(6), 88 (5), 87 (23), 86 (60), 81 (6), 77 (20), 59 (11), 57 (100), 41 (59). Anal. Calcd for $C_3H_7NOS_2$: C, 46.3; H, 8.3; N, 6.8. Found: C, 46.4; H, 8.7; N, 6.7. No 2*H*-azirine could be detected by TLC.

Hydrolysis of (*Z*)-3,3-Dimethyl-1,1-bis(methylthio)-2-butanone *O*-[(Methylamino)carbonyl]oxime (10). A total of 0.203 g (0.768 mmol) of **10** was dissolved in 12.5 mL of 1 M methanolic potassium hydroxide. After being stirred at room temperature 2.5 h, the solution was concentrated to ca. 5 mL and extracted with CH_2Cl_2. After the organic extracts were dried ($MgSO_4$) and concentrated, 0.162 g of solid residue was obtained. ^1H NMR indicated a 1:1 mixture of starting carbamate and (*Z*)-3,3-dimethyl-1,1-bis(methylthio)-2-butanone oxime (**17**). The oxime was isolated by thick-layer chromatography as a white crystalline solid: mp 122-128 °C; ^1H NMR ($CDCl_3$) δ 9.29 (1 H, s, OH), 4.27 (1 H, s, CH), 2.28 (6 H, s, SCH_3), 1.23 (9 H, s, *tert*-butyl); IR (neat) 3250 (OH), 2900 and 2850 (CH), 1620 (N=C), 1420, 1400, 1350, 1240, 1160, 950, 880 cm^{-1}; ^{13}C NMR ($CDCl_3$) δ 163.19 (C=N), 51.23 (CH), 37.33 (Cq), 28.23 ($(CH_3)_3$), 17.51 (SCH_3); mass spectrum, *m/e* (relative intensity) 207 (19, M^+), 161 (22), 160 (78), 159 (99), 144 (30), 143 (9), 129 (12), 107 (45), 86 (31), 77 (73), 57 (100), 41 (62). Anal. Calcd for $C_8H_{17}NOS_2$: C, 46.3; H, 8.3; N, 6.8. Found: C, 46.6; H, 8.5; N, 6.7.

Registry No. **8**, 73926-56-4; **9**, 73926-57-5; **10**, 73926-58-6; **11**, 73940-61-1; **12**, 73926-59-7; **13** (isomer 1), 73926-60-0; **13** (isomer 2), 73940-62-2; **14**, 73926-61-1; **15**, 73926-62-2; **16**, 73926-63-3; **17**, 73926-64-4; **18**, 73926-65-5.

4,5,6,7-Tetrahydrobenzo[*b*]thiophenes via Diisobutylaluminum Hydride Mediated Detosylation Reactions

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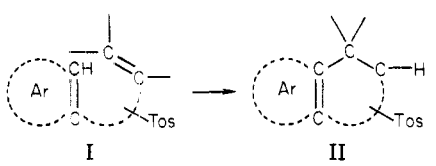
A novel synthesis of 4,4-dimethyl-4,5,6,7-tetrahydrobenzo[*b*]thiophene (**3a**), its 7-substituted derivatives **3b-d** and also 7,7-dimethyl-4,5,6,7-tetrahydrobenzo[*b*]thiophene (**12b**) is presented. The strategy centers on the facile diisobutylaluminum hydride mediated detosylation of precursors **2a-d** and **12a**. Some of the latter, such as **2a,b** and **12a**, are cleanly and efficiently prepared by FSO_3H-SO_2 induced cycloalkylation of **1a,b** and **11b**. The others, **2c** and **2d**, are derived from **2a** via phase-transfer alkylation techniques. A number of approaches toward open systems **1a-d** are described.

The synthetic power of the sulfone group has recently been reviewed.[1] The *p*-toluenesulfonyl group (tosyl, Tos), in particular, is currently drawing attention because of its role in modern carbon-carbon bond construction. When on carbon, it enhances existing C-H acidity and stabilizes a subsequently generated carbanion. These react with carbon electrophiles, after which the tosyl fragment, having served its purpose, is removed. In this sense the tosyl group is unique in that it stabilizes a carbanion on the carbon to which it is attached, while being of sufficient nucleofugicity to allow its replacement by hydrogen.[2] In practice tosyl derivatives are easily manipulated substances, readily identified by methyl NMR signals around 2.40 ppm.

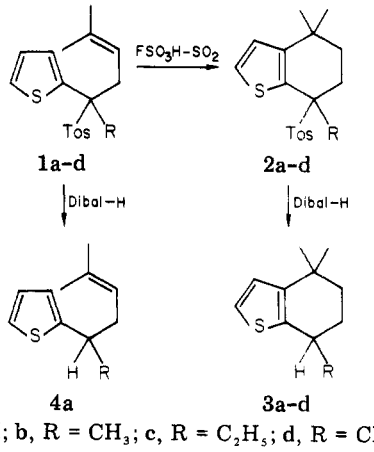
A strategy incorporating ring closures of pretosylated alkyl aromatic systems such as I to derivatives II seems to have no recorded precedent. It would offer intriguing prospects in providing structures predisposed to the manipulations given above. We decided to examine this possibility.



I II

Thiophene-based models were chosen since cycloalkylation onto thiophene is known to occur readily;[3] moreover, the resulting benzo[*b*]thiophenes comprise an area of past involvement of one of us.[4] Realization of the objective would hinge on elaborating reaction conditions of sufficient power to bring about ring closure, yet mild enough to allow the tosyl group to come through unscathed. Such a method is now described; conditions are presented for obtaining **2a,b** from **1a,b**. In addition, a novel C-detosylation method featuring the use of diisobutylaluminum hydride (Dibal-H) has been found to remove tosyl fragments from thiophene systems **1a** and **2a-d** (Scheme I).

Scheme I



a, R = H; b, R = CH_3; c, R = C_2H_5; d, R = $CH_2C_6H_5$

(1) P. D. Magnus, *Tetrahedron*, **33**, 2019 (1977).

(2) Another such fragment is the cyano moiety; for example, treatment of tetradecylnitrile with lithium in ethylamine gives, besides reduction to the tetradecylamine, also decyanation to tridecane: P. G. Arapakos, M. K. Scott, and F. E. Huber, Jr., *J. Am. Chem. Soc.*, **91**, 2059 (1969).

(3) See, for instance, B. Iddon and R. M. Scrowston in *Adv. Heterocycl. Chem.*, **11**, 177-381 (1970).

(4) (a) E. F. Godefroi, U.S. Patent 3 111 527 (1963); *Chem. Abstr.*, **60**, 2895 (1964); (b) H. J. J. Loozen and E. F. Godefroi, *J. Org. Chem.*, **38**, 1056 (1973).

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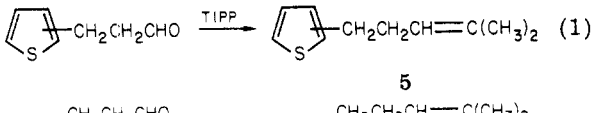
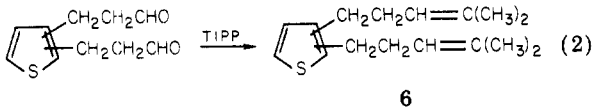
Attention was focused first on synthesizing **1a**. Non-tosylated versions like **5** and all possible systems **6** had been reported earlier via Wittig olefination of the appropriate carboxaldehydes (eq 1,2).[5,6] A recent report from



(1)

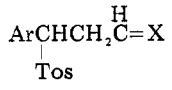
5



(2)

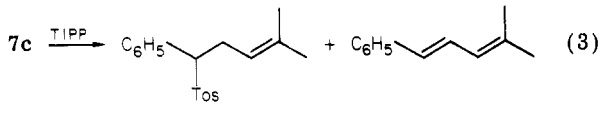
6

our laboratories, moreover, described facile entries into **7a–c**,[7] suggesting these as logical departure points for **1a**.



7a, Ar = C_6H_5; X = OCH_2CH_2O
b, Ar = 2-thienyl; X = OCH_2CH_2O
c, Ar = C_6H_5; X = O
d, Ar = 2-thienyl; X = O

Easily accessible **7c** served as model compound in probes with triphenylisopropylidenephosphorane (TIPP). This gave 35% of solid **8**, but NMR examination of the mother liquors showed these to consist mostly of non-tosyl systems (eq 3).

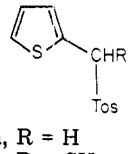


(3)

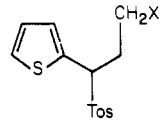
8

This situation worsened when **7d**, obtained from **7b**, was treated with TIPP; only minor amounts of **1a** resulted (NMR inspection), the major product consisting of detosylated material. The approach was abandoned in favor of one involving reversal of the Wittig components; this necessitated the preparation of **10d**.

2-Thienyl(*p*-toluenesulfonyl)methane was therefore derived from 2-(chloromethyl)thiophene[8] and NaTos in DMF, according to the procedure for the phenyl analogue.[7] Treatment in THF with butyllithium (BuLi) followed by ethylene oxide led cleanly to 87% of **10a**. The alcohol was



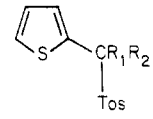
9a, R = H
b, R = CH_3
c, R = C_2H_5
d, R = $CH_2C_6H_5$



10a, X = OH
b, X = OTos
c, X = I
d, X = $P^+(C_6H_5)_3\ I^-$

converted to iodide **10c** via tosyl ester **10b** and treatment with sodium iodide. The reaction with triphenylphosphine

Table I. 2-Substituted Thiophenes



compd	R_1	R_2	method[a] (yield, %)[b]	mp, °C[c]
1c	ethyl	prenyl	ethylation of 1a (37) prenylation of 9c (89)	83–84
1d	benzyl	prenyl	benzylation of 1a (87) prenylation of 9d (88)	122 dec
9c	ethyl	hydrogen	ethylation of 9a (83)	116–117
9d	benzyl	hydrogen	benzylation of 9a (84)	159

[a] Phase-transfer techniques as described for 1a (Experimental Section) using ethyl bromide, benzyl chloride, or prenyl bromide. [b] Yield based on amount obtained with mp < 5 °C below analytical sample. [c] Satisfactory elemental analyses (C, H ± 0.3%) were found.

then furnished phosphonium salt **10d**. All efforts to obtain **1a** from the ylide derived from **10d** failed. This is not surprising since in **10d** all aliphatically bonded hydrogens are somewhat acidic. Both the tosyl and triphenylphosphonium fragments are potential leaving groups, so that deprotonation of any of the sp^3 carbon atoms of **10d** could well lead to undesirable reactions.

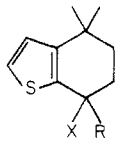
Compound **1a** was ultimately obtained in 76% yield by phase-transfer alkylation of **9a** with prenyl bromide. Related reaction conditions have recently been described.[9a,b] These circumstances also permitted ethylation and benzylation of **9a** to give **9c** and **9d** but failed to give reproducible yields of **9b**. Compounds **9c,d** were then either prenylated to furnish **1c,d**, or **1a** could be ethylated or benzylated to give the same compounds. Compound **1b** was obtained by methylating the anion of **1a**. Short of the aforementioned methylation, the alkylations to **2c,d** proceeded via simple efficient phase-transfer techniques (see Experimental Section or Table I).

Exploratory cyclizations were done on easily accessible **1a**, the reaction being monitored by observing the NMR shifts of the *vic*-dimethyl signals from ca. 1.6 to 1.0 ppm in the ring-closed material. Results were initially disappointing. Conditions such as trifluoroacetic acid–methylene chloride, reported earlier as efficacious in cyclizing non-tosyl analogue **4a** to **3a**,[5] gave, at ambient temperature after 6 h, no reaction but produced tars on raising the temperatures. This also occurred in sulfuric acid, either concentrated at 0 °C or as a 50% solution at reflux temperature. A system frequently used in cationic cyclization reactions is tin tetrachloride in methylene chloride.[10] With **1a** this failed to bring about reaction at −78 °C (0.5 h) and at 0 °C (1.5 h) but led to decomposition in 2.5 h at 20 °C.

Suitable conditions for the cycloalkylation of **1a** were found in liquid SO_2 containing catalytic amounts of fluorosulfuric acid (FSO_3H). The reaction, an extremely rapid one as judged by NMR, was quenched with alcoholic sodium methoxide after 1 min; it furnished consistently ca.

(5) A. Corvers, J. H. van Mil, M. M. E. Sap, and H. M. Buck, *Recl. Trav. Chim. Pays-Bas*, **98**, 18 (1977).
(6) C. G. M. Janssen, A. A. Macco, H. M. Buck, and E. F. Godefroi, *Recl. Trav. Chim. Pays-Bas*, **98**, 448 (1979).
(7) C. G. M. Janssen, P. M. van Lier, H. M. Buck, and E. F. Godefroi, *J. Org. Chem.*, **44**, 4199 (1979).
(8) Suspected health hazards associated with HCl–CH_2O mixtures (see insert bis(chloromethyl) ether in "Organic Syntheses", Collect. Vol. IV, p 101; and also B. L. van Duuren, A. Sivak, B. M. Goldschmidt, C. Katz, and S. Melchionne, *J. Natl. Cancer Inst.*, **43**, 481 (1969)) made us refrain from using the thiophene chloromethylation procedure given in "Organic Syntheses", Collect. Vol. III, pp 197–199. Instead we opted for the somewhat more laborious route, involving $LiAlH_4$ reduction of 2-thiophenecarboxaldehyde (92%) and follow-up treatment with thionyl chloride (95%).
(9) (a) G. F. Veenstra and B. Zwanenburg, *Synthesis*, 519 (1975); (b) J. Golinski, A. Jonczyk, and M. Makosza, *Synthesis*, 461 (1979); (c) J. Wildeman and A. M. van Leusen, *Synthesis*, 733 (1979).
(10) For a recent survey of cationic cyclization methods as applied toward steroid synthesis, see W. S. Johnson, *Angew. Chem.*, **88**, 33 (1976).

Table II.
4,4-Dimethyl-4,5,6,7-tetrahydrobenzo[b]thiophenes



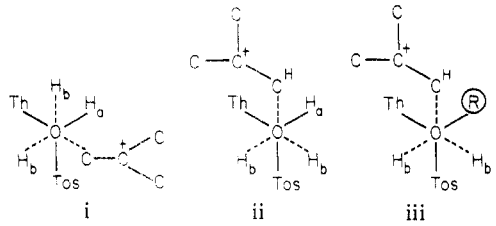
compd	X	R	method (yield, %)[d]	mp, °C[e]
2b	tosyl	methyl	cyclization of 1b (44)[a] methylation of 2a (78)[b]	129-130
2c	tosyl	ethyl	cyclization of 1c (4)[a] ethylation of 2a (69)[b]	117-118
2d	tosyl	benzyl	benzylation of 2a (62)	dec
3b	hydrogen	methyl	detosylation[c]	liquid
3c	hydrogen	ethyl	detosylation[c]	liquid
3d	hydrogen	benzyl	detosylation[c]	liquid

[a] Cyclizations as for 2a, involving 1 equiv of HSO_3F. [b] Alkylation as for open systems 1b-d. [c] Detosylation for 45 min with 3.0 mol of Dibal-H per mol of substrate. [d] Yield based on amount obtained with mp < 5 °C below analytical sample (for 2b-d). [e] Satisfactory elemental analyses (C, H ± 0.3%) were found.

65% of **2a** on 20-g batches. Although superacid systems such as these have found extensive use in the generation and study of long-lived carbonium ions,[11] the application of FSO_3H toward unidirectional high-yield synthetic transformations seems to be rather limited.[12]

Related cyclizations of **1b–d** were examined next with, again, the *vic*-dimethyl NMR shifts serving as reaction criterion. The cyclization of methyl analogue **1b** proceeded considerably more slowly than **1a** with catalytic amounts of FSO_3H; switching to stoichiometric equivalency and monitoring the reaction by observing the NMR disappearance of starting material led, after 5 h, to isolation of 44% of cyclized **2b**. Identical conditions provided only 4% of **2c** from **1c**, but no more than spectrally detectable **2d** from **1d**. For practical purposes **2b** was thereafter prepared by anion methylation of **2a** (tandem treatment with BuLi and MeI); systems **2c,d** were likewise obtained from **2a** via phase-transfer ethylation and benzylation (see Table II).

We rationalize our findings as follows. Cyclization of **1a** can only take place via suitably dispositioned cations in conformation ii; other conformations (for instance i)



i ii iii

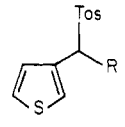
would not be expected to lead to cycloalkylation. Our failure to effect ring closure in all but the SO_2-run reactions might be attributable to solvation and stabilization of the intermediate cations by the SO_2. A second aspect has to do with the magnitude of nonbonded interactions generated on trying to cyclize **2b–d**. Inspection of Newman projections iii of precyclization **1a–d** clearly shows them to be adversely affected by increasing the steric demand of R. This view would be in line with the observed yield decreases on cyclizing the series **1a–d**.

Detosylation of saturated carbon atoms may be achieved by a number of reported methods. These include Li-$EtNH_2$,[13] NaHg,[14] and Zn-HOAc.[15] These reagents have one thing in common; by analogy to reductions of other substrates they act via electron-transfer protonation. Thiophenes, however, have been shown to be vulnerable to such conditions,[16] prompting us to search for alternative detosylation methods.

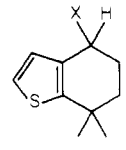
During the course of related work, there arose the need to deoxygenate **1a** to its corresponding sulfide. Earlier work by Gardner had shown Dibal-H to be an effective agent for reducing sulfones to sulfides.[17] We chose to test the procedure on **1a**; on contacting it with Dibal-H, however, the odor of *p*-thiocresol was soon unmistakable and workup of the reaction mixture afforded a 70% yield of **4a**.[18] Dibal-H became therefore a logical first choice as a potential detosylating agent for **2a–d**.

Optimal conditions for the Dibal-H reaction with **2a–d** were determined by TLC monitoring. Starting material **2a** was found to be completely consumed on using a 1.5-fold excess of reducing agent. The others, **2b–d**, required a 3-fold excess. On scaling up to 0.005-molar runs, the reactions of **2a–d** with Dibal-H were found to be highly exothermic; moreover, isobutene was evolved, which was trapped and NMR characterized. All cases examined led to completely desulfurized products **3a–d** in synthetically clean and good-yield processes (Table II).

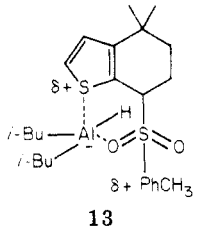
Our results are at variance with the Dibal-H mediated sulfone → sulfide reductions reported earlier.[17] The discrepancy may well stem from the presence of the thiophene sulfur in the substrate. In the case reported here, one might envision the intermediacy of chelated or loosely bound S–Al–O complexes as illustrated in **13**; these, of



11a, R = H
b, R = prenyl



12a, X = Tos
b, X = H



13

course, would be precluded in Gardner's substrates. Sit-

(11) G. A. Olah, *Angew. Chem., Int. Ed. Engl.*, **12**, 173 (1973).
(12) Some examples are the following: (a) cyclodehydration, W. Baker, G. E. Coates, and F. Glocking, *J. Chem. Soc.*, 1376 (1951); (b) rearrangement of geraniol, D. V. Banthorpe, P. A. Bouillier, and W. D. Fordham, *J. Chem. Soc., Perkin Trans. 1*, 1637 (1974); (c) isomerization of 3,5-cycloheptadienone, K. E. Hine and R. F. Childs, *J. Am. Chem. Soc.*, **95**, 3289 (1973).
(13) (a) B. M. Trost and T. J. Fullerton, *J. Am. Chem. Soc.*, **95**, 293 (1973); (b) P. A. Grieco and Y. Masaki, *J. Org. Chem.*, **39**, 2135 (1974).
(14) (a) G. H. Posner and D. J. Brunelle, *J. Org. Chem.*, **38**, 2747 (1973); (b) M. Julia and B. Badet, *Bull. Soc. Chim. Fr.*, 1363 (1975); (c) B. M. Trost, H. C. Arndt, P. E. Strege, and T. R. Verhoeven, *Tetrahedron Lett.*, **39**, 3477 (1976); (d) Y. H. Chang and H. W. Pinnick, *J. Org. Chem.*, **43**, 373 (1978).
(15) B. Koutek, L. Pavlickova, and M. Soucek, *Collect. Czech. Chem. Commun.*, 192 (1974).
(16) S. F. Birch and D. T. McAllan, *J. Chem. Soc.*, 2556 (1951).
(17) J. N. Gardner, S. Kaiser, A. Krubiner, and H. Lucas, *Can. J. Chem.*, **51**, 1419 (1973).
(18) Dibal-H mediated detosylations of related open systems are currently under investigation.
(19) G. Wittig and D. Wittenberg, *Justus Liebigs Ann. Chem.*, **606**, 1, (1957).
(20) R. Köster, A. Bussmann, and G. Schroth, *Justus Liebigs Ann. Chem.*, 2130 (1975). We modified the procedure slightly by keeping the crude reaction mixture at 145 °C for 1 h prior to distillation.

uation **13** would be conducive to hydride delivery to C-7, originating either from aluminum or the β-carbon of the aluminum-bonded isobutyl group. We were curious to test this hypothesis and decided therefore to prepare the isomer of **2a**, i.e., **12a**, in which chelation would be precluded.

3-(Chloromethyl)thiophene was treated with NaTos in DMF, giving **11a** (78%) which yielded **11b** via the previously described phase-transfer prenylation. This was cyclized in liquid sulfur dioxide in a FSO_3H-promoted process and gave the desired **12a** in 92% yield.

Detosylation of **12a** was first probed by using 1.5 equiv of Dibal-H under identical conditions as for **2a**. The transformation, followed via TLC, was incomplete as evidenced by failure of total disappearance of the substrate. Increasing the stoichiometry to 3 equiv did lead, after 45 min, to an isolated 72% yield of **12b**. These findings point against the occurrence or necessity of chelates such as **13** in the detosylation of **2a** by means of Dibal-H; they do not preclude the intermediacy of other noncyclic S–Al–O species.

Experimental Section

General Methods. We thank Messrs. P. van den Bosch and H. Eding for microanalytical data. Nuclear magnetic resonance spectra (NMR) were recorded on a Varian EM-360A spectrometer. Melting points (recorded on a Fisher-Johns block) are uncorrected.

1-(2-Thienyl)-1-(*p*-toluenesulfonyl)-4-methylpent-3-ene (1a). A mixture of 6.3 g (0.025 mol) of **9a**, 4.1 g (0.027 mol) of prenyl bromide,[14] 37.5 mL of 50% sodium hydroxide, 10 mL of THF, and 0.5 g of tetrabutylammonium bromide was thoroughly stirred for 18 h. Water (500 mL) was added to give a solid product, which was then filtered off and washed with water, isopropyl alcohol, and diisopropyl ether, respectively. The yield was 6.1 g (76%), mp 106 °C; analytical material from toluene gave mp 107–108 °C: NMR ($CDCl_3$) δ 1.61 (s, 6, $(CH_3)_2$), 2.30–3.40 (m, 2, CH_2C=), 2.37 (s, 3, $TosCH_3$), 4.07 (dd, 1, CHTos), 4.85 (t, 1, CH=), 6.52–7.54 (m, 7, Ar H).

Anal. Calcd for $C_{17}H_{20}O_2S_2$: C, 63.71; H, 6.29. Found: C, 63.73; H, 6.12.

2-(2-Thienyl)-2-(*p*-toluenesulfonyl)-5-methylhex-4-ene (1b). To a stirred solution of 6.4 g (0.02 mol) of **1a** in 20 mL of dry THF was added, dropwise at 0 °C, 14.1 mL of commercial 15% BuLi in hexane. After the mixture was stirred for 0.5 h at room temperature, 4.26 g (0.06 mol) of methyl iodide was introduced at room temperature. Stirring was continued for 1 h, whereupon the mixture was poured onto 300 mL of water. The formed solid was filtered, rinsed with fresh water, and triturated with isopropyl alcohol to furnish 6.6 g (78%) of **1b**, mp 73–74 °C. Analytical material was obtained on recrystallization from low-boiling petroleum ether–benzene: mp 74–75 °C; NMR ($CDCl_3$) δ 1.60 and 1.64 (2 s, 9, 3 CH_3), 2.33 (s, 3, $TosCH_3$), 3.00 (br d, 2, CH_2), 4.80 (t, 1, C=CH), 6.65–7.40 (m, 7, Ar H).

Anal. Calcd for $C_{18}H_{22}O_2S_2$: C, 64.63; H, 6.63. Found: C, 64.84; H, 6.68.

4,4-Dimethyl-7-(*p*-toluenesulfonyl)-4,5,6,7-tetrahydrobenzo[*b*]thiophene (2a). To a solution of 15 g (0.047 mol) of **1a** in 40 mL of liquid sulfur dioxide at −78 °C was added 0.4 mL of freshly distilled fluorosulfuric acid. The dark mixture was stirred for 1 min and was then quenched by addition of 0.06 mol of NaOMe in a little methyl alcohol. The resulting yellow solution was then poured into an ether–water mixture, which was thereafter neutralized with 5 N NaOH. The ether layer was separated, washed, dried, and evaporated to leave 15 g of crude material. Trituration in the cold with diisopropyl ether provided 9.9 g (66%) of white product, mp 90 °C. Recrystallization from diisopropyl ether furnished the analytical sample: mp 91–92 °C; NMR ($CDCl_3$) δ 0.95 and 1.10 (2 s, 6, 2 CH_3), 1.24–1.97 (m, 2, CH_2CCTos), 1.97–2.50 (m, 2, CH_2CTos), 2.39 (s, 3, $TosCH_3$), 4.38 (t, 1, CHTos), 6.67–7.73 (2 AB, 6, Ar H).

Anal. Calcd for $C_{17}H_{20}O_2S_2$: C, 63.71; H, 6.29. Found: C, 63.80; H, 6.46.

4,4-Dimethyl-4,5,6,7-tetrahydrobenzo[*b*]thiophene (3a). To a stirred, nitrogen-covered solution of 1.6 g (0.005 mol) of **2a** in 3 mL of dry toluene was added, in one portion at room temperature, 1.5 equiv (0.0075 mol) of Dibal-H in 5 mL of toluene. Immediate evolution of isobutene was observed, together with a temperature rise to ca. 100 °C. After 5 min the mixture was cooled, and to it was carefully added 0.53 mL of ethanol, 2.21 mL of water, and 1.11 mL of concentrated hydrochloric acid. The organic layer was decanted and the residue was extracted with diethyl ether. The combined organic layers were washed with water, 5 N sodium hydroxide solution, and water until neutral, dried, and evaporated to leave 0.85 g of crude material. This was filtered through silica (5 g, 70–230 mesh ASTM) and eluted with petroleum ether 40/65, ca. 30 mL, to give after evaporation 0.65 g of TLC-pure product: NMR ($CDCl_3$) δ 1.21 (s, 6, 2 CH_3), 1.40–2.32 (m, 4, CH_2CH_2), 2.72 (t, 2, $ThCH_2$), 6.87 (AB, 2, ThH).

1-Phenyl-1-(*p*-toluenesulfonyl)-4-methylpent-3-ene (8). To a stirred nitrogen-covered slurry of 4.32 g (0.01 mol) of isopropyltriphenylphosphonium iodide[13] in 50 mL of dry ether was added 7.05 mL of 15% commercial BuLi in hexane. Stirring was continued for 2 h whereupon 2.9 g (0.01 mol) of **7c**[7] in 30 mL of dry benzene was introduced. After another 22 h the reaction was quenched with 0.5 mL of methyl alcohol, filtered, and evaporated to leave 2.4 g of oily residue. This was repeatedly triturated with 60% alcohol and finally with ice-cold isopropyl alcohol to give solid **8**: 1.1 g (35%); mp 115 °C; NMR ($CDCl_3$) δ 1.58 (s, 6, 2 CH_3), 2.40 (s, 3, $TosCH_3$), 2.69–3.25 (m, 2, CH_2), 4.00 (dd, 1, CHTos), 4.78 (t, 1, CH=), 6.94–7.53 (m, 9, Ar H). Analytical material prepared from isopropyl alcohol had mp 117–118 °C.

Anal. Calcd for $C_{19}H_{22}O_2S$: C, 72.57; H, 7.05. Found: C, 72.91; H, 7.23.

2-Thienyl(*p*-toluenesulfonyl)methane (9a). A mixture of 132.5 g (1.0 mol) of 2-(chloromethyl)thiophene[8] and 178 g (1.0 mol) of NaTos in 300 mL of dry DMF was stirred and brought to 110 °C; this brought about a slightly exothermic reaction, causing a temperature rise to 135 °C. After 15 min, 3000 mL of water was added to give solid product which was removed by filtration and was washed with water, alcohol, and ether to give, after air drying, 176 g (70%) of sulfone, mp 131–132 °C. Analytical material from ethyl alcohol had mp 132–133 °C: NMR ($CDCl_3$) δ 2.39 (s, 3, $TosCH_3$), 4.30 (s, 2, CH_2), 6.70–7.65 (m, 7, Ar H).

Anal. Calcd for $C_{12}H_{12}O_2S_2$: C, 57.11; H, 4.79. Found: C, 57.28; H, 4.64.

1-(2-Thienyl)-1-(*p*-toluenesulfonyl)propan-3-ol (10a). To a stirred solution of 25.2 g (0.10 mol) of **9a** in 50 mL of dry THF was added dropwise, at 0 °C, 84 mL of commercial 15% BuLi in hexane (0.20 mol). Lithiation was allowed to proceed for 0.5 h at room temperature; the temperature was then lowered to −30 °C and 8.8 g (0.20 mol) of ethylene oxide was introduced. After 0.5 h the mixture was allowed to come to room temperature, kept there for 0.5 h, and then quenched by addition of 200 mL of water. This afforded solid material, which was filtered and rinsed with fresh water. The product was taken up in a minimum of chloroform, dried, and stripped, leaving 25.5 g (87%) of carbinol, mp 140 °C. A sample was purified from toluene: mp 143–144 °C; NMR ($CDCl_3$) δ 1.84–2.96 (m, 3, CH_2CTos and OH), 2.39 (s, 3, $TosCH_3$), 3.13–4.04 (m, 2, CH_2O), 4.63 (dd, 1, CHTos), 6.62–7.61 (m, 7, Ar H).

Anal. Calcd for $C_{14}H_{16}O_3S_2$: C, 56.73; H, 5.44. Found: C, 56.96; H, 5.51.

1-(2-Thienyl)-1-(*p*-toluenesulfonyl)prop-3-yl *p*-Toluenesulfonate (10b). *p*-Toluenesulfonyl chloride, 14 g (0.073 mol), was added to 20 g (0.067 mol) of carbinol **10a** in 40 mL of pyridine at −5 °C. After 18 h at −5 °C it was poured onto 500 mL of stirred ice–water, ultimately giving solid product. Filtration, washing with water, and finally trituration with isopropyl alcohol yielded 28.1 g of brown material, mp ca. 95 °C. This was repeatedly leached out with small partions of boiling dibutyl ether, depositing, on cooling, 14.7 g (48%) of crystals, which on isopropyl alcohol trituration had mp 104–105 °C. Analytical material was obtained on recrystallization from methyl alcohol: mp 106–107 °C; NMR ($CDCl_3$) δ 2.01–3.26 (m, 2, CH_2CTos), 2.38 (2 s, 6, 2 $TosCH_3$), 3.26–4.27 (m, 2, CH_2OTos), 4.43 (dd, 1, CHTos), 6.53–7.77 (m, 11, Ar H).

Anal. Calcd for $C_{21}H_{22}O_5S_3$: C, 55.97; H, 4.92. Found: C, 56.17; H, 5.01.

1-(2-Thienyl)-1-(*p*-toluenesulfonyl)-3-iodopropane (10c). A stirred solution of 14.8 g (0.033 mol) of **10b** and 14.8 g (0.099 mol) of sodium iodide in 110 mL of acetone was allowed to reflux

for 1 h. The solids were removed by filtration and the filtrate was evaporated; the residue was partitioned between benzene and water. Scrubbing of the organic phase with water, drying, and solvent removal left crude product which was triturated with methyl alcohol. This material, 12.4 g (93%), had mp 101 °C. A sample was recrystallized from methyl alcohol: mp 101–102 °C; NMR ($CDCl_3$) δ 2.40 (s, 3, $TosCH_3$), 2.40–3.46 (m, 4, CH_2CH_2), 4.51 (dd, 1, CHTos), 6.75–7.52 (m, 7, Ar H).

Anal. Calcd for $C_{14}H_{15}IO_2S_2$: C, 41.38; H, 3.72. Found: C, 41.60; H, 3.75.

1-(2-Thienyl)-1-(*p*-toluenesulfonyl)prop-3-ylphosphonium Iodide (10d). A solution of 4.06 g (0.01 mol) of **10c**, 2.6 g (0.01 mol) of triphenylphosphine, and 10 mL of toluene was refluxed for 2 h. The mixture was cooled, and the toluene was then decanted from the produced oily layer; this was rubbed with ether to give 4.7 g (70%) of solid product, mp 202–204 °C, which was recrystallized from ethyl alcohol–acetone–ether: mp 204–205 °C; NMR ($CDCl_3$) δ 2.08–3.50 (m, 4, CH_2CH_2), 2.34 (s, 3, $TosCH_3$), 5.78 (dd, 1, CHTos), 6.65–8.02 (m, 22, Ar H).

Anal. Calcd for $C_{32}H_{30}IO_2PS_2$: C, 57.49; H, 4.52. Found: C, 57.38; H, 4.70.

3-Thienyl(*p*-toluenesulfonyl)methane (11a). In analogy to **9a**, **11a** was obtained in 78% yield. Analytical material, obtained from isopropyl alcohol, had mp 102–103 °C: NMR ($CDCl_3$) δ 2.37 (s, 3, $TosCH_3$), 4.30 (s, 2, CH_2Tos), 6.77–7.63 (2 AB, 7, Ar H).

Anal. Calcd for $C_{12}H_{12}O_2S_2$: C, 57.11; H, 4.79. Found: C, 57.26; H, 4.80.

1-(3-Thienyl)-1-(*p*-toluenesulfonyl)-4-methylpent-3-ene (11b). Analogous to **1a**, **11b** was obtained in 77% yield. Analytical material was obtained from diisopropyl ether: mp 99–100 °C; NMR ($CDCl_3$) δ 1.53 (s, 6, $(CH_3)_2$), 2.33 (s, 3, $TosCH_3$), 2.47–3.30 (m, 2, $TosCCH_2$), 4.00–4.20 (m, 1, C=CH), 4.80 (t, 1, TosCH), 6.67–7.53 (2 AB, 7, Ar H).

Anal. Calcd for $C_{17}H_{20}O_2S_2$: C, 63.71; H, 6.29. Found: C, 63.74; H, 6.43.

4,4-Dimethyl-7-(*p*-toluenesulfonyl)-4,5,6,7-tetrahydrobenzo[*b*]thiophene (12a). Analogous to **2a**, **12a** was obtained in 92% yield. Analytical material, obtained from diisopropyl ether had mp 107–108 °C: NMR ($CDCl_3$) δ 0.83–1.64 (m, 2, CH_2CCTos), 1.00 and 1.21 (2 s, 6, $(CH_3)_2$), 1.92–2.51 (m, 2, CH_2CTos), 2.38 (s, 3, $TosCH_3$), 4.25 (t, 1, CHTos), 7.02 (s, 2, ThH), 6.96–7.62 (AB, 4, Tos H).

Anal. Calcd for $C_{17}H_{20}O_2S_2$: C, 63.71; H, 6.29. Found: C, 63.55; H, 6.35.

7,7-Dimethyl-4,5,6,7-tetrahydrobenzo[*b*]thiophene (12b). Analogous to **3a**, 3 equiv of Dibal-H was used to obtain **12b**. The reaction mixture was stirred for 45 min: yield 72%; NMR ($CDCl_3$) δ 1.30 (s, 6, $(CH_3)_2$), 1.46–2.06 (m, 4, CH_2CH_2), 2.40–2.72 (m, 2, $ThCH_2$), 6.76 (AB, 2, ThH).

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Registry No. **1a**, 73838-08-1; **1b**, 73838-09-2; **1c**, 73838-10-5; **1d**, 73838-11-6; **2a**, 73838-12-7; **2b**, 73838-13-8; **2c**, 73838-14-9; **2d**, 73838-15-0; **3a**, 62469-66-3; **3b**, 73838-16-1; **3c**, 73855-13-7; **3d**, 73838-17-2; **7c**, 71370-89-3; **8**, 73838-18-3; **9a**, 20895-79-8; **9c**, 73838-19-4; **9d**, 73838-20-7; **10a**, 73838-21-8; **10b**, 73838-22-9; **10c**, 73838-23-0; **10d**, 73838-24-1; **11a**, 73838-25-2; **11b**, 73838-26-3; **12a**, 73838-27-4; **12b**, 62429-58-7; prenyl bromide, 870-63-3; isopropyltriphenylphosphonium iodide, 1530-33-2; 2-(chloromethyl)thiophene, 765-50-4; ethylene oxide, 75-21-8; triphenylphosphine, 603-35-0.

Supplementary Material Available: NMR data for compounds in Tables I and II and elemental analyses for C and H (2 pages). Ordering information is given on any current masthead page.

Glycosidic Disecoeudesmanolides and Other Secosesquiterpene Lactones from *Picradeniopsis* Species. X-ray Analysis of Bahia I[1]

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The unusual disecoeudesmanolide glycosides **3a** and **5a** were isolated from an Arizona collection of *Picradeniopsis woodhousei* (Gray) Rydb. in addition to the heliangolide woodhousin (**8a**) and the flavone jaceidin. *P. woodhousei* from New Mexico gave the secoeudesmanolide precursor **7a** of **3a** and **5a**, the woodhousin analogue **8c**, the guaianolide **9**, and the secoheliangolide **11a**. The structures were determined by chemical transformations and spectroscopic means. Eucannabinolide (**13**) and bahia II (**14b**) were isolated from *Picradeniopsis oppositifolia* (Nutt.) Rydb. The stereochemistries of **14b** and its congeners bahia I and bahifolin were settled by X-ray analysis of bahia I (**14a**).

Ivangulin (**1b**),[2,3] eriolangin (**2a**),[4] and eriolanin (**2b**)[4] are the only secoeudesmanolides so far found in nature.[5] We now report isolation and structure determination of the first known disecoeudesmanolides in the form of the glycosides **3a** and **5a** as well as discovery of their putative secoeudesmanolide precursor **7a** and the first secoheliangolide **11a**. The diseco compounds were found on reexamination of *Picradeniopsis woodhousei* (Gray) Rydb. [*Bahia woodhousei* (Gray) Gray] from Arizona[6,8] together with 5,7,4′-trihydroxy-3,6,3′-trimethoxyflavone (jaceidin) and the previously reported heliangolide woodhousin

(1) Supported in part by a grant from the U.S. Public Health Service (CA-13121) through the National Cancer Institute.

(2) Herz, W.; Sumi, Y.; Sudarsanam, V.; Raulais, D. *J. Org. Chem.* **1967**, *32*, 3658.

(3) The stereochemistry of ivangulin at C-4 was settled by total synthesis: Grieco, P. A.; Oguri, T.; Wang, C.-L.; Williams, E. *J. Org. Chem.* **1977**, *42*, 4113.

(4) Kupchan, S. M.; Baxter, R. L.; Chiang, C. K.; Gilmore, C. J.; Bryan, R. F. *J. Chem. Soc., Chem. Commun.* **1973**, 842. Bryan, R. F.; Gilmore, C. J. *Acta Crystallogr., Sect. B* **1975**, *B31*, 2213.

(5) Eriolangin and eriolanin were active against P-388 lymphocytic leukemia in the mouse.[4] Ivangulin exhibited no activity against L-1210 lymphocytic leukemia in the mouse in tests carried out under the auspices of the National Cancer Institute.

(6) Our plant material came from the location of our earlier collection[7] of *P. woodhousei*. It was labeled *Bahia neomexicana* but was identified as *P. woodhousei* by Professor L. C. Anderson.

(7) Herz, W.; Bhat, S. V. *J. Org. Chem.* **1972**, *37*, 1906.

(8) The ditypic genus *Picradeniopsis* was relegated to the allied genus *Bahia* by Ellison[9] but has since been resegregated in work that came to our attention after publication of ref 7.[10]

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