as the reaction of mesylate **1** exemplifies (Scheme 1). The regioselective formation of **2** in this reaction is most probably the result of an intramolecular alkoxide-induced heterolysis of the sulfonate ester bond, followed by a fast intramolecular abstraction of the axial proton at C(6) by the alcoholate at C(4).[2,3] The selective introduction of the double bond at C(6)–C(7) makes this approach a very useful one for the synthesis of natural products possessing this structural characteristic.

Application of this approach, i.e., the reaction **3** → **4**, in the total synthesis of eudesmane and guaiane sesquiterpenes possessing an isopropyl group at C(7) in combination with a C(6)–C(7) double bond[4] thus required the preparation of mesylate **3**. Unfortunately, all attempts to synthesize **3** failed,[5] thereby frustrating this potential route to **4**. We therefore focused our attention on the chemistry of (*p*-tolylsulfonyl)methyl isocyanide (**5**) (TosMIC)[6] in the expectation of finding an alternative synthetic route to compounds like **4**.

Scheme 1



Scheme 2



Because the base-catalyzed methylation[7] of TosMIC condensation products **7**, derived from the unsymmetrically substituted ketones **6**, was expected to produce mixtures of double bond isomers **8**, subsequent acid-catalyzed hydrolysis[8] of **8** should lead to mixtures of α,β-unsaturated ketones **9** and **10** (Scheme 2). On the other hand, the selective synthesis of ketones **10** with the double bond in the C(6)–C(7) position using TosMIC[9] might be possible by intramolecular alkoxide-directed

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(2) Orru, R. V. A., Wijnberg, J. B. P. A.; Jenniskens, L. H. D.; de Groot Ae. *J. Org. Chem.* **1993**, *58*, 1199.

(3) The numbering system given in structure **1** will be followed throughout this paper.

(4) Connolly, J. D.; Hill, R. A. *Dictionary of Terpenoids*; Chapman & Hall: London, 1991; Vol. 1, Mono- and Sesquiterpenoids.

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(6) (a) van Leusen, A. M. In *Perspectives in the Organic Chemistry of Sulfur*; Zwanenburg, B., Klunder, A. J. A., Eds.; Elsevier: Amsterdam, 1987; pp 119–144. (b) van Leusen, A. M.; van Leusen, D. In *Encyclopedia of Reagents for Organic Synthesis*; Paquette, L. A., Ed.; Wiley-Interscience: New York, 1995, in press.

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(8) Moskal, J.; van Leusen, A. M. *Tetrahedron Lett.* **1984**, *25*, 2585.

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deprotonation with a properly positioned hydroxyl group as internal base, analogous to the work discussed above.[1,2] If this could be achieved, the final step of this approach to compounds like **4** would be the conversion of the acyl moiety into an isopropyl group or, if desired, into another three-carbon functionality.

In order to explore the use of TosMIC in the selective synthesis of α,β-unsaturated acyldecalins **10**, 1-isocyano-1-tosylalkenes **7** were prepared starting from the readily available perhydronaphthalenones **6**. Compound **7a**, in which no hydroxyl group is present, was used as a reference compound. Compounds **7b–d** were synthesized to study the directive effect of a strategically positioned hydroxyl group at C(4). The O-silylated compound **7e** was subjected to the same reaction conditions as well to gather additional support for our hypothesis that only a free hydroxyl group would be able to direct the double bond formation to the C(6)–C(7) position. Finally, 1-isocyano-1-tosylalkene **13**, derived from enone **12**, was prepared to examine the possible influence of a conjugated double bond on the regioselectivity of olefin formation. The short syntheses of racemic 6-eudesmen-4α-ol (**18**), a sesquiterpene alcohol isolated from *Ageratina saltillensis*,[10] and racemic vetiselinene (**22**), a minor constituent of vetiver oil,[11] illustrate the value of this approach in natural product synthesis.

Results and Discussion

Ketones **6a–d** and enone **12** were synthesized following known literature procedures (see the Experimental Section). The O-silylated ketone **6e** was prepared from **6c** using hexamethyldisilazane (HMDS) and TMSCl.[12] The experimental conditions described in the literature[7,8] were employed with slight modifications[13] to synthesize 1-isocyano-1-tosylalkenes **7** and **13**. Reaction of ketone **6a** with TosMIC followed by dehydration ($POCl_3$, Et_3N) afforded **7a** as a ca. 1:1 *E*/*Z* isomeric mixture in 91% yield. Attempts to separate this mixture of isomers by column chromatography resulted in partial (on silica gel) or almost total (on alumina) isomerization of the double bond into the endocyclic positions. Therefore, **7a** was roughly purified by rapid filtration over silica gel. Methylation (2.3 equiv of *t*-BuOK, DME, MeI) of **7a** afforded compound **8a** as an unstable mixture of diastereoisomers, and for this reason **8a** was immediately treated with concd HCl. According to GC and ^1H NMR analysis, the obtained product appeared to be a 10:1 mixture of the C(7)–C(8) and C(6)–C(7) double bond isomers **9a** and **10a**, respectively. In the ^1H NMR spectrum the olefinic proton of the major compound **9a** gives rise to a relatively broad signal ($W_{1/2} \sim 10$ Hz) at δ 6.75 as a result of *two* vicinal and *two* small allylic couplings. The corresponding proton of the isomeric minor compound **10a** appears as a relatively small signal ($W_{1/2} \sim 4$ Hz) at δ 6.46 as a result of *one* vicinal and *two* small allylic couplings.

The reaction of TosMIC with hydroxy ketone **6b** and subsequent dehydration ($POCl_3$, $(i\text{-}Pr)_2NH$) yielded **7b** as a ca. 1:1 *E*/*Z* mixture in 98% yield. To prevent O-methylation during the conversion of **7b** to the corresponding α,β-unsaturated ketone(s), 1.2 equiv of *t*-BuOK was used. Hydrolysis with 40% aqueous $HClO_4$ then gave an easily separable mixture of **9b** (8%), **10b** (70%), and **11b** (8%). The axial orientation of the hydroxyl group at C(4) in combination with the C(6)–C(7) double bond makes product **10b** susceptible to acid-catalyzed dehydration, and this explains the formation of the small amount of dienone **11b**. Thus, migration of the double bond in this alkylation step occurs with *high regioselectivity* (10:1) in favor of the C(6)–C(7) position. The ^1H NMR spectrum of the major product **10b** shows a small one-proton signal ($W_{1/2} \sim 2.5$ Hz) at δ 7.01 for the olefinic H-6. The C(6)–C(7) position of the double bond in **10b** was ascertained by ^1H NOE difference spectroscopy. By irradiation of H-6 at δ 7.01, a strong NOE with the Me-C(4) at δ 1.31 was observed as a consequence of the 1,3-*peri* repulsion[14] between H-6 and Me-C(4). The olefinic proton signal in the ^1H NMR spectrum of the minor product **9b** appears as a relatively broad multiplet ($W_{1/2} \sim 8$ Hz) at δ 6.77. By irradiation of this signal, no NOE with the Me-C(4) was observed. These observations unequivocally establish the identity of **9b** and **10b** and also confirm the initial structural assignments of **9a** and **10a**.

Starting from hydroxy ketone **6c**, the procedure outlined above for **6b** was followed and afforded the products **9c**, **10c**, and **11c** in yields of 5, 46, and 2.5%, respectively, overall from **6c**. In this case also the C(6)–C(7) double bond was formed with high regioselectivity.

The synthesis of **7d** from **6d** proceeded very smoothly (97% yield). The following step, the methylation of **7d**, however, was troublesome, and a serious loss of material was observed when the same reaction conditions were used as described for **7b** and **7c**. This problem could be solved by simply adding *t*-BuOK to a solution of **7d** and MeI in THF at −45 °C, instead of adding MeI to a mixture of **7d** and *t*-BuOK in THF at the same temperature. In this way, after hydrolysis and separation, **10d** and **11b** were isolated in 60 and 3.5% overall yields, respectively, from **6d**. Only a trace amount of **9d** could be detected in the crude product mixture.

That the regioselective C(6)–C(7) double bond formation is closely connected with the presence of a free hydroxyl group in the substrates was demonstrated starting from the O-silylated ketone **6e**. When the procedure outlined above for **6b** and **6c** was applied to **6e**, a 48:1 mixture of **9c** and **10c**, respectively, was obtained; purification gave **9c** in 75% overall yield from **6e**. Not surprisingly, during the final step, the strongly acidic conditions result in cleavage of the Si–O bond.

The effect of a conjugated double bond on the regioselectivity was tested starting with enone **12**. Under the same reaction conditions as used with ketone **6a**, (*Z*)-**13** was selectively formed in 86% yield (Scheme 3); its configuration was ascertained by irradiation of the olefinic signal for H-C(6) at δ 7.20 which gave a NOE with

(9) Two other two-carbon homologation procedures are less suitable for this approach, one (a) because of the use of very toxic chemicals (HMPA, mercury(II) salts), the other (b) because (weak) Lewis acid are required. See: (a) Seebach, D.; Kolb, M. *Liebigs Ann. Chem.* **1977**, 811. (b) Satoh, T.; Itoh, M.; Ohara, T.; Yamakawa, K. *Bull. Chem. Soc. Jpn.* **1987**, *60*, 1839.

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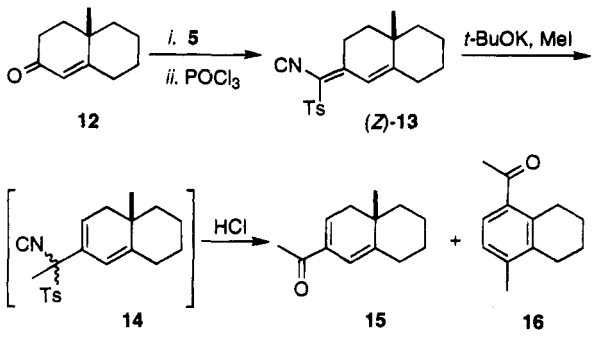
(12) Sweeley, C. C.; Bentley, R.; Makita, M.; Wells, W. W. *J. Am. Chem. Soc.* **1963**, *85*, 2497.

(13) The use of $(i\text{-}Pr)_2NH$ in the synthesis of **7b–e** gave ca. 15% higher yields in comparison with the use of Et_3N; see: Obrecht, R.; Herrmann, R.; Ugi, I. *Synthesis* **1985**, 400. It was also found that, in the methylation step, THF could be used as a substitute for the more expensive DME.

(14) The 1,3-interaction between peri substituents in a bicyclic system is termed the 1,3-*peri* repulsion; for instance, see: Shibata, T.; Ohkura, T.; Shimizu, N.; Inayama, S. *Heterocycles* **1986**, *24*, 893.

Scheme 3



the two ortho protons of the tosyl group at δ 7.82. Methylation of **13** occurred with exclusive migration of the double bond into the C(7)–C(8) position to give the cross-conjugated dienone **15** (44%) and the aromatic ketone **16** (11%). This latter compound is probably formed via an oxidative rearrangement of **15**; conjugated dienone **11c** was not detected.

These results clearly show that the hydroxyl group at C(4) influences the regioselectivity during alkylation of the 1-isocyano-1-tosylalkenes **7**. In addition, this regioselectivity is *independent* of the configuration of both the hydroxyl group and the double bond of **7**.[15]

The regioselective formation of the C(6)–C(7) double bond, starting from substrates **7b** and **7c**, in which the hydroxyl group at C(4) is axially orientated, resembles the intramolecular alkoxide-directed elimination of 1,4-diol monosulfonate esters in which also the C(6)–C(7) double bond is formed.[1,2] Thus, initial deprotonation of the axial hydroxyl group under the strongly basic conditions employed in the alkylation reaction is followed by an fast intramolecular abstraction of the axial C(6) proton[16] and concomitant methylation of the resulting allylic carbanion. According to the principle of stereoelectronic control,[17] this process is only possible when this β H–C(6) bond is approximately parallel to the π orbital of the exocyclic double bond. Examination of molecular models suggests that this is indeed the case.

Similarly for **7d**, the equatorial hydroxyl group at C(4) and the α H–C(6) are close together (1,3-*peri* relationship), thus allowing a facile intramolecular proton transfer. The intramolecular abstraction of α H–C(6), however, must now occur through a boat (or a twist-boat) conformation. Only in this conformation is the α H–C(6) bond appropriately aligned to overlap with the π orbital of the exocyclic double bond at C(7). It is interesting to note that semiempirical calculations performed with the PM3 Hamiltonian[18] method incorporated in the MOPAC package[19] show an enthalpy difference of ~2.7 kcal/mol for **7d**[20] in favor of a boatlike conformation (~99%) in which the dihedral angle between the α H–C(6) bond and the exocyclic double bond is ~70°. This means that the α H–C(6) bond deviates ~20° from the parallel orientation to the adjacent π orbital of the double bond. Apparently, because of the proximity of α H–C(6) and the α hydroxyl group at C(4) (Figure 1, right), this deviation of ~20° does not hamper intramolecular proton abstraction.[16a] For comparison, in the chair conformation of **7d** there is inefficient overlap, the dihedral angle between the α H–C(6) bond and the double bond being ~30° (deviation ~60°).

Similar PM3 calculations for **7b** show an enthalpy difference of ~1.0 kcal/mol in favor of the chair conformation. Thus **7b** exists preferentially (~84%) in the chair conformation (Figure 1, left). A deviation of ~10° for the β H–C(6) bond from the ideal parallel orientation with the adjacent π orbital was calculated. In the less stable boatlike conformation of **7b** this deviation amounts to ~25°. These calculations suggest that the regioselective formation of the C(6)–C(7) double bond proceeds through the preferred chair- and boatlike conformations of **7b** and **7d**, respectively.[21]

Compounds **7a** and **7e**, in which the hydroxyl group is absent, show regioselective formation of the products **9** with the double bond in the C(7)–C(8) position. This regioselectivity toward the C(7)–C(8) double bond is probably the result of an intermolecular abstraction of one of the sterically less shielded protons at C(8).[22] A similar regioselectivity has been noticed for the alkylation of ketene thioacetals under the influence of a strong base.[9a] Procedures in which no base is used generally give mixtures of double bond isomers.[9b]

In contrast with the 1,4-diol monosulfonate esters,[1,2,23] inductive effects do not seem to be significant for the reactivity of **7a–e**, as the reaction rates of these compounds (with or without a free hydroxyl group) are about the same.

The short syntheses of (±)-6-eudesmen-4α-ol (**18**) and (±)-vetiselinene (**22**) highlight the applicability of this method for the total synthesis of natural products. For the synthesis of **18**, compound **10d** was subjected to a Peterson olefination reaction[24] to afford diene **17** (Scheme 4). Selective hydrogenation[25] of the double bond of the isopropenyl group then gave the desired product **18** in 61% overall yield from **10d**. The spectroscopic data of this synthetic (±)-**18** are identical with those of natural **18**.[10]

The synthesis of **22** also requires the transformation of the acyl moiety into an isopropyl group. However, all attempts to carry out this transformation in the same way as described above for the synthesis of **18** failed, due to ready hydrogenation of the C(7)–C(8) double bond. Therefore, we examined a reduction–alkylation reaction sequence. This strategy required a protected hydroxyl group at C(4) as in **9e**. Reduction of compound **9e** with $NaBH_4$ in the presence of $CeCl_3 \cdot 7H_2O$[26] afforded alcohol **19** as a ca. 7:3 mixture of two diastereoisomers in

(15) The directing effect of the geometry of TosMIC–ketone condensation products on the regioselectivity of double bond migrations in the alkylation step is under investigation by the group of Prof. A. M. van Leusen at Groningen University.

(16) (a) Menger, F. M.; Chow, J. F.; Kaiserman, H.; Vasquez, P. C. *J. Am. Chem. Soc.* **1983**, *105*, 4996. (b) Lansbury, P. T.; Mojica, C. A. *Tetrahedron Lett.* **1986**, *27*, 3967.

(17) Deslongchamps, P. *Stereoelectronic Effects in Organic Chemistry*; Pergamon Press: Oxford, 1983.

(18) Stewart, J. P. P. *J. Comput. Chem.* **1989**, *10*, 209.

(19) The QCPE No. 455 program was used.

(20) The semiempirical PM3 calculations were carried out with one isomer of **7**. Experimentally, it was demonstrated that the regioselectivity was independent of the configuration of **7**.

(21) In principle, the reactions may also proceed through the less stable conformers of **7b** and **7d** (Curtin–Hammett/Winstein–Holness Kinetics). See: Seeman, J. I. *Chem. Rev.* **1983**, *83*, 83.

(22) Semiempirical PM3 calculations on **7a** and **7e** suggest that these compounds preferentially exist in a flattened boatlike conformation. In this conformation α H–C(8) is better aligned for effective overlap with the adjacent π orbital than β H–C(8). Consequently, α H–C(8) is easier to abstract.

(23) Orru, R. V. A.; Wijnberg, J. B. P. A.; Bouwman, C. A.; de Groot, Ae. *J. Org. Chem.* **1994**, *59*, 374.

(24) Peterson, D. J. *J. Org. Chem.* **1968**, *33*, 780.

(25) James, B. R.. *Homogeneous Hydrogenation*; Wiley-Interscience: New York 1973; pp 219–228.

(26) Luche, J. L. *J. Am. Chem. Soc.* **1978**, *100*, 2226.

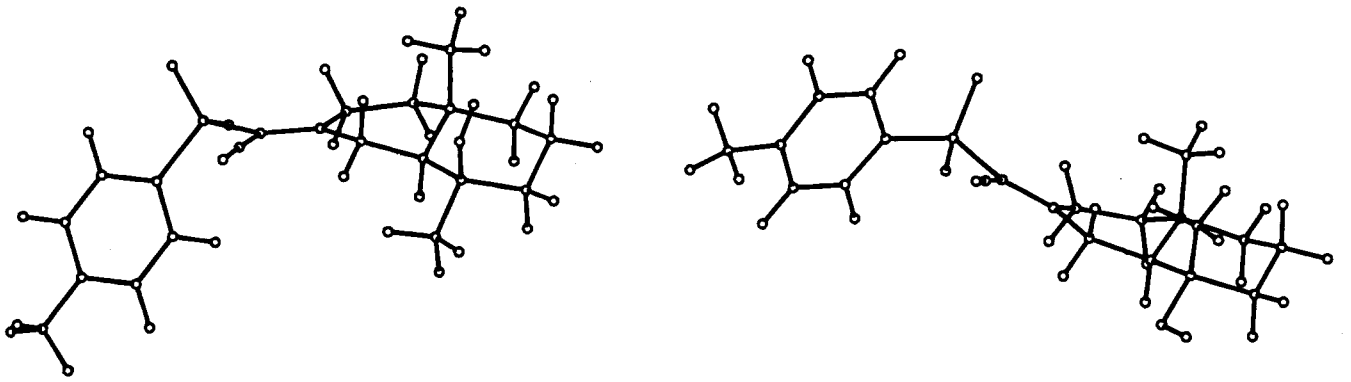
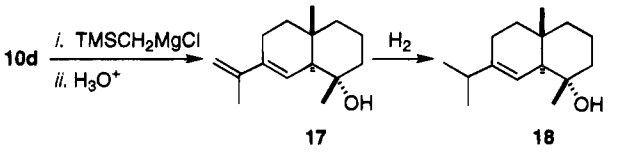
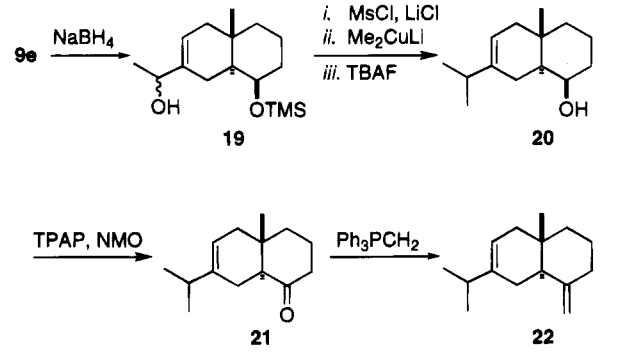


Figure 1. Calculated structures (PM3 Hamiltonian) for the chairlike conformation of **7b** (left) and the boatlike conformation of **7d** (right).

Scheme 4



Scheme 5



quantitative yield (Scheme 5). Conversion of the hydroxyl group of **19** to the corresponding chloride followed by alkylation with Me_2CuLi and cleavage of the silyl ether bond gave alcohol **20** in 60% overall yield from **9e**. Oxidation of **20** with tetrapropylammonium perruthenate (TPAP) and 4-methylmorpholine *N*-oxide (NMO)[27] gave the known ketone **21** which was transformed to (±)-vetiselinene (**22**) by a Wittig reaction as described in the literature.[28]

Experimental Section[29]

Materials. The starting ketones **6a**,[30] **6b**,[31] **6c**,[32] **6d**,[31] and **12**[33] were prepared following previously described procedures.

(4aα,8α,8aβ)-(±)-Octahydro-4a-methyl-8-[(trimethylsilyl)oxy]-2(1*H*)-naphthalenone (6e). A solution of hydroxy ketone **6c** (980 mg, 5.4 mmol) in pyridine (90 mL) was treated with HMDS (6 mL, 28 mmol) and TMSCl (2.9 mL, 22 mmol) at rt for 5 h. Evaporation of the solvent under reduced pressure and flash chromatography (4:1 petroleum ether (bp 40–60 °C)/EtOAc) gave the O-silylated ketone **6e** (1.32 g, 96%) as a colorless oil: ^{1}H NMR δ −0.01 (s, 9 H), 0.90–2.60 (13 H), 1.13 (s, 3 H), 3.64 (dd, J = 2.7, 5.4 Hz, 1 H); ^{13}C NMR δ 0.0 (3 q), 16.7 (t), 18.1 (q), 33.1 (s), 33.8 (t), 38.2 (t), 40.3 (t), 42.3 (t), 42.8 (t), 47.2 (d), 70.7 (d), 213.2 (s); MS m/z (rel intensity) 254 (M^+, 5), 239 (100), 211 (18), 147 (29), 129 (39), 105 (18), 73 (53); HRMS m/z calcd for $C_{13}H_{23}O_2Si$ (M^+ − 15) 239.1467, found 239.1461.

Preparation of 1-Isocyano-1-tosylalkenes. General Procedure. To a stirred suspension (ca. 0.1–0.15 M) of *t*-BuOK in dry THF was added TosMIC (ca. 1.2 equiv) at −45 °C. After the mixture was stirred for 20 min, ca. 0.9 equiv of the ketone **6** (or **12**) in dry THF was added dropwise. The reaction mixture was stirred at −45 °C for 2 h, and then 1 equiv of phosphorous acid was added. Stirring was continued at −45 °C for 10 min, and then Et_3N or $(i\text{-Pr})_2NH$ (10 equiv) was added, followed by dropwise addition of $POCl_3$ (1.5–2 equiv). The mixture was stirred at −45 °C for another 10 min, allowed to come to 0 °C, and stirred at this temperature for an additional 1.5 h. The reaction mixture was then diluted with aqueous NH_4Cl and extracted with three portions of CH_2Cl_2. The combined organic layers were washed with brine, dried, and concentrated. The remaining residue was rapidly filtered over a silica column using mixtures of petroleum ether (bp 40–60 °C) and EtOAc to give the 1-isocyano-1-tosylalkene **7** (or **13**).

a. The general procedure was employed by using 1.02 g (6.1 mmol) of **6a** and Et_3N. Workup and filtration (9:1 petroleum ether (bp 40–60 °C)/EtOAc) afforded 1.90 g (91%) of **7a**. According to ^{1}H NMR analysis, **7a** was a 1:1 mixture of two geometric isomers: ^{1}H NMR (major peaks) δ 0.89 (s, 3 H), 2.44 (s, 3 H), 3.47, 3.73 (m, m, 1:1 ratio, 1 H), 7.36 (d, J = 8.1 Hz, 2 H), 7.81 (d, J = 8.1 Hz, 2 H); HRMS m/z calcd for $C_{20}H_{25}NO_2S$ (M^+) 343.1606, found 343.1606.

b. The general procedure was employed by using 900 mg (4.5 mmol) of **6b** and $(i\text{-Pr})_2NH$. Workup and filtration (3:2 petroleum ether (bp 40–60 °C)/EtOAc) afforded 1.68 g (98%) of **7b**. According to ^{1}H NMR analysis, **7b** was a 1:1 mixture of two geometric isomers: ^{1}H NMR (major peaks) δ 1.11 (s, 3 H), 1.17, 1.24 (s, s, 1:1 ratio, 3 H), 2.44 (s, 3 H), 3.70, 3.93 (m, m, 1:1 ratio, 1 H), 7.37 (d, J = 8.2 Hz, 2 H), 7.82 (d, J = 8.2 Hz, 2 H); HRMS m/z calcd for $C_{20}H_{24}NO_3S$ (M^+ − 15) 358.1477, found 358.1479.

c. The general procedure was employed by using 1.10 g (6.0 mmol) of **6c** and $(i\text{-Pr})_2NH$. Workup and filtration (3:2 petroleum ether (bp 40–60 °C)/EtOAc) afforded 2.14 g (99%) of **7c**. According to ^{1}H NMR analysis, **7c** was a 2.5:1 mixture of two geometric isomers: ^{1}H NMR (major peaks) δ 1.11 (s, 3 H), 2.42 (s, 3 H), 3.54, 3.71 (m, m, 2.5:1 ratio, 1 H), 3.79, 3.83 (dd, dd, 1:2.5 ratio, 1 H), 7.35 (d, J = 8.3 Hz, 2 H), 7.80 (d, J = 8.3 Hz, 2 H); HRMS m/z calcd for $C_{20}H_{23}NO_2S$ (M^+ − 18) 341.1450, found 341.1448.

d. The general procedure was employed by using 510 mg (2.6 mmol) of **6d** and $(i\text{-Pr})_2NH$. Workup and filtration (3:2

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(28) Garratt, P. J.; Porter, J. R. *J. Org. Chem.* **1986**, *51*, 5450.
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petroleum ether (bp 40–60 °C)/EtOAc) afforded 942 mg (97%) of **7d**. According to ^{1}H NMR analysis, **7d** was a 1:1 mixture of two geometric isomers: ^{1}H NMR (major peaks) δ 0.98 (s, 3 H), 1.10, 1.14 (s, s, 1:1 ratio, 3 H), 2.45 (s, 3 H), 3.76, 4.04 (m, m, 1:1 ratio, 1 H), 7.36 (d, J = 8.2 Hz, 2 H), 7.85, 7.90 (d, d, 1:1 ratio, J = 8.2 Hz, 2 H); HRMS m/z calcd for $C_{21}H_{25}NO_2S$ (M^+ − 18) 355.1606, found 355.1605.

e. The general procedure was employed by using 235 mg (0.92 mmol) of **6e** and $(i\text{-Pr})_2$NH. Workup and filtration (9:1 petroleum ether (bp 40–60 °C)/EtOAc) afforded 367 mg (92%) of **7e**. According to ^{1}H NMR analysis, **7e** was a 2:1 mixture of two geometric isomers: ^{1}H NMR (major peaks) δ 0.05, 0.10 (s, s, 1:2 ratio, 3 H), 1.08, (s, 3 H), 2.46 (s, 3 H), 3.38, 3.72 (m, m, 2:1 ratio, 1 H), 7.37 (d, J = 8.3 Hz, 2 H), 7.83, 7.84 (d, d, 2:1 ratio, J = 8.3 Hz, 2 H); HRMS m/z calcd for $C_{22}H_{30}NO_3SSi$ (M^+ − 15) 416.1716, found 416.1719.

f. The general procedure was employed by using 1.00 g (6.2 mmol) of **12** and Et_3N. Workup and filtration (9:1 petroleum ether (bp 40–60 °C)/EtOAc) afforded 1.92 g (86%) of **13** as a single product: mp 95–97 °C (from MeOH) dec; ^{1}H NMR δ 1.08 (s, 3 H), 1.17–1.70 (m, 8 H), 1.87 (m, 1 H), 2.30–2.54 (m, 2 H), 2.42 (s, 3 H), 2.68 (dt, J = 4.0, 17.1 Hz, 1 H), 7.20 (s, 1 H), 7.34 (d, J = 8.0 Hz, 2 H), 7.82 (d, J = 8.0 Hz, 2 H); ^{13}C NMR δ 21.6 (q), 21.6 (t), 22.1 (q), 25.3 (t), 27.6 (t), 33.7 (t), 35.5 (s), 36.6 (t), 41.3 (t), 115.1 (d), 118.1 (s), 128.0 (2d), 129.7 (2d), 135.8 (s), 145.1 (s), 148.3 (s), 164.6 (s), 172.8 (s); HRMS m/z calcd for $C_{20}H_{23}NO_2S$ (M^+) 341.1453, found 341.1452.

Methylation of 1-Isocyano-1-tosylalkenes and Subsequent Hydrolysis. General Procedure. To a solution (ca. 0.1 M) of **7** (or **13**) in DME or THF was added 1.2–2.3 equiv of t-BuOK at −45 °C. After the mixture was stirred for 10 min, 1.2–2.3 equiv of MeI was added. Stirring was continued for 2 h, during which time the temperature was gradually warmed to 0 °C. The reaction mixture was poured into aqueous NH_4Cl and extracted with three portions of CH_2Cl_2. The combined organic layers were washed with brine, dried, and evaporated. Flash chromatography (mixtures of petroleum ether (bp 40–60 °C)/EtOAc) gave the 3-isocyano-3-tosyl-1-alkenes **8** (or **14**).[34] A vigorously stirred solution (ca. 0.03 M) of these compounds **8** (or **14**) in ether was treated with concd HCl at rt for 10 min or with 40% aqueous $HClO_4$ at reflux temperature for 45 min. The reaction mixture was then carefully quenched with solid Na_2CO_3 and diluted with aqueous $NaHCO_3$. The two-phase mixture was separated, and the aqueous layer was extracted with three portions of ether. The combined organic layers were washed with brine, dried, and evaporated to afford the crude reaction product. Product ratios, yields, and pure compounds were obtained by chromatographical techniques.

a. The general procedure was employed by using 520 mg (1.51 mmol) of **7a**, DME, and concd HCl. Workup and flash chromatography (10:1 petroleum ether (bp 40–60 °C)/EtOAc) gave an inseparable 10:1 mixture of **9a** and **10a**, respectively, in 58% yield. The spectroscopic data of **9a** and **10a** are shown below.

(4aα,8aβ)-(±)-(1,4,4a,5,6,7,8,8a-Octahydro-4a-methyl-2-naphthalenyl)-1-ethanone (9a): ^{1}H NMR (major peaks) δ 0.69 (s, 3 H), 2.21 (s, 3 H), 6.75 (m, $W_{1/2}$ ~ 10 Hz, 1 H); ^{13}C NMR δ 16.4 (q), 22.0 (t), 25.1 (q), 26.6 (t), 27.7 (t), 28.6 (t), 31.8 (s), 39.6 (d), 40.7 (t), 43.0 (t), 138.9 (s), 139.9 (d), 199.1 (s); MS m/z (rel intensity) 192 (M^+, 14), 177 (7), 149 (9), 109 (15), 81 (32), 67 (20), 43 (100). HRMS (10:1 mixture) m/z calcd for $C_{13}H_{20}O$ (M^+) 192.1514, found 192.1513.

(4aα,8aβ)-(±)-(3,4,4a,5,6,7,8,8a-Octahydro-4a-methyl-2-naphthalenyl)-1-ethanone (10a): ^{1}H NMR (major peaks) δ 0.69 (s, 3 H), 2.21 (s, 3 H), 6.46 (m, $W_{1/2}$ ~ 4 Hz, 1 H); ^{13}C NMR (major peaks) δ 15.3 (q), 21.1 (t), 21.5 (t), 27.0 (t), 45.3 (d), 145.0 (d); MS m/z (rel intensity) 192 (M^+, 17), 177 (13), 149 (12), 109 (21), 81 (20), 67 (25), 43 (100).

b. The general procedure was employed by using 1.68 g (4.5 mmol) of **7b**, THF, and 40% aqueous $HClO_4$. Workup and flash chromatography (4:1 petroleum ether (bp 40–60 °C)/EtOAc) yielded, in order of elution, 58 mg (6%) of **11b**, 63 mg (6%) of **9b**, and 552 mg (55%) of **10b**. The spectroscopic data of **9b**, **10b**, and **11b** are shown below.

(4aα,8α,8aβ)-(±)-(1,4,4a,5,6,7,8,8a-Octahydro-8-hydroxy-4a,8-dimethyl-2-naphthalenyl)-1-ethanone (9b): ^{1}H NMR δ 0.91 (s, 3 H), 1.02–2.14 (m, 11 H), 1.17 (s, 3 H), 2.26 (s, 3 H), 2.50 (m, 1 H), 6.77 (m, $W_{1/2}$ ~ 8 Hz, 1 H); ^{13}C NMR δ 17.8 (t), 19.0 (q), 20.6 (t), 25.2 (q), 30.2 (q), 32.1 (s), 40.9 (t), 41.2 (t), 45.1 (t), 46.6 (d), 71.1 (s), 138.9 (s), 139.5 (d), 199.2 (s); MS m/z (rel intensity) 222 (M^+, 18), 204 (95), 189 (58), 137 (99), 43 (100); HRMS m/z calcd for $C_{14}H_{22}O_2$ (M^+) 222.1620, found 222.1614. Anal. Calcd for $C_{14}H_{22}O_2$: C, 75.63; H, 9.97. Found: C, 75.88; H, 10.23.

(4aα,8α,8aβ)-(±)-(3,4,4a,5,6,7,8,8a-Octahydro-8-hydroxy-4a,8-dimethyl-2-naphthalenyl)-1-ethanone (10b): mp 72–73 °C (from petroleum ether (bp 40–60 °C)/EtOAc); ^{1}H NMR δ 0.93 (s, 3 H), 1.13 (m, 1 H), 1.22–2.00 (m, 9 H), 1.31 (s, 3 H), 2.20–2.31 (m, 2 H), 2.30 (s, 3 H), 7.01 (br s, $W_{1/2}$ ~ 2.5 Hz, 1 H); ^{13}C NMR δ 17.9 (q), 17.9 (t), 21.2 (t), 25.3 (q), 29.6 (q), 32.8 (s), 39.0 (t), 39.7 (t), 40.9 (t), 52.2 (d), 71.2 (s), 139.2 (d), 140.2 (s), 199.4 (s); MS m/z (rel intensity) 222 (M^+, 17), 137 (100), 43 (17); HRMS m/z calcd for $C_{14}H_{22}O_2$ (M^+) 222.1620, found 222.1617. Anal. Calcd for $C_{14}H_{22}O_2$: C, 75.63; H, 9.97. Found: C, 75.32; H, 10.00.

(±)-(3,4,4a,5,6,7-Hexahydro-4a,8-dimethyl-2-naphthalenyl)-1-ethanone (11b): mp 69–71 °C (from petroleum ether (bp 40–60 °C)); ^{1} H NMR δ 0.88 (s, 3 H), 1.15–1.90 (m, 6 H), 1.82 (s, 3 H), 2.10–2.34 (m, 3 H), 2.33 (s, 3 H), 2.49 (dd, J = 6.0, 18.0 Hz, 1 H), 7.41 (d, J = 1.5 Hz, 1 H); ^{13}C NMR δ 18.2 (t), 19.1 (q), 20.5 (t), 23.2 (q), 25.3 (q), 31.9 (s), 33.5 (t), 36.5 (t), 37.4 (t), 133.6 (s), 134.3 (d), 135.2 (s), 138.3 (s), 199.5 (s); MS m/z (rel intensity) 204 (M^+, 100), 189 (93), 161 (57), 43 (37); HRMS m/z calcd for $C_{14}H_{20}O$ (M^+) 204.1514, found 204.1514. Anal. Calcd for $C_{14}H_{20}O$: C, 82.30; H, 9.84. Found: C, 82.00; H, 10.06.

c. The general procedure was employed by using 2.02 g (5.6 mmol) of **7c**, THF, and 40% aqueous $HClO_4$. Workup and flash chromatography (3:2 petroleum ether (bp 40–60 °C)/EtOAc) yielded, in order of elution, 29 mg (2.5%) of **11c**, 61 mg (5%) of **9c**, and 541 mg (46%) of **10c**. The spectroscopic data of **9c**, **10c**, and **11c** are shown below.

(4aα,8α,8aβ)-(±)-(1,4,4a,5,6,7,8,8a-Octahydro-8-hydroxy-4a-methyl-2-naphthalenyl)-1-ethanone (9c): mp 112–114 °C (from petroleum ether (bp 40–60 °C)/EtOAc); ^{1}H NMR δ 0.97 (s, 3 H), 1.14 (dt, J = 3.3, 13.0 Hz, 1 H), 1.30–2.05 (m, 9 H), 2.21–2.30 (2 H), 2.29 (s, 3 H), 3.91 (dd, J = 2.7, 5.5 Hz, 1 H), 6.79 (m, $W_{1/2}$ ~ 9 Hz, 1 H); ^{13}C NMR δ 16.8 (t), 19.8 (q), 24.2 (t), 25.2 (q), 31.8 (s), 34.2 (t), 40.7 (t), 42.9 (d), 44.7 (t), 69.6 (d), 138.9 (s), 139.8 (d), 199.3 (s); MS m/z (rel intensity) 208 (M^+, 17), 190 (57), 175 (85), 147 (57), 91 (100), 43 (83); HRMS m/z calcd for $C_{13}H_{20}O_2$ (M^+) 208.1463, found 208.1461. Anal. Calcd for $C_{13}H_{20}O_2$: C, 74.96; H, 9.68. Found: C, 74.64; H, 9.65.

(4aα,8α,8aβ)-(±)-(3,4,4a,5,6,7,8,8a-Octahydro-8-hydroxy-4a-methyl-2-naphthalenyl)-1-ethanone (10c): mp 86–87 °C (from petroleum ether (bp 40–60 °C)/EtOAc); ^{1}H NMR δ 0.97 (s, 3 H), 1.06–2.45 (m, 12 H), 2.30 (s, 3 H), 4.15 (dd, J = 2.6, 5.4 Hz, 1 H), 6.77 (m, $W_{1/2}$ ~ 4 Hz, 1 H); ^{13}C NMR δ 16.8 (t), 18.6 (q), 21.3 (t), 25.3 (q), 32.2 (s), 33.9 (t), 38.7 (t), 39.5 (t), 48.5 (d), 70.5 (d), 139.7 (s), 142.5 (d), 199.3 (s); MS m/z (rel intensity) 208 (M^+, 50), 193 (25), 175 (85), 147 (20), 137 (100), 111 (17), 43 (82); HRMS m/z calcd for $C_{13}H_{20}O_2$ (M^+) 208.1463, found 208.1460. Anal. Calcd for $C_{13}H_{20}O_2$: C, 74.96; H, 9.68. Found: C, 74.93; H, 9.71.

(±)-(3,4,4a,5,6,7-Hexahydro-4a-methyl-2-naphthalenyl)-1-ethanone (11c): ^{1}H NMR δ 0.93 (s, 3 H), 1.16–1.93 (m, 6 H), 2.00–2.40 (m, 3 H), 2.30 (s, 3 H), 2.51 (dd, J = 5.6, 17.5 Hz, 1 H), 5.86 (t, J = 3.8 Hz, 1 H), 6.90 (d, J = 1.8 Hz, 1 H); ^{13}C NMR δ 18.1 (t), 20.5 (t), 23.3 (q), 25.3 (q), 26.4 (t), 31.8 (s), 36.2 (t), 36.8 (t), 133.2 (d), 135.4 (s), 139.3 (d), 141,0 (s), 199.3 (s); MS m/z (rel intensity) 190 (M^+, 8), 175 (6), 147 (8), 91 (4), 43 (100); HRMS m/z calcd for $C_{13}H_{18}O$ (M^+) 190.1357, found 190.1356. The ^{1}H NMR spectrum of **11c** is identical with that reported in the literature.[35]

(34) These compounds were obtained as mixtures of diastereoisomers.

d. The general procedure was employed by using 900 mg (2.41 mmol) of **7d**, THF, and 40% aqueous $HClO_4$. In this reaction *t*-BuOK was added to the solution of **7d** and MeI in THF. Workup and flash chromatography (4:1 petroleum ether (bp 40–60 °C)/EtOAc) gave, in order of elution, 17.5 mg (3.5%) of **11b** and 329 mg (62%) of **(4aα,8β,8aβ)-(±)-(3,4,4a,5,6,7,8,8a-octahydro-8-hydroxy-4a,8-dimethyl-2-naphthalenyl)-1-ethanone (10d)** as a solid: mp 73–74 °C (from petroleum ether (bp 40–60 °C)); ^1H NMR δ 0.80 (s, 3 H), 1.07–1.72 (m, 8 H), 1.16 (s, 3 H), 1.87 (ddt, J = 1.3, 3.3, 12.5 Hz, 1 H), 2.10–2.43 (m, 3 H), 2.32 (s, 3 H), 7.07 (d, J = 1.3 Hz, 1 H); ^{13}C NMR δ 17.9 (q), 20.1 (t), 20.8 (t), 23.0 (q), 25.2 (q), 33.3 (s), 39.1 (t), 39.5 (t), 42.9 (t), 55.2 (d), 71.5 (s), 139.0 (s), 140.5 (d), 199.6 (s); MS m/z (rel intensity) 222 (M^+, 25), 164 (9), 138 (10), 137 (100), 125 (7), 43 (37); HRMS m/z calcd for $C_{14}H_{22}O_2$ (M^+) 222.1620, found 222.1619. Anal. Calcd for $C_{14}H_{22}O_2$: C, 75.63; H, 9.97. Found: C, 75.93; H, 10.21.

e. The general procedure was employed by using 346 mg (0.68 mmol) of **7e**, THF, and 40% aqueous $HClO_4$. Workup and flash chromatography (1:1 petroleum ether (bp 40–60 °C)/EtOAc) gave **9c** in 81% yield.

f. The general procedure was employed by using 1.81 g (5.3 mmol) of **13**, DME, and concd HCl. Workup and flash chromatography (10:1 petroleum ether (bp 40–60 °C)/EtOAc) gave, in order of elution, 113 mg (11%) of **16** and 445 mg (44%) of **15**. The spectroscopic data of **15** and **16** are shown below.

(±)-(4,4a,5,6,7,8-Hexahydro-4a-methyl-2-naphthalenyl)-1-ethanone (15): ^1H NMR δ 0.88 (s, 3 H), 1.13–1.83 (m, 6 H), 2.19–2.25 (m, 4 H), 2.25 (s, 3 H), 6.08 (d, J = 1.3 Hz, 1 H), 6.66 (dt, J = 1.3, 4.2 Hz, 1 H); ^{13}C NMR δ 21.8 (q), 22.5 (t), 25.1 (q), 26.3 (t), 31.3 (t), 34.3 (s), 41.0 (t), 42.1 (t), 113.7 (d), 134.5 (d), 136.1 (s), 146.7 (s), 196.9 (s); MS m/z (rel intensity) 190 (M^+, 13), 175 (30), 105 (20), 91 (14), 43 (100); HRMS m/z calcd for $C_{13}H_{18}O$ (M^+) 190.1357, found 190.1355.

(±)-(5,6,7,8-Tetrahydro-4-methyl-1-naphthalenyl)-1-ethanone (16): mp 36–37 °C (from MeOH/H_2O); ^1H NMR δ 1.70–1.90 (m, 4 H), 2.24 (s, 3 H), 2.53 (s, 3 H), 2.64 (t, J = 6.0 Hz, 2 H), 2.96 (t, J = 6.0 Hz, 2 H), 7.03 (d, J = 7.8 Hz, 1 H), 7.39 (d, J = 7.8 Hz, 1 H); ^{13}C NMR δ 20.2 (q), 22.6 (t), 22.8 (t), 27.5 (t), 28.5 (t), 30.1 (q), 126.3 (d), 126.6 (d), 136.4 (s), 136.9 (s), 137.0 (s), 140.7 (s), 202.6 (s); MS m/z (rel intensity) 188 (M^+, 53), 173 (100), 145 (59); HRMS m/z calcd for $C_{13}H_{16}O$ (M^+) 188.1201, found 188.1208.

(1α,4aβ,8aα)-(±)-1,2,3,4,4a,5,6,8a-Octahydro-1,4a-dimethyl-7-(1-methylethenyl)-1-naphthalenol (17). To 164 mg (6.7 mmol) of Mg turnings and a crystal of I_2 in 2.5 mL of dry ether was added dropwise a solution of 0.97 mL (6.7 mmol) of $(CH_3)_3SiCH_2Cl$ in 4.8 mL of dry ether. The mixture was heated at reflux for 1 h and cooled to 10 °C, and then a solution of 200 mg (0.90 mmol) of **10d** in 4.8 mL of dry ether was added dropwise. After stirring for 1.5 h, the reaction mixture was carefully quenched with saturated aqueous NH_4Cl and diluted with H_2O. The two-phase mixture was separated, and the aqueous layer was extracted with four 30-mL portions of ether. The combined organic layers were washed with brine, dried, and evaporated. The remaining residue (266 mg) was dissolved in 10 mL of THF and cooled to 0 °C, and then a solution of two drops of concd H_2SO_4 in 10 mL of THF was added. After the mixture was stirred at 0 °C for 15 min, 20 mL of saturated aqueous $NaHCO_3$ was added. The organic solvent was removed under reduced pressure, and the aqueous phase was extracted with three 60-mL portions of CH_2Cl_2. The combined organic layers were washed with brine, dried, and concentrated. The crude product was flash chromatographed (9:1 petroleum ether (bp 40–60 °C)/EtOAc) to give 138 mg (70%) of **21**: mp 96–97 °C (from petroleum ether (bp 40–60 °C)/EtOAc); ^1H NMR δ 0.81 (s, 3 H), 1.05–1.70 (m, 8 H), 1.12 (s, 3 H), 1.84 (dt, J = 1.3, 12.1 Hz, 1 H), 1.94 (s, 3 H), 2.10 (br s, 1 H), 2.21–2.32 (m, 2 H), 4.84 (br s, 1 H), 4.95 (br s, 1 H), 6.02 (d, J = 0.8 Hz, 1 H); ^{13}C NMR δ 17.8 (q), 20.4 (t), 20.8 (q), 22.4 (q), 23.2 (t), 33.6 (s), 39.2 (t), 40.5 (t), 43.2 (t), 55.1 (d), 72.2 (s), 109.8 (t), 123.7 (d), 136.3 (s), 143.6 (s); MS m/z (rel intensity) 220 (M^+, 34), 162 (39), 135 (100), 107 (30), 93 (20), 79 (38); HRMS m/z calcd for $C_{15}H_{24}O$ (M^+) 220.1827, found 220.1830. Anal. Calcd for $C_{15}H_{24}O$: C, 81.76; H, 10.98. Found: C, 81.58; H, 11.00.

(1aα,4aβ,8aα)-(±)-1,2,3,4,4a,5,6,8a-Octahydro-1,4a-dimethyl-7-(1-methylethyl)-1-naphthalenol ((±)-6-eudesmen-4α-ol) (18). A solution of 230 mg (1.05 mmol) of **17** and 50 mg of tris(triphenylphosphine)rhodium(I) chloride in 20 mL of a 1:1 mixture of benzene and MeOH was shaken in a Parr hydrogenator under 29 psi of H_2 for 6 h. The solvents were removed under reduced pressure, and the residual mixture was flash chromatographed (9:1 petroleum ether (bp 40–60 °C)/EtOAc) to give 200 mg (87%) of **18**:[36] mp 61–62 °C (from petroleum ether (bp 40–60 °C)/EtOAc); ^1H NMR δ 0.79 (s, 3 H), 0.87 (m, 1 H), 0.95–1.68 (m, 8 H), 0.99 (d, J = 6.9 Hz, 3 H), 1.00 (d, J = 6.9 Hz, 3 H), 1.10 (s, 3 H), 1.81 (dt, J = 1.3, 12.5 Hz, 1 H), 1.97–2.03 (m, 2 H), 2.20 (hept, J = 6.9 Hz, 1 H), 5.52 (s, 1 H); ^{13}C NMR δ 17.5 (q), 20.4 (t), 21.5 (q), 21.7 (q), 22.2 (q), 23.3 (t), 33.7 (s), 34.9 (d), 39.3 (t), 40.6 (t), 43.1 (t), 54.3 (d), 72.3 (s), 117.0 (d), 143.7 (s); MS m/z (rel intensity) 222 (M^+, 17), 204 (100), 189 (47), 161 (75), 121 (52), 81 (82), 43 (75); HRMS m/z calcd for $C_{15}H_{26}O$ (M^+) 222.1984, found 222.1982. Anal. Calcd for $C_{15}H_{26}O$: C, 81.02; H, 11.79. Found: C, 81.16; H, 12.18. The spectroscopic data of (±)-**18** are identical with those reported for natural **18**.[10]

(4aα,8α,8aβ)-(±)-[1,4,4a,5,6,7,8,8a-Octahydro-8a-methyl-8-[(trimethylsilyl)oxy]-2-naphthalenyl]-1-ethanone (9e). Compound **9c** (470 mg, 2.26 mmol) was treated with TMSCl and HMDS as described for the silylation of **6c**. Workup and flash chromatography (4:1 petroleum ether (bp 40–60 °C)/EtOAc) gave 607 mg (96%) of **9e**: mp 60–62 °C (from petroleum ether (bp 40–60 °C)/EtOAc); ^1H NMR δ 0.54 (s, 9 H), 0.90 (s, 3 H), 1.0–2.2 (m, 11 H), 2.24 (s, 3 H), 3.81 (d, J = 2.4 Hz, 1 H), 6.71 (m, $W_{1/2}$ ~ 9 Hz, 1 H); ^{13}C NMR δ 0.10 (3q), 16.8 (t), 19.6 (q), 24.5 (t), 25.1 (q), 31.9 (s), 34.7 (t), 40.9 (t), 43.2 (d), 44.8 (t), 70.1 (d), 138.9 (d), 139.4 (s), 198.8 (s); MS m/z (rel intensity) 280 (M^+, 0.7), 265 (20), 190 (85), 175 (100), 147 (38), 105 (17); HRMS m/z calcd for $C_{15}H_{25}O_2Si$ (M^+ − 15) 265.1624, found 265.1619. Anal. Calcd for $C_{16}H_{28}O_2Si$: C, 68.53; H, 10.07. Found: C, 68.55; H, 10.21.

(4aα,8α,8aβ)-(±)-[1,4,4a,5,6,7,8,8a-Octahydro-8a-methyl-8-[(trimethylsilyl)oxy]-2-naphthalenyl]-1-ethanol (19). A solution of ketone **9e** (500 mg, 1.78 mmol) and $CeCl_3 \cdot 7H_2O$ (665 mg, 1.78 mmol) in MeOH (5 mL) was treated with $NaBH_4$ (75 mg, 1.98 mmol) at 0 °C. After 5 min, the reaction was quenched with aqueous NH_4Cl. The usual workup and flash chromatography (2:1 petroleum ether (bp 40–60 °C)/EtOAc) afforded 502 mg (100%) of compound **19** as a ca. 7:3 mixture of two diastereoisomers.

19 (major isomer): ^1H NMR δ 0.07 (s, 9 H), 0.95 (s, 3 H), 1.07 (m, 1 H), 1.26 (d, J = 6.5 Hz, 3 H), 1.2–2.2 (m, 11 H), 3.80 (dd, J = 2.7, 5.5 Hz, 1 H), 4.16 (q, J = 6.5 Hz, 1 H), 5.52 (m, $W_{1/2}$ ~ 9 Hz, 1 H); ^{13}C NMR δ 0.14 (q), 16.9 (t), 19.3 (q), 21.9 (q), 26.1 (t), 32.4 (s), 34.9 (t), 41.3 (t), 43.6 (d), 43.7 (d), 70.4 (d), 71.5 (d), 118.5 (d), 140.7 (s); MS m/z (rel intensity) 282 (M^+, 0.2), 265 (3), 264 (7), 192 (93), 177 (57), 174 (45), 159 (50), 149 (100), 133 (90); HRMS m/z calcd for $C_{16}H_{26}OSi$ (M^+ − 18) 264.1909, found 264.1906.

19 (minor isomer): ^1H NMR δ 0.07 (s, 9 H), 0.93 (s, 3 H), 1.07 (m, 1 H), 1.26 (d, J = 6.5 Hz, 3 H), 1.2–2.2 (m, 11 H), 3.82 (dd, J = 2.1, 5.5 Hz, 1 H), 4.20 (q, J = 6.5 Hz, 1 H), 5.52 (m, $W_{1/2}$ ~ 9 Hz, 1 H); ^{13}C NMR δ 0.15 (q), 16.9 (t), 19.3 (q), 21.3 (q), 26.1 (t), 32.3 (s), 34.9 (t), 41.3 (t), 43.5 (d), 43.8 (d), 70.4 (d), 72.2 (d), 120.5 (d), 140.7 (s); MS m/z (rel intensity) 282 (M^+, 0.2), 265 (3), 264 (7), 192 (87), 177 (56), 174 (51), 159 (58), 149 (100), 133 (86); HRMS m/z calcd for $C_{16}H_{26}OSi$ (M^+ − 18) 264.1909, found 264.1911.

(1aβ,4aβ,8aα)-(±)-1,2,3,4,4a,5,8,8a-Octahydro-4a-methyl-7-(1-methylethyl)-1-naphthalenol (20). The procedure of Meyers[37] et al. was employed. To a cooled solution of **19** (231 mg, 0.82 mmol) and anhyd LiCl (61 mg, 1.43 mmol) in dry DMF (0.7 mL) was added 2,6-lutidine (0.2 mL, 1.7 mmol). After the mixture was stirred at 0 °C for 45 min, MsCl (0.1

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(36) According to GC analysis, the purity of **18** was >98%.

(37) Collington, E. W.; Meyers, A. I. *J. Org. Chem.* **1971**, *36*, 3044.

mL, 1.22 mmol) was added, and the resulting slurry was stirred at 0 °C for an additional 1.5 h. The reaction mixture was then quenched with saturated aqueous $CuSO_4$ and extracted with three portions of ether. The combined extracts were successively washed with saturated aqueous $CuSO_4$ and brine, dried, and concentrated. The resulting oil was dissolved in THF (1 mL) and added to 6.9 mL of 0.21 M $(CH_3)_2CuLi$[38] at −30 °C. The reaction mixture was stirred at this temperature for 3 h and then quenched with saturated aqueous NH_4Cl. After extraction with ether, the combined organic layers were successively washed with 3% aqueous NH_4Cl until the washings did not color blue any more. After drying and concentration, the resulting residue was treated overnight with 3.5 mL of 1.1 M TBAF (3.8 mmol) in THF. Evaporation and flash chromatography (7:3 petroleum ether (bp 40−60 °C)/EtOAc) gave 105 mg (61%) of compound **20**: ^{1}H NMR δ 0.97 (s, 3 H), 0.99 (d, J = 7.3 Hz, 6 H), 1.0−2.3 (m, 13 H), 3.84 (dd, J = 2.7, 5.5 Hz, 1 H), 5.26 (m, $W_{1/2} \sim 9$ Hz, 1 H); ^{13}C NMR δ 16.8 (t), 19.5 (q), 21.2 (q), 21.7 (q), 26.7 (t), 32.0 (s), 34.4 (t), 35.0 (d), 41.0 (t), 43.5 (d), 44.1 (t), 70.4 (d), 116.8 (d), 142.4 (s); MS m/z (rel intensity) 208 (M^+, 9), 190 (63), 175 (94), 147 (100), 133 (75), 105 (47), 97 (20), 95 (20), 91 (35), 81 (26); HRMS m/z calcd for $C_{14}H_{24}O$ (M^+) 208.1827, found 208.1828.

(4aβ,8aα)-(±)-3,4,4a,5,8,8a-Hexahydro-4a-methyl-7-(1-methylethyl)-1(2*H*)-naphthalenone (21). The alcohol **20** (67 mg, 0.32 mmol) was dissolved in CH_2Cl_2 (2 mL) containing NMO (90 mg, 0.66 mmol) and 4 Å molecular sieves (100 mg). After 5 min, TPAP (11 mg, 0.03 mmol) was added and the mixture was stirred at rt for 4 h. After evaporation of the solvent, the remaining residue was flash chromatographed (9:1 petroleum ether (bp 40−60 °C)/EtOAc) to give 64 mg (96%) of **21**: ^{1}H NMR δ 0.71 (s, 3 H), 0.97 (d, J = 6.9 Hz, 3 H), 0.98 (d, J = 6.9 Hz, 3 H), 1.5−2.5 (m, 12H), 5.25 (br d, J = 5.0 Hz, 1 H); ^{13}C NMR δ 18.1 (q), 21.1 (q), 21.6 (q), 22.2 (t), 22.8 (t), 35.0 (d), 37.8 (s), 39.9 (t), 41.5 (t), 41.7 (t), 53.2 (d), 115.7 (d), 141.8 (s), 212.8 (s); MS m/z (rel intensity) 206 (M^+, 100), 191 (71), 173 (41), 163 (70), 145 (56), 135 (34), 131 (57), 93 (32), 91 (35); HRMS m/z calcd for $C_{14}H_{22}O$ (M^+) 206.1671, found 206.1671.

(38) This solution was prepared just before use by adding 2.9 mL of 1 M MeLi in ether to a suspension of 281 mg (1.45 mmol) of CuI in 4 mL of dry THF at −80 °C and stirring for 45 min during which time the temperature was allowed to come to −30 °C.

(4aβ,8aα)-(±)-1,2,3,4,4a,5,8,8a-Octahydro-4a-methyl-1-methylene-7-(1-methylethyl)naphthalene ((±)-Vetiselinene, 22). To a stirred solution of 1.7 mL of 0.36 M (dimethylsulfinyl)sodium in dry DMSO was added Ph_3PCH_3-Br (224 mg, 0.62 mmol) at rt. After the mixture was stirred for 10 min, the resulting yellow solution was added via syringe to a solution of **21** (49 mg, 0.25 mmol) in dry DMSO (0.2 mL). The reaction mixture was stirred at rt for 27 h, and after addition of 10 mL of H_2O, the mixture was extracted with eight 15-mL portions of pentane. The combined organic layers were washed with H_2O and brine and dried. Flash chromatography (pentane) gave 38 mg (78%) of (±)-vetiselinene (**22**): ^{1}H NMR δ 0.67 (s, 3 H), 1.01 (d, J = 6.8 Hz, 6 H), 1.1−2.5 (m, 12 H), 4.57 (d, J = 1.5 Hz, 1 H), 4.77 (dd, J = 1.5, 3.0 Hz, 1 H), 5.28 (br d, J = 5.0 Hz, 1 H); ^{13}C NMR δ 17.1 (q), 21.3 (q), 21.7 (q), 23.6 (t), 25.9 (t), 34.5 (s), 35.1 (d), 37.2 (d), 41.6 (t), 41.9 (t), 44.9 (d), 106.0 (t), 116.3 (d), 142.0 (s), 150.7 (s); MS m/z (rel intensity) 204 (M^+, 50), 189 (28), 161 (59), 147 (28), 133 (62), 119 (38), 105 (91), 91 (79), 79 (51), 41 (100); HRMS m/z calcd for $C_{15}H_{24}$ (M^+) 204.1878, found 204.1881. The spectroscopic data of (±)-**22** are identical with those reported in the literature.[28,39]

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Supplementary Material Available: ^{1}H NMR spectra for compounds **6e, 9a, 11c, 15, 16,** and **19−22** (10 pages). This material is contained in libraries on microfiche, immediately follows this article in the microfilm version of the journal, and can be ordered from the ACS; see any current masthead page for ordering information.

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