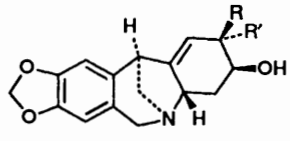
Radical-mediated Synthesis of the 5,11-Methanomorphanthridine Ring System: Formal Total Synthesis of Montanine-type *Amaryllidaceae* Alkaloids, (±)-Montanine, (±)-Coccinine and (±)-Pancracine

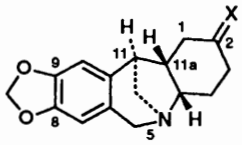
Miyuki Ishizaki, Ken-ichi Kurihara, Eiko Tanazawa and Osamu Hoshino*
Faculty of Pharmaceutical Sciences, Science University of Tokyo, 12, Ichigaya Funagawara-machi, Shinjuku-ku, Tokyo 162, Japan

Radical-mediated reaction of the phenyl sulfide **16** and the phenyl selenide **17** in boiling toluene or *o*-xylene containing AIBN gave, in moderate yields, the 5,11-methanomorphanthridine ring system **4**, which is a basic skeleton of montanine-type *Amaryllidaceae* alkaloids, and formal total synthesis of the title alkaloids **1**–**3** by conversion of 5,11-methanomorphanthridin-2-one **5**, derived from *N*-(4-oxocyclohex-2-enyl)-4-phenylthiotetrahydroisoquinoline **21** using this methodology, into the 2,3-benzylidenedioxy-5,11-methanomorphanthridine **31** is achieved.

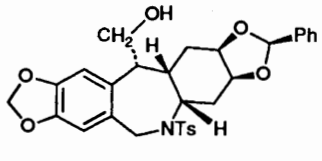
It has been widely known that free-radical reactions are useful methods in organic synthesis, since the discovery of the reaction of chemically generated radicals by D. H. R. Barton *et al.*[1] Although there are numerous reports[2] on the synthesis of natural products by means of radical reactions, to our knowledge no derivatives of the title ring system **4** have been synthesized by this method. In continuation of our study[3] on the synthesis of *Amaryllidaceae* alkaloids[4] we have recently reported the formation of the title ring system **4** by reductive cyclization[5] of 11-hydroxymethyl-5-tosylmorphanthridine using sodium bis-(2-methoxyethoxy)aluminium hydride, and a first total synthesis[6] of (±)-montanine **1**,[7] (±)-coccinine **2**,[7] and (±)-pancracine **3**[8] starting from the 11-hydroxymethyl-5-tosylmorphanthridine **6** using this method. Concurrently, Overman and Shim[9] have also succeeded in a total synthesis of (±)-pancracine **3** *via* aza-Cope rearrangement–Mannich cyclization.



Montanine **1** R = H, R′ = OMe
Coccinine **2** R = OMe, R′ = H
Pancracine **3** R = H, R′ = OH



4 X = H_2
5 X = O



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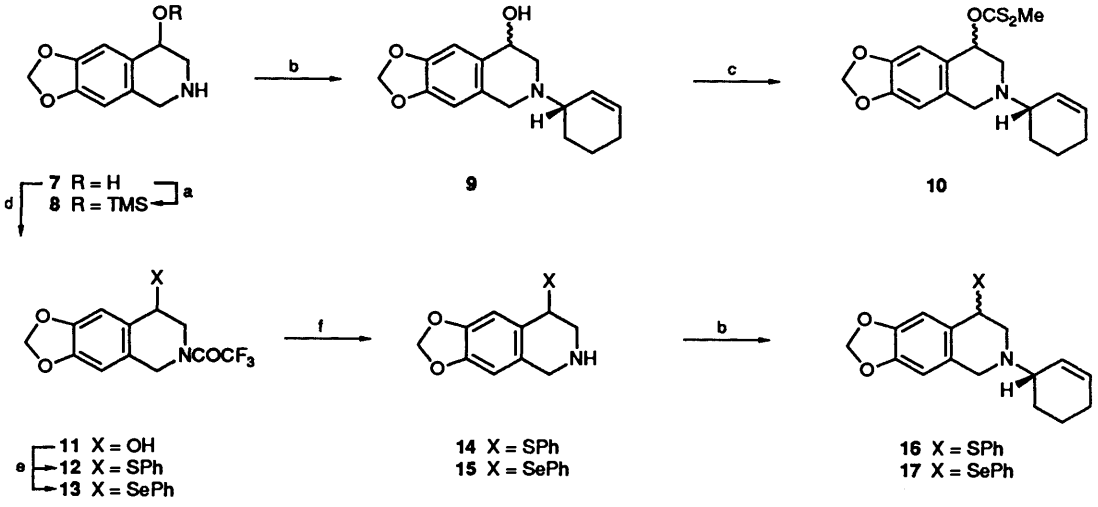
In order to explore the biological activity of 5,11-methanomorphanthridine derivatives, however, a more convenient method for the synthesis of the ring system was a necessary requirement. As mentioned above, in the execution of this project radical reactions seemed to be suitable for bond formation between 11- and 11a-positions in the ring system (*ex.* compounds **4** or **5**), because the radical precursors could be readily prepared and the reaction might proceed in a favoured 5-*exo*-trigonal process.[10] In this paper, we describe a convenient synthesis of the title ring system **4** by radical-mediated reaction of 4-[(methylthio)(thiocarbonyl)oxy]- (**10**), 4-phenylthio-(**16**) or 4-phenylseleno-(**17**) *N*-(cyclohex-2-enyl)-6,7-(methylenedioxy)-tetrahydroisoquinolines and formal total synthesis of (±)-montanine **1**, (±)-coccinine **2**, and (±)-pancracine **3** *via* 5,11-methanomorphanthridine-2-one **5** starting from *N*-(4-oxocyclohex-2-enyl)-4-(phenylthio)tetrahydroisoquinoline **21** by application of this methodology.

Results and Discussion

As radical precursors, *N*-(cyclohex-2-enyl)tetrahydroisoquinolines having halogeno, (alkylthio) (thiocarbonyl)oxy, arylthio, or arylseleno groups[11] were considered. However, since attempts to displace hydroxy groups with halogeno groups were unsuccessful, the xanthate **10**, phenyl sulfide **16** and phenyl selenide **17** were chosen as the precursors. Their preparation is as follows. 6,7-Methylenedioxy-4-trimethylsiloxytetrahydroisoquinoline **8**, obtained by trimethylsilylation of the tetrahydroisoquinolin-4-ol **7**,[12] reacted with 3-bromocyclohexene[13] under basic conditions to give, after acid treatment, the *N*-(cyclohex-2-enyl)tetrahydroisoquinolin-4-ol **9** in 79% yield. Treatment of compound **9** in the usual way afforded, in 56% yield, xanthates **10** as a 1:1 diastereoisomeric mixture, which was separated by column chromatography into its components **10a** and **10b**, although their stereochemistry was uncertain (Scheme 1).

As for the phenyl sulfide **16** and the phenyl selenide **17**, the *N*-(trifluoroacetyl)tetrahydroisoquinolin-4-ol **11**, prepared by trifluoroacetylation of compound **7**, was treated with PhSH or PhSeH in the presence of ZnI_2[14] in 1,2-dichloroethane at room temperature to give the corresponding phenyl sulfide **12** or phenyl selenide **13** in 98 or 79% yield, respectively. Hydrolysis of compound **12** or compound **13** with aq. K_2CO_3 in methanol gave the corresponding tetrahydroisoquinoline **14** or **15** in good yield, treatment of which with 3-bromocyclohexene in a similar manner to that described above afforded compound **16** (quantitative yield) or compound **17** (68%), each as an inseparable 1:1 mixture of diastereoisomers.

At first, attempted cyclization under usual conditions [Bu_3SnH, azoisobutylnitride (AIBN)] was performed using the diastereoisomeric mixture **10**, because the same radical intermediate could be generated from each diastereoisomer. Surprisingly, reaction of diastereoisomeric mixtures **10** with Bu_3SnH (1.2–2.0 mol equiv.) in the presence of AIBN (0.5 mol equiv.) in boiling benzene did not take place. In addition, a similar attempt in boiling toluene or *o*-xylene gave 5,11-methanomorphanthridine **4**[5b] in low yields, accompanied by the 1,2-dihydroisoquinoline **18**, which could be formed by Chugaev reaction, and recovered substrate **10**. However, the results were



Scheme 1 *Reagents:* (a) TMSCl, Et_3N, CH_2Cl_2; then water; (b) 3-bromocyclohexene, Et_3N, $CHCl_3$; (c) NaH, CS_2, MeI, THF; (d) $(CF_3CO)_2O$, K_2CO_3, $CHCl_3$; then water (e) PhSH or PhSeH, ZnI_2, CH_2ClCH_2Cl; (f) K_2CO_3, aq. MeOH

Table 1 Radical reaction of xanthates **10** with Bu_3SnH in the presence of Et_3B

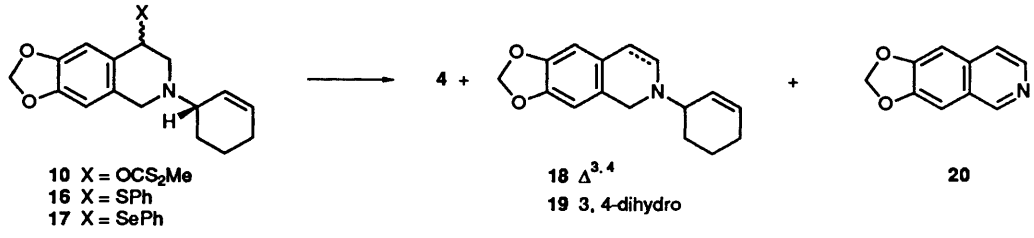
Entry[a]	Et_3B (mol equiv.)	Bu_3SnH (mol. equiv.)	Time (*t*/h)	Yield (%)[b] 4	19	20	Recovery of **10** (%)
1	1.2	1.2	9	12.7	7.8	19.5	19.5
2	2.0	1.2	9	14.3	19.7	11.7	14.7
3	1.2	2.0	4	15.7	57.3	5.6	6.2
4	2.0	2.0	4	17.8	42.2	12.2	0
5[c]	2.0	2.0	4	18.1	45.4	13.8	0
6[c]	2.0	2.0	4	17.6	44.7	13.5	0

[a] See Experimental section for the general procedure. [b] Isolated yield. [c] One of the diastereoisomers was used.

Table 2 Radical reaction of xanthates **10** with Bu_3SnH in the presence of Et_3B under various conditions

Entry[a]	Solvent	Concentration (mol dm^{-3})	Time (*t*/h)	Yield (%)[b] 4	19	20	Recovery of **10** (%)
1	benzene	0.04	9	4.0	40.6	0	10.0
2	benzene	0.01	11	9.3	37.2	10.0	6.9
3	toluene	0.08	4	7.1	62.9	0	0
4	toluene	0.04	4	13.5	44.9	13.9	5.7
5	toluene	0.02	4	17.8	42.2	12.2	0
6	toluene	0.01	9	18.5	33.9	9.0	1.7
7[c]	toluene	0.015	11	20.1	5.3	27.6	22.2
8	*o*-xylene	0.04	4	6.2	0	15.4	19.3

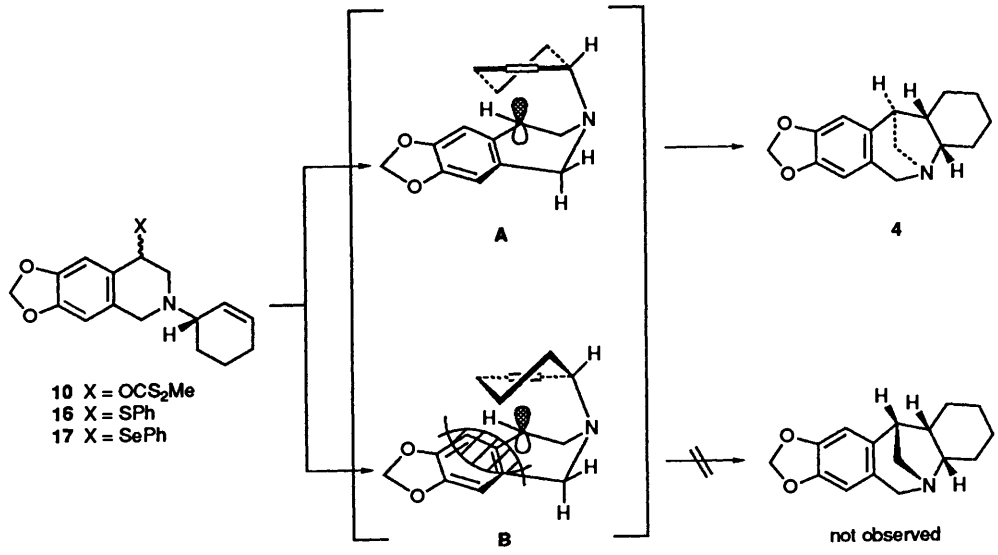
[a] See Experimental section for general procedure. [b] Isolated yield. [c] A syringe pump was used.



Scheme 2 *Reagents:* AIBN or Et_3B, Bu_3SnH

not reproducible and the yield of cyclized product **4** was less than 17%.

It is known that trialkylboranes[15] are suitable mediators for radical reaction, and Et_3B[16] was recently used as a radical initiator. Therefore, a similar reaction in the presence of Et_3B instead of AIBN under various conditions was carried out. Whereas the reaction did not proceed at low temperature, that at elevated temperature gave compound **4**. The results are given in Tables 1 and 2. As expected, diastereoisomers **10a** and **10b** gave similar results (Table 1, entries 5 and 6) to those obtained with diastereoisomeric mixtures **10** (entry 4), showing that the diastereoisomeric mixture could be used without separation. In these cases, formation of 6,7-methylenedioxyisoquinoline **20**[17] accompanied with the tetrahydroisoquinoline **19** and substrate



Scheme 3

Table 3 Radical reaction of the phenyl sulfide **16** and the phenyl selenide **17** with Bu_3SnH in the presence of AIBN

Entry [a]	Substrate	Solvent	Time (*t*/h)	Yield (%) [b] 4	19	20
1	**16**	benzene	2	16.5	67.6	*d*
2	**16**	toluene	2	22.1	53.2	*d*
3 [c]	**16**	toluene	8	45.5	26.7	7.6
4	**16**	*o*-xylene	2	46.2	44.0	trace
5 [c]	**16**	*o*-xylene	8	39.1	19.4	12.4
6	**17**	benzene	2	9.4	64.2	*d*
7	**17**	toluene	2	14.8	55.3	*d*
8 [c]	**17**	toluene	8	42.6	18.1	17.1
9	**17**	*o*-xylene	8	16.4	41.6	*d*

[a] See Experimental section for general procedure. [b] Isolated yield. [c] A syringe pump was used. [d] Not isolated.

Table 4 Radical reaction of the phenyl sulfide **21** with Bu_3SnH in the presence of AIBN under various conditions

Entry [a]	Solvent	Concentration (mol dm^{-3})	Time (*t*/h)	Yield (%) [b] 5	23
1 [c,d]	toluene	0.01	3	51.3	*e*
2 [d]	toluene	0.01	2	46.3	*e*
3	toluene	0.01	4	74.4	9.1
4 [d]	*o*-xylene	0.01	2	53.5	21.2
5	*o*-xylene	0.01	4	80.1	8.9
6	*o*-xylene	0.02	4	75.3	12.4
7	*o*-xylene	0.04	4	72.2	17.3
8	*o*-xylene	0.08	4	61.5	20.0
9	*o*-xylene	0.01	0.5	79.8	8.2
10 [f]	*o*-xylene	0.01	8	68.2	trace

[a] See Experimental section for general procedure. [b] Isolated yield. [c] 12.9% of substrate **21** was recovered. [d] A syringe pump was not used. [e] Not isolated. [f] 12.2% of substrate **21** was recovered.

10 was observed (Scheme 2). Although a 0.01–0.02 mol dm^{-3} concentration in toluene was found to be favourable (Table 2, entries 5–7), the yield of cyclized product **4** could not be improved. The structure of product **4** was identical in all respects with that of an authentic sample[5b] as shown by comparison of both its ^1H NMR and its IR spectrum.

Since xanthate **10** was found to be an unsuitable radical precursor even in the reaction at elevated temperature because of its low reactivity, the similar reaction of the phenyl sulfide **16** or the phenyl selenide **17** was examined. In contrast to xanthate **10**, reaction of substrate **16** or **17** under the usual conditions (Bu_3SnH, AIBN)* readily proceeded to give compound **4** in improved yields, although formation of the tetrahydroisoquinoline **19** could not be reduced. The results are summarized in Table 3. Interestingly, the higher the reaction temperature the higher the yield of product **4** (entries 1, 2 and 4). These findings suggested that the transition state in the radical cyclization of substrates **16** and **17** would require a high activation energy. The reaction in boiling *o*-xylene afforded compound **4** in 46.2% yield (entry 4). A dilution method using a syringe pump seemed to be effective both in giving compound **4** and in retarding formation of unwanted product **19** (entries 3, 5 and 8). Furthermore, the phenyl sulfide **16** was found to be a radical precursor superior to the phenyl selenide **17**, since the latter was slightly unstable. It is noteworthy that the radical reaction proceeded at elevated temperature[18] to give compound **4** in acceptable yields.

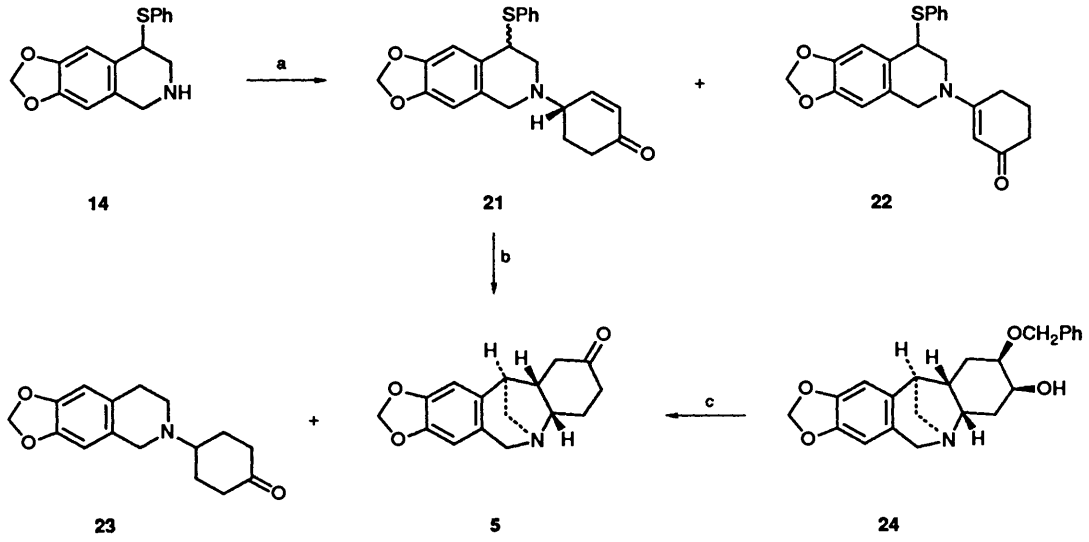
Stereoselective formation of one isomer **4** from a diastereoisomeric mixture could be interpreted by assuming steric repulsion between the tetrahydroisoquinoline ring and the cyclohexenyl group in benzylic radical **A** or **B** in the transition state of the radical cyclization, in which benzylic radical **A** is preferable to the radical **B** as depicted in Scheme 3.

Therefore, the 5,11-methanomorphanthridine **4** was prepared in moderate yields by radical-mediated cyclization of the phenyl sulfide **16** and the phenyl selenide **17**.

This methodology appeared to be readily applicable to the preparation of the 5,11-methanomorphanthridin-2-one **5**, which could be converted into 2,3-benzylidenedioxy-5,11-methanomorphanthridine **31**, previously synthesized as a key compound for the total synthesis[6] of (±)-montanine **1**, (±)-coccinine **2**, and (±)-pancracine **3**.

As a radical precursor for this route, the *N*-(4-oxocyclohex-2-enyl)-4-(phenylthio)tetrahydroisoquinoline **21** was prepared by heating a mixture of compound **14**, 4-bromocyclohex-2-enone[19] and Et_3N in acetonitrile–tetrachloromethane containing Et_4NI. In this case, an inseparable 1:1 mixture of diastereoisomers **21** and a regioisomer **22** were obtained in 55.8 and 11.7% yield, respectively.

* Use of Ph_3SnH–AIBN in place of Bu_3SnH–AIBN in boiling toluene (0.01 mol dm^{-3}) gave unsatisfactory results (**4**: 6.1% and **19**: 81.2%).



Scheme 4 *Reagents:* (a) 4-Bromocyclohex-2-enone, Et_3N, Et_4NI, MeCN, CCl_4; (b) Bu_3SnH, AIBN; (c) MsCl, Et_3N, $CHCl_3$; then H_2, 2% $PdCl_2$, charcoal, MeOH; then DBU, PhMe

Contrary to our expectations, reaction of sulfide **21** with Bu_3SnH (2.0 mol equiv.) in boiling toluene (0.01 mol dm^{-3}) containing AIBN (0.2 mol equiv.) did not occur. After several attempts, the reaction was found to require 4.0 mol equiv. of Bu_3SnH and 0.4 mol equiv. of AIBN, with which the dilution method using *o*-xylene as solvent was likewise effective. The results are shown in Table 4.

Interestingly, in these cases the tetrahydroisoquinoline **23**, which could be formed by conjugated reduction[20] of the α,β-unsaturated carbonyl group, was obtained (Scheme 4). Although prolonged reaction times did not afford compound **23**, the reaction was incomplete (entry 10). The analogous reaction of compound **21** in higher concentration using *o*-xylene, however, decreased the yield of compound **5** and increased formation of uncyclized product **23** (entries 6–8). The findings that the yield of compound **5** in the present reaction was better than that of compound **4** can be attributed to the enhanced reactivity of radical precursor **21** bearing an electron-deficient olefin[21] such as an α,β-unsaturated carbonyl moiety. The structure of product **5** was confirmed by comparison of the spectral data (^1H NMR, IR) with those of an authentic sample derived from **24**[6] in 3 steps (overall 63.5% yield) (see Experimental section).

With 5,11-methanomorphanthridin-2-one **5** in hand, we turned our attention to 2,3-benzylidenedioxy-5,11-methanomorphanthridine **31**[6] derived from compound **5**, completing a formal total synthesis of the title alkaloids **1**–**3**. To this end, conversion of ketone **5** into intermediate **28** *via* mesate **26** or **27** was carried out. Reduction ($NaBH_4$)* of ketone **5** gave an inseparable diastereoisomeric mixture of alcohols **25** in quantitative yield. Unexpectedly, dehydroxylation ($POCl_3$–pyridine) or Chugaev reaction (*via* xanthate) of substrate **25** failed. However, the alcohol **25** was converted in the usual manner to a mesyl derivative, which was readily separated into its constituents **26** and **27** in 47 and 49% yield, respectively (Scheme 5). Their stereochemistry was confirmed by conversion of compound **24**[6] into the mesate **26** in 4 steps[22] (see Experimental section).

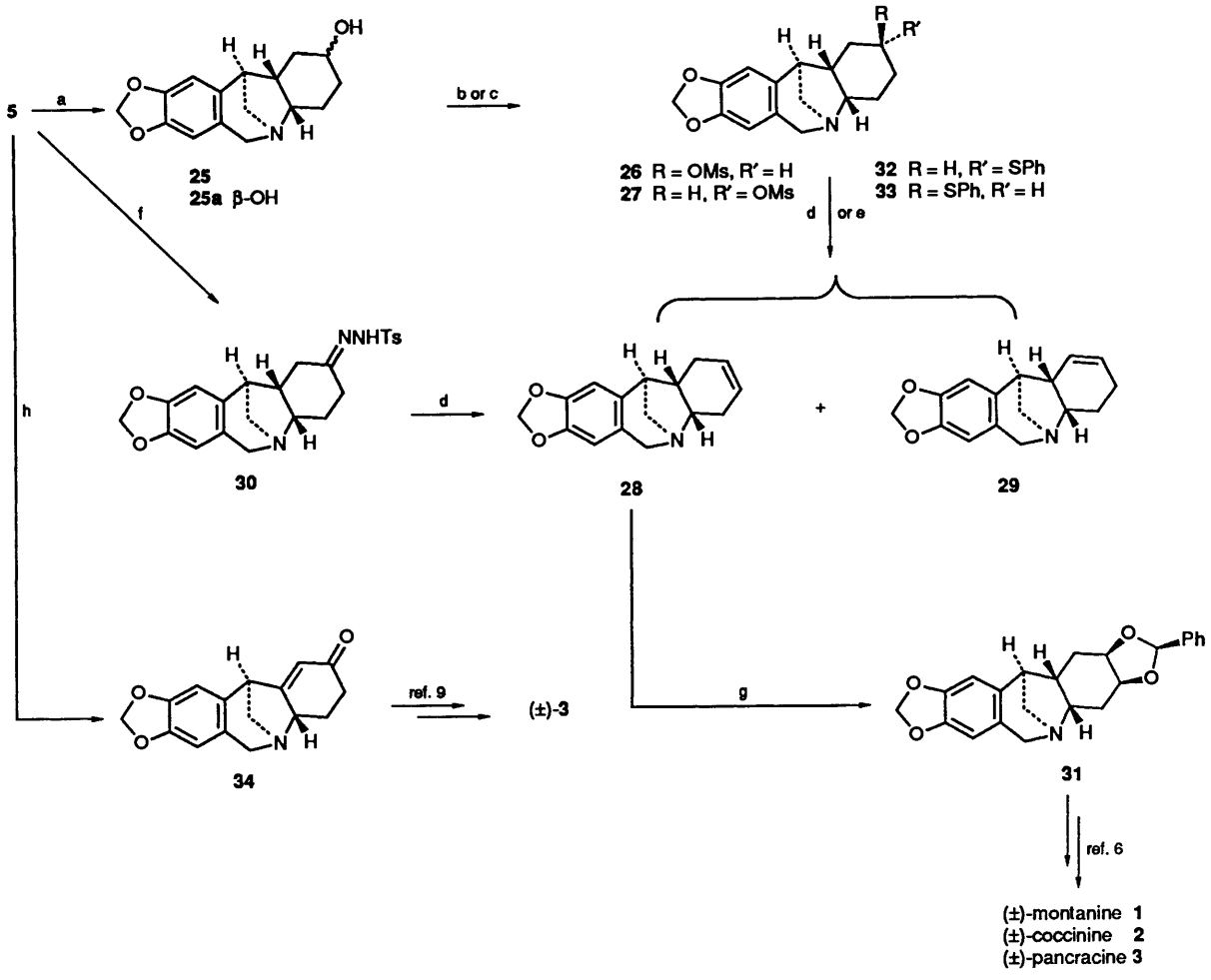
Based on an inspection of Dreiding models, dehydromesylation of compound **26** under basic conditions was anticipated to produce more predominantly the desired olefin **28** compared with **27** because of the former having the sterically less hindered proton at the 4-position as compared with the latter. With this in mind, reaction of mesyl ester **26** with Bu^tOK in dimethyl sulfoxide (DMSO) at room temperature was performed to give, after purification, intermediates **28** and **29** in 42 and 40% yield respectively, whereas that with 1,8-diazabicyclo[5.4.0]undec-7-ene (DBU) in boiling toluene gave compounds **28** and **29** in 13 and 39% yield. Structures of compounds **28** and **29** were deduced on the basis of their ^1H NMR spectra, showing that 1- and 4-protons (δ 1.56–2.60) for the former **28** resonate at lower field than the 3- and 4-protons (δ 1.36–2.20) for the latter **29**. This assumption was supported by the conversion of the alkene **28** into compound **31** as described below. On the other hand, unfortunately, similar reaction of the 2α-mesate **27** furnished, in 89% yield, the undesired regioisomer **29** as the sole product. The reason why only compound **29** was formed is unknown.

Since reaction of the mesyl esters **26** and **27** resulted in predominant formation of the undesired olefin **29**, *syn* elimination of sulfides **32** and **33** was explored. Reaction of alcohols **25** with diphenyl disulfide and Bu_3P in refluxing 1,2-dimethoxyethane (DME)[23] afforded 2α- and 2β-phenyl sulfides (**32** and **33**) in 46.4 and 49.5% yield, respectively. Stereochemistry of the α-product **32** was confirmed by comparison of its ^1H NMR spectrum with that of the 2α-sulfide derived from the 2β-alcohol **25a** in a similar manner. Conversion of sulfides **32** and **33** into olefin **28** or **29** was carried out as follows. Oxidation of the alcohol **32** with $NaIO_4$ in methanol afforded, in 95.2% yield, a 1.3:1 diastereoisomeric mixture of sulfoxides, which was heated in toluene to give olefins **28** and **29** in 48.7 and 40.8% yield. Similar reaction of sulfide **33** gave a 1.2:1 diastereoisomeric mixture of sulfoxides, heating of which in toluene produced olefins **28** and **29** in 41.6 and 51.3% yield, respectively. Although the reaction took place as expected, the desired olefin **28** could not be obtained preferentially. This result might be due to the diastereoisomeric mixture of sulfoxides.‡

In order to improve the yield of olefin **28**, an alternative route was examined. Although conversion of *p*-tosylhydrazone **30** into olefin **28** was attempted under various basic conditions[24] [BuLi, Bu^sLi, Bu^tLi or lithium diisopropylamide (LDA)], the reaction did not occur. However, treatment of

* Reduction of compound **5** with diisobutylaluminium hydride or BH_3·THF gave a ~1:1 diastereoisomeric mixture of alcohols **25** in moderate yield.

‡ *syn* Elimination of 8,9-methylenedioxy-2-phenylseleno-5,11-methanomorphanthridines was also unfruitful.



Scheme 5 *Reagents and conditions:* (a) $NaBH_4$, MeOH; (b) MsCl, Et_3N, $CHCl_3$; (c) $(PhS)_2$, Bu_3P, DME; (d) Bu^{t}OK, DMSO; (e) $NaIO_4$; aq. MeOH; then PhMe, heat; (f) $TsNHNH_2$, MeOH; (g) OsO_4 (cat.), NMNO; then $PhCH(OMe)_2$, *p*-$TsOH{\cdot}H_2O$, $CHCl_3$; (h) DDQ, 1,4-dioxane

compound **30** with Bu^{t}OK in DMSO at 100 °C gave olefins **28** and **29** in 34 and 27% yield, respectively, although stereoselectivity in the reaction was again poor.

Finally, since olefin **28** was obtained in moderate yields, vicinal dihydroxylation of compound **28** by oxidation with OsO_4 in the presence of *N*-methylmorpholine *N*-oxide[25] (NMNO), followed by benzylidenation in the usual manner[6] afforded compound **31** in 75% overall yield, ^1H NMR and IR spectra of which were identical with those of an authentic sample.[6]

In conclusion, the present radical reaction, which readily proceeded at elevated temperature, was found to be the third method for synthesis of the 5,11-methanomorphanthridine ring system, and a formal total synthesis* of montanine-type *Amaryllidaceae* alkaloids **1**–**3** was accomplished through sulfide **21** by application of this methodology (see Scheme 5).

Experimental

M.p.s were measured on Büchi or Yanagimoto (hot plate) melting-point apparatus and are uncorrected. IR spectra were performed with a Hitachi 260-10 spectrometer and ^1H NMR spectra were taken with a JEOL JMX-FX 100 (100 MHz) spectrometer using tetramethylsilane as internal standard. *J*-Values are given in Hz. Mass spectra were measured on a Hitachi M-80 or a JEOL JMS D-300 spectrometer. Preparative TLC (PLC) was run on Merck 5744 or Merck 7730 plates (Kieselgel).

6,7-*Methylenedioxy*-4-*trimethylsiloxy*-1,2,3,4-*tetrahydroisoquinoline* **8**.—To a stirred solution of the tetrahydroisoquinolin-4-ol **7**[12] (1.0027 g, 5.2 mmol) and Et_3N (1.31 g, 12.9 mmol) in tetrahydrofuran (THF) (50 cm^3) was added dropwise at room temperature chlorotrimethylsilane (TMSCl) (1.5 cm^3, 11.7 mmol). After 0.5 h, the mixture was filtered through Celite 545. The filtrate was evaporated under reduced pressure to give an oily residue, which was stirred at room temperature in a mixture of dichloromethane (20 cm^3) and water (10 cm^3) for 0.5 h. The organic phase was separated, dried (Na_2SO_4), and evaporated under reduced pressure to give the title compound **8** (1.374 g, 99.4%) as an oil; $\delta_H(CDCl_3)$ 6.70 and 6.44 (each 1 H, s, 2 × ArH) 5.88 (2 H, s, OCH_2O), 4.52 (1 H, t, *J* 4, 4-H), 3.86 (2 H, s, 1-H_2), 3.04 (2 H, d, *J* 4, 3-H_2), 2.20 (1 H, s, NH) and 0.20 (9 H, s, 3 × Me); $\nu_{max}(CHCl_3)/cm^{-1}$ 1480; *m/z* 265 (M^+) (Found: M^+, 265.1128. Calc. for $C_{13}H_{19}NO_3Si$: *M*, 265.1133).

N-(*Cyclohex*-2-*enyl*)-6,7-*methylenedioxy*-1,2,3,4-*tetrahydroisoquinolin*-4-*ol* **9**.—To an ice-cold, stirred solution of TMS ether **8** (3.0806 g, 11.6 mmol) and Et_3N (1.41 g, 13.9 mmol) in chloroform (100 cm^3) was added dropwise a solution of 3-bromocyclohexene [13] (2.05 g, 12.7 mmol) in chloroform (10 cm^3). The mixture was stirred at room temperature for 15 h and the solvent was removed under reduced pressure to give a

* Oxidation of compound **5** with 2,3-dichloro-5,6-dicyano-*p*-benzoquinone (DDQ)[26] in boiling dioxane gave a known enone **34** (m.p. 49–50 °C; 76%) (see Experimental section), which is converted already into (±)-pancracine **3**, although compound **34** was not identified directly with an authentic sample.[9]

residue, which was dissolved in 3 mol dm^{-3} HCl. The aqueous phase was washed with diethyl ether and was then made alkaline with 3 mol dm^{-3} NaOH. The aqueous phase was extracted with chloroform. The extract was washed with brine, dried (K_2CO_3), and evaporated under reduced pressure to give an oily residue. Chromatography of the oil on alumina [(1:1) ethyl acetate–hexane and then ethyl acetate only] afforded the alcohol **9** (2.511 g, 79.4%) as an oil: $\delta_H(CDCl_3)$ 6.80 and 6.46 (each 1 H, s, 2 × ArH), 5.88 (2 H, s, OCH_2O), 5.50–5.98 (2 H, m, CH=CH), 4.32–4.50 (1 H, m, 4-H), 3.67 and 3.62 (each 1 H, s, 1-H_2), 3.24–3.48 (1 H, m, NCH), 2.52–3.12 (4 H, m, 3-H_2 and CH_2CH=) and 1.40–2.12 (4 H, m, CH_2CH_2); $\nu_{max}(CHCl_3)/cm^{-1}$ 3200–3625; *m/z* 273 (M^+) (Found: M^+ 273.1362. Calc. for $C_{16}H_{19}NO_3$: *M*, 273.1364).

S-*Methyl* O-[N(*Cyclohex*-2-*enyl*)-6,7-*methylenedioxy*-1,2,3,-4-*tetrahydroisoquinolin*-4-*yl*] *Dithiocarbonate* **10**.—To a stirred suspension of NaH (97 mg, 2.4 mmol) in THF (1 cm^3) was added dropwise a solution of the alcohol **9** (550 mg, 2 mmol) in CS_2 (2.5 cm^3) under argon. The mixture was refluxed for 0.5 h before being cooled to room temperature, MeI (0.18 cm^3, 2.9 mmol) was added, and the mixture was refluxed for 10 min. After the reaction was quenched with water, the product was taken up in chloroform. The extract was washed with brine, dried (K_2CO_3), and evaporated under reduced pressure to give an oily residue. Chromatography of this oil on silica gel [(1:5) hexane–chloroform and then chloroform only] yielded a mixture of diastereoisomers **10** (407 mg, 55.7%) as an oil; $\delta_H(CDCl_3)$ 6.76 and 6.44 (each 1 H, s, 2 × ArH), 5.88 (2 H, s, OCH_2O), 5.50–5.96 (2 H, m, CH=CH), 4.97 (1 H, t, *J* 3, 4-H), 3.72 and 3.69 (each 1 H, s, 1-H_2), 3.40 (1 H, br s, $w_{\frac{1}{2}}$ 14.3, NCH), 2.78–3.18 (2 H, m, 3-H_2), 2.44 (3 H, s, SMe) and 1.36–2.12 (6 H, m, =CHCH_2CH_2CH_2); $\nu_{max}(CHCl_3)/cm^{-1}$ 1625 and 1480; *m/z* 363 (M^+) (Found: M^+, 363.0947. Calc. for $C_{18}H_{21}NO_3S_2$: *M*, 363.0961).

A mixture of diastereoisomers **10** was separated by chromatography on silica gel with the same eluent to give components **10a** and **10b**, each as an oil, although stereochemistry was not characterized.

Compound **10a**: $\delta_H(CDCl_3)$ 6.76 and 6.44 (each 1 H, s, 2 × ArH), 5.88 (2 H, s, OCH_2O), 5.50–5.96 (2 H, m, CH=CH), 4.97 (1 H, t, *J* 3, 4-H), 3.72 (2 H, s, 1-H_2), 3.40 (1 H, br s, $w_{\frac{1}{2}}$ 14.3, NCH), 3.10 and 2.89 (each 1 H, dd, *J* 3 and 13, 3-H_2), 2.44 (3 H, s, SMe) and 1.36–2.11 (6 H, m, =CHCH_2CH_2CH_2); $\nu_{max}(CHCl_3)/cm^{-1}$ 1625 and 1480; *m/z* 363 (M^+) (Found: M^+, 363.0955. Calc. for $C_{18}H_{21}NO_3S_2$: *M*, 363.0961). Compound **10b**: $\delta_H(CDCl_3)$ 6.76 and 6.44 (each 1 H, s, 2 × ArH), 5.88 (2 H, s, OCH_2O), 5.52–5.96 (2 H, m, CH=CH), 4.97 (1 H, t, *J* 3, 4-H), 3.69 (2 H, s, 1-H_2), 3.36 (1 H, br s, $w_{\frac{1}{2}}$ 14.3, NCH), 3.04 (2 H, d, *J* 3, 3-H_2), 2.44 (3 H, s, SMe) and 1.40–2.12 (6 H, m, =CHCH_2CH_2CH_2); $\nu_{max}(CHCl_3)/cm^{-1}$ 1625 and 1480; *m/z* (M^+) (Found: M^+, 363.0945).

6,7-*Methylenedioxy*-N-*trifluoroacetyl*-1,2,3,4-*tetrahydroisoquinolin*-4-*ol* **11**.—To a stirred suspension of amino alcohol **7** (7.66 g, 30.7 mmol) and K_2CO_3 (18.93 g, 137 mmol) in chloroform (300 cm^3) was added dropwise at room temperature trifluoroacetic anhydride (15 cm^3, 106 mmol). After 0.5 h, water (150 cm^3) was added and the mixture was stirred for an additional 2 h. The organic phase was then separated and the aqueous phase was re-extracted with chloroform. The combined extracts were washed successively with 1 mol dm^{-3} HCl and brine, dried (Na_2SO_4), and removed under reduced pressure to give a solid. Chromatography of this solid on silica gel [(1:10) hexane–chloroform] afforded the amide **11** (9.04 g, 78.8%), m.p. 99–100 °C (from chloroform–hexane); $\delta_H(CDCl_3)$ 6.86 (1 H, s, ArH), 6.54 and 6.57 (each 0.5 H, s, ArH), 5.94 (2 H, s, OCH_2O), 4.03–5.00 (3 H, m, 1-H_2 and 4-H) and 3.48–4.03 (2 H, m, 3-H_2); $\nu_{max}(CHCl_3)/cm^{-1}$ 3200–3625 and 1680; *m/z* 289 (M^+) (Found: C, 49.9; H, 3.6; N, 4.9. Calc. for $C_{12}H_{10}F_3NO_4$: C, 49.84; H, 3.49; N, 4.84%).

N-(*Cyclohex*-2-*enyl*)-6,7-*methylenedioxy*-4-*phenylthio*-1,2,3,4-*tetrahydroisoquinoline* **16** *and* N-(*Cyclohex*-2-*enyl*)-6,7-*methylenedioxy*-4-*phenylseleno*-1,2,3,4-*tetrahydroisoquinoline*-**17**.—Compound **16**. A mixture of the trifluoroacetamide **11** (2.0233 g, 7.0 mmol), anhydrous ZnI_2 [14] (1.1758 g, 3.68 mmol), and PhSH (0.86 cm^3, 8.38 mol) in 1,2-dichloroethane (50 cm^3) was stirred at room temperature for 1 h. After addition of 3 mol dm^{-3} NaOH, the organic phase was separated and the aqueous phase was extracted with chloroform. The combined extracts were washed with brine, dried (Na_2SO_4), and removed under reduced pressure to give 6,7-methylenedioxy-4-phenylthio-*N*-trifluoroacetyl-1,2,3,4-tetrahydroisoquinoline **12** (2.606 g, 97.7%) as a 1:1 mixture of diastereoisomers, m.p. 123–123.5 °C (from ethyl acetate–hexane); $\delta_H(CDCl_3)$ 7.42–7.64 (1 H, m, ArH), 7.16–7.42 (4 H, m, 4 × ArH), 6.92 and 6.88 (each 0.5 H, s, ArH), 6.56 and 6.52 (each 0.5 H, s, ArH), 5.94 (2 H, s, OCH_2O) 4.80 and 4.36 (each 0.5 H, d, *J* 16, 1-H), 4.59 (1 H, s, 1-H), 4.22–4.52 (1 H, m, 4-H), 3.90 (1 H, d, *J* 4, 3-H) and 3.35–3.64 (1 H, m, 3-H); $\nu_{max}(CHCl_3)/cm^{-1}$ 1675; *m/z* 381 (M^+) (Found: C, 56.6; H, 3.9; N, 3.5. Calc. for $C_{18}H_{14}F_3NO_3S$: C, 56.69; H, 3.70; N, 3.67%).

A mixture of sulfide **13** (1.9046 g, 5.0 mmol) and 5% aq. K_2CO_3 (20 cm^3) in methanol (50 cm^3) was refluxed for 0.5 h. After removal of methanol under reduced pressure, the mixture was extracted with chloroform. The extract was washed with brine, dried (K_2CO_3), and evaporated under reduced pressure to give 6,7-methylenedioxy-4-phenylthio-1,2,3,4-tetrahydroisoquinoline **14** (1.4211 g, 99.7%), m.p. 67 °C (from diethyl ether–hexane); $\delta_H(CDCl_3)$ 7.12–7.52 (5 H, m, Ph), 6.84 and 6.47 (each 1 H, s, 2 × ArH), 5.88 (2 H, s, OCH_2O), 4.24 (1 H, t, *J* 3, 4-H), 3.88 (2 H, s, 1-H_2), 3.10 and 3.20 (each 1 H, dd, *J* 3 and 13.2, 3-H_2) and 2.17 (1 H, s, NH); $\nu_{max}(CHCl_3)/cm^{-1}$ 3280; *m/z* 285 (M^+) (Found: M^+, 285.0825. Calc. for $C_{16}H_{15}NO_2S$: *M*, 285.0822).

To a stirred solution of secondary amine **14** (854.5 mg, 3.0 mmol), Et_3N (793.9 mg, 7.85 mmol) and 4-(dimethylamino)-pyridine (DMAP) (221.5 mg, 1.97 mmol) in chloroform (30 cm^3) was added at room temperature a solution of 3-bromocyclohexene (840.1 mg, 5.22 mmol) in chloroform (1 cm^3). After 26 h, the mixture was washed successively with saturated aq. $NaHCO_3$ and brine, dried (K_2CO_3), and evaporated under reduced pressure to give an oily residue. Chromatography of this oil on silica gel (chloroform) afforded a mixture of diastereoisomers **16** (1.0918 g, 99.8%) as an oil: $\delta_H(CDCl_3)$ 7.36–7.55 (2 H, m, 2 × ArH), 7.12–7.35 (3 H, m, 3 × ArH), 6.80 and 6.89 (each 0.5 H, s, 5-H), 6.45 (1 H, s, 8-H), 5.86 (2 H, s, OCH_2O), 5.52–5.92 (2 H, m, CH=CH), 4.24–4.44 (1 H, m, 4-H), 3.72 (2 H, br s, 1-H_2), 3.40 (1 H, br s, $w_{\frac{1}{2}}$ 18.9, NCH), 2.70–3.14 (2 H, m, 3-H_2) and 1.36–2.08 (6 H, m, =CHCH_2CH_2CH_2); $\nu_{max}(CHCl_3)/cm^{-1}$ 1480; *m/z* 365 (M^+); (Found: M^+, 365.1436. Calc. for $C_{22}H_{23}NO_2S$: *M*, 365.1447). Further separation of diastereoisomers was not attempted.

Compound **17**. A mixture of trifluoroacetamide **11** (289.2 mg, 1.0 mmol), anhydrous ZnI_2 (164.7 mg, 0.5 mmol), and PhSeH (130 × 10^{-3} cm^3, 1.2 mmol) in 1,2-dichloroethane (5 cm^3) was stirred at room temperature for 0.5 h. Similar work-up as described for sulfide **12** gave an oily residue. Chromatography of this oil on silica gel [(1:1) chloroform–hexane and then chloroform only] produced 6,7-methylenedioxy-4-phenylseleno-N-trifluoroacetyl-1,2,3,4-tetrahydroisoquinoline **13** (336.1 mg, 78.5%), m.p. 130–130.5 °C (from chloroform–hexane); $\delta_H(CDCl_3)$ 7.58–7.74 (1 H, m, ArH), 7.20–7.52 (4 H, m, 4 × ArH), 6.84 and 6.80 (each 0.5 H, s, ArH), 6.50 and 6.49 (each 0.5 H, s, ArH), 5.94 (2 H, s, OCH_2O), 4.80 and

4.51 (each 0.5 H, d, *J* 16, 1-H), 4.50 (1 H, s, 1-H), 4.36–4.68 (1 H, m, 3-H), 3.99 (1 H, t, *J* 5, 4-H) and 3.32–3.64 (1 H, m, 3-H); $\nu_{max}(CHCl_3)/cm^{-1}$ 1680; *m/z* 428 (M^+) (Found: C, 50.4; H, 3.5; N, 3.0. Calc. for $C_{18}H_{14}F_3NO_3Se$: C, 50.48; H, 3.30; N, 3.27%).

A mixture of *selenide* **13** (852.2 mg, 2.0 mmol) and 5% aq. K_2CO_3 (10 cm^3) in methanol (25 cm^3) was refluxed for 15 min. Similar work-up as described for sulfide **14** gave 6,7-methylenedioxy-4-phenylseleno-1,2,3,4-tetrahydroisoquinoline **15** (649.5 mg, 97.8%), m.p. 69.5 °C (from diethyl ether–hexane); $\delta_H(CDCl_3)$ 7.44–7.68 (2 H, m, 2 × ArH), 7.12–7.38 (3 H, m 3 × ArH), 6.80 and 6.41 (each 1 H, s, 2 × ArH), 5.87 (2 H, s, OCH_2O), 4.46 (1 H, t, *J* 2, 4-H), 3.90 (2 H, s, 1-H_2) 3.16 (2 H, d, *J* 2, 3-H_2) and 2.04 (1 H, br s $w_{\frac{1}{2}}$ 15.7, NH); $\nu_{max}(CHCl_3)/cm^{-1}$ 3300; *m/z* 333 (M^+) (Found: M^+ 333.0245. Calc. for $C_{16}H_{15}NO_2Se$: *M*, 333.0266).

To a stirred solution of secondary amine **15** (649.5 mg, 1.96 mmol), Et_3N(509.0 mg, 5.03 mmol) and DMAP (145.6 mg, 1.99 mmol) in chloroform (30 cm^3) was added at room temperature a solution of 3-bromocyclohexene (606.4 mg, 3.77 mmol) in chloroform (1 cm^3). After 26 h, similar work-up as described for sulfide **16** produced an oily residue. Chromatography of this oil on silica gel (chloroform) gave a mixture of diastereoisomers **17** (555.7 mg, 68.9%) as an oil; $\delta_H(CDCl_3)$ 7.44–7.66 (2 H, m, 2 × ArH), 7.12–7.34 (3 H, m, 3 × ArH), 6.72 and 6.60 (each 0.5 H, s, 5-H), 6.43 (1 H, s, 8-H), 5.85 (2 H, s, OCH_2O), 5.56–5.94 (2 H, m, CH=CH), 4.36–4.52 (1 H, m, 4-H), 3.76 and 3.72 (each 1 H, s, 1-H_2), 3.40 (1 H, br s, $w_{\frac{1}{2}}$ 18.9, NCH), 2.76–3.26 (2 H, m, 3-H_2) and 1.36–2.08 (6 H, m, =CH$CH_2CH_2CH_2$); $\nu_{max}(CHCl_3)/cm^{-1}$ 1480; *m/z* 413 (M^+) (Found: M^+, 413.0894. Calc. for $C_{22}H_{23}NO_2Se$: *M*, 413.0893). Further separation of diastereoisomers was not attempted.

General Procedure for Radical Reaction of Substrate **10**, **16** *or* **17** (*Tables* 1 *and* 2).—(a) *In the presence of* Et_3B. A mixture of radical precursor **10** (0.28 mmol), Et_3B (1.2–2.0 mol equiv.; 1 mol dm^{-3} in hexane) and Bu_3SnH (1.2–2.0 mol equiv.) in an appropriate solvent was refluxed under argon. The solvent was then evaporated off under reduced pressure to leave a residue, which was dissolved in diethyl ether. The organic phase was re-extracted with 3 mol dm^{-3} HCl and the aq. phase was washed with diethyl ether and made to alkaline with 3 mol dm^{-3} NaOH. The product was taken up in chloroform. The organic extract was washed with brine, dried (K_2CO_3), and evaporated under reduced pressure to produce an oily residue, which was purified by PLC on silica gel plates with (1:30) and (1:10) methanol–chloroform as developing solvent to afford products **4**, **19** and **20**.

8,9-Methylenedioxy-5,11-methanomorphanthridine **4**: $\delta_H(CDCl_3)$ 6.46 (1 H, s, 7-H), 6.41 (1 H, s, 10-H), 5.84 (2 H, s, OCH_2O), 4.32 and 3.69 (each 1 H, d, *J* 17.1, 6-H_2), 3.12 (1 H, dd, *J* 2.8 and 12, 12-H), 2.86 (1 H, d, *J* 12, 12-H), 2.84–3.12 (1 H, m, 4a-H), 2.38 (1 H, d, *J* 2.8, 11-H), 2.06–2.38 (1 H, m, 11a-H) and 1.06–1.88 (8 H, m, 1-, 2-, 3- and 4-H_2); $\nu_{max}(CHCl_3)/cm^{-1}$ 3040, 1500, 1480 and 1340; *m/z* 257 (M^+) ^1H NMR and IR spectra of compound **4** were identical with those of an authentic sample.[5b]

N-(Cyclohex-2-enyl)-6,7-methylenedioxy-1,2,3,4-tetrahydroisoquinoline **19** was an oil; $\delta_H(CDCl_3)$ 6.52 and 6.47 (each 1 H, s, 2 × ArH), 5.81 (2 H, s, OCH_2O), 5.56–5.98 (2 H, m, CH=CH), 3.68 (2 H, s, 1-H_2), 3.40 (1 H, br s, $w_{\frac{1}{2}}$ 12.9, NCH), 2.78 (4 H, s, 3- and 4-H_2) and 1.40–2.12 (6 H, m, =CH$CH_2CH_2CH_2$); $\nu_{max}(CHCl_3)/cm^{-1}$ 1480; *m/z* 257 (M^+) (Found: M^+, 257.1413. Calc. for $C_{16}H_{19}NO_2$: *M*, 257.1414).

6,7-Methylenedioxyisoquinoline **20**; m.p. 119–120 °C (from chloroform–hexane) (lit.[17] 119–120 °C); $\delta_H(CDCl_3)$ 8.96 (1 H, s, 1-H), 8.34 and 7.45 (each 1 H, d, *J* 6, 3- and 4-H), 7.16 and 7.04 (each 1 H, s, 8- and 5-H) and 6.08 (2 H, s, OCH_2O); $\nu_{max}(CHCl_3)/cm^{-1}$ 1600; *m/z* 173 (M^+) (Found: C, 69.1; H, 3.8; N, 8.1. Calc. for $C_{10}H_7NO_2$: C, 69.36; H, 4.07; N, 8.09%).

(b) *Without a syringe pump in the presence of AIBN*. A mixture of radical precursor **16** or **17** (0.28 mmol), AIBN (0.2 mol equiv.) and Bu_3SnH (2.0 mol equiv.) in an appropriate solvent was refluxed under argon. Similar work-up as described above afforded compounds **4**, **19** and **20**. The results are shown in Table 3.

(c) *With a syringe pump in the presence of AIBN*.—A solution of AIBN (0.2 mol equiv.) and Bu_3SnH (2 mol equiv.) in an appropriate solvent was added dropwise to a solution of radical precursor **16** or **17** (0.28 mmol) in the same solvent using a syringe pump over a period of 1 h except for entries 3, 5 and 8 (Table 3) (over a period of 7 h). After the addition was complete, the mixture was refluxed for an additional 1 h. Similar work-up as described above afforded compounds **4**, **19** and **20**. The results are shown in Table 3.

6,7-*Methylenedioxy*-N-(4-*oxocyclohex*-2-*enyl*)-4-*phenylthio*-1,2,3,4-*tetrahydroisoquinoline** **21** *and* 6,7-*Methylenedioxy*-N-(3-*oxocyclohex*-1-*enyl*)-4-*phenylthio*-1,2,3,4-*tetrahydroisoquinoline** **22**.—To a stirred suspension of compound **14** (2.8514 g, 10.0 mmol), Et_3N (3.56 g, 35.2 mmol) and Et_4NI (7.715 g, 30.0 mmol) in acetonitrile (60 cm^3) was added dropwise at room temperature a solution of 4-bromocyclohex-2-enone (30 mmol), freshly prepared from cyclohex-2-enone (2.89 g, 30 mmol), *N*-bromosuccinimide (5.34 g, 30 mmol) and benzoyl peroxide (37.4 mg, 0.15 mmol) in tetrachloromethane (40 cm^3) according to the reported method.[19] After the mixture had been refluxed for 3 h, 3 mol dm^{-3} NaOH was added to the ice-cooled mixture. The organic phase was separated and the aqueous phase was extracted with chloroform. The combined organic extracts were washed with brine, dried (K_2CO_3), and evaporated under reduced pressure to give an oily residue. Chromatography of this oil on silica gel [(1:3) ethyl acetate–hexane] produced compounds **21** (2.1144 g, 55.8%) and **22** (0.4430 g, 11.7%), each as an oil. For compound **21**: $\delta_H(CDCl_3)$ 7.16–7.52 (5 H, m, Ph), 6.99 (1 H, dt, *J* 2 and 10, NCHC*H*=CHCO), 6.88 and 6.79 (each 0.5 H, s, ArH), 6.46 (1 H, s, 8-H), 6.00 (1 H, dt, *J* 2.8 and 10, NCHCH=C*H*CO), 5.88 (2 H, s, OCH_2O), 4.37 (1 H, t, *J* 4, 4-H), 3.79 and 3.74 (each 1 H, s, 1-H_2), 3.54–3.88 (1 H, m, NCH), 2.84–3.02 (2 H, m, 3-H_2) and 1.68–2.60 (4 H, m, $COCH_2CH_2$); $\nu_{max}(CHCl_3)/cm^{-1}$ 1680; *m/z* 379 (M^+) (Found: M^+, 379.1240. Calc. for $C_{22}H_{21}NO_3S$: *M*, 379.1240). For compound **22**: $\delta_H(CDCl_3)$ 7.12–7.52 (5 H, m, Ph), 7.04 and 6.46 (each 1 H, s, 5- and 8-H), 5.99 (1 H, t, *J* 4.4, COCH=C), 5.89 (2 H, s, OCH_2O), 4.46 (1 H, dd, *J* 4.8 and 6.8, 4-H), 3.92 (2 H, s, 1-H_2), 3.52 (1 H, dd, *J* 4.8 and 12.4, 3-H), 3.24 (1 H, dd, *J* 6.8 and 12.4, 3-H), 2.20–2.58 (4 H, m, $COCH_2$ and =CHCH_2) and 1.76–2.08 (2 H, m, $CH_2CH_2CH_2$); $\nu_{max}(CHCl_3)/cm^{-1}$ 1675; *m/z* 379 (M^+) (Found: M^+ 379.1235).

General Procedure for Radical Reaction of Enone **21** (*Table* 4).—(a) *Without a syringe pump* (*entries* 1, 2 and 4). A stirred solution of the phenyl sulfide **21** (0.20 mmol), AIBN (0.08 mmol) and Bu_3SnH (0.8 mmol) in toluene or *o*-xylene was refluxed under argon. The solvent was then evaporated off under reduced pressure to leave a residue, which was dissolved in diethyl ether. The organic phase was re-extracted with 3 mol dm^{-3} HCl. The aqueous phase was washed with diethyl ether and made alkaline with 3 mol dm^{-3} NaOH. The product was taken up in chloroform. The organic extract was washed with brine, dried (K_2CO_3), and evaporated under reduced pressure to give an oily residue. PLC with (1:20) methanol–chloroform as a developing solvent afforded compounds **5** and **23**. The spectra of cyclised product **5** was identical with those of an authentic sample derived from compound **24** as described below.

* 4- (**21**) and 3-(6,7-methylenedioxy-4-phenylthio-1,2,3,4-tetrahydroquinolin-2-yl)cyclohex-2-enone (**22**).

Compound **23**: oil; $\delta_H(CDCl_3)$ 6.53 and 6.46 (each 1 H, s, 2 × ArH), 5.84 (2 H, s, OCH_2O), 3.68 (2 H, s, 1-H_2), 2.68–2.93 (1 H, m, NCH), 2.80 (4 H, s, 3- and 4-H_2), 2.28–2.58 (4 H, m, CH_2COCH_2) and 1.80–2.24 [4 H, m, $NCH(CH_2CH_2)_2CO$]; $\nu_{max}(CHCl_3)/cm^{-1}$ 1705; *m/z* 273 (M^+) (Found: M^+ 273.1368. Calc. for $C_{16}H_{19}NO_3$: *M*, 273.1366).

(b) *With a syringe pump.* (i) *Entries* 3, 5–10. To a 0.01 mol dm^{-3} solution of enone **21** (0.21 mmol) in toluene or *o*-xylene was added a mixture of Bu_3SnH (0.84 mmol) in the same solvent containing AIBN (0.084 mmol) over a period of 3 h and the whole was refluxed for 1 h. Similar work-up as described above gave compounds **5** and **23**.

(ii) *Preparative scale.* To a solution of compound **21** (3.58 g, 9.4 mmol) in *o*-xylene (370 cm^3) was added dropwise under reflux a solution of Bu_3SnH (10.9 g, 37.5 mmol) and AIBN (0.6170 g, 3.76 mmol) in *o*-xylene (100 cm^3) over a period of 1 h. After the addition was complete, the mixture was refluxed for an additional 1 h. Similar work-up as described above afforded compound **5** (1.9630 g, 76.7%), m.p. 126–127 °C, and compound **23** (0.2424 g, 9.4%), spectral data of which were identical with those of authentic samples obtained in method (a) above.

8,9-*Methylenedioxy*-5,11-*methanomorphanthridin*-2-*one* **5** *from* 2β-*Benzyloxy*-8,9-*methylenedioxy*-5,11-*methanomorphanthridin*-3β-*ol* **24**.—To an ice-cold, stirred solution of the alcohol **24** (1.5646 g, 4.13 mmol) and Et_3N (0.84 g, 8.3 mmol) in dichloromethane (20 cm^3) was added dropwise methanesulfonyl chloride (0.61 g, 8.0 mmol). After 15 min, the reaction was quenched with 3 mol dm^{-3} NaOH and the aqueous phase was extracted with chloroform. The organic extract was washed with brine, dried (K_2CO_3), and evaporated under reduced pressure to leave an oily residue. Chromatography of this oil on silica gel [(1:20) methanol–chloroform] afforded 2β-benzyloxy-8,9-methylenedioxy-3β-methylsulfonyloxy-5,11-methanomorphanthridine (1.6428 g, 87.0%), m.p. 164–164.5 °C (from ethyl acetate–hexane); $\delta_H(CDCl_3)$ 7.29 (5 H, s, Ph), 6.42 and 6.48 (each 1 H, s, 7- and 10-H), 5.86 (2 H, s, OCH_2O), 4.85 (1 H, dt, *J* 3.6 and 10, 3-H), 4.60 (2 H, s, $PhCH_2$), 4.22 and 3.72 (each 1 H, d, *J* 16, 6-H_2), 3.92 (1 H, q, *J* 3.6, 2-H), 3.20–3.48 (1 H, m, 4a-H), 3.11 (1 H, dd, *J* 2 and 10.9, 12–H), 2.99 (3 H, s, Me), 2.90 (1 H, d, *J* 10.9, 12-H), 2.59 (1 H, d, *J* 2, 11-H), 1.76–2.68 (4 H, m) and 1.24–1.64 (1 H, m) $\nu_{max}(CHCl_3)/cm^{-1}$ 1480; *m/z* 457 (M^+) (Found: C, 62.8; H, 6.0; N, 2.7. Calc. for $C_{24}H_{27}NO_6S$: C, 63.01; H, 5.95; N, 3.06%).

A suspension of the mesyl ester obtained above (456.6 mg, 1.0 mmol), charcoal (600 mg) and 2% aq. $PdCl_2$ (5 cm^3) in methanol (16 cm^3) was stirred under hydrogen at room temperature for 14 h. The mixture was then filtered and the filtrate was made alkaline with 3 mol dm^{-3} NaOH. The mixture was extracted with chloroform. The organic extract was washed with brine, dried (K_2CO_3), and evaporated under reduced pressure to give an oily residue, which was refluxed with 1,8-diazabicyclo[5.4.0]undec-7-ene (BDU) (151.7 mg, 1 mmol) in toluene (20 cm^3) for 3 h. After removal of the solvent under reduced pressure, chromatography of the residue on silica gel [(1:20) methanol–chloroform] afforded compound **5** (196.7 mg, 72.6%), m.p. 125 °C (from ethyl acetate–hexane); $\delta_H(CDCl_3)$ 6.47 and 6.44 (each 1 H, s, 2 × ArH), 5.86 (2 H, s, OCH_2O), 4.39 and 3.79 (each 1 H, d, *J* 17.1, 6-H_2), 3.32 (1 H, dd, *J* 2 and 12, 12-H), 3.22–3.48 (1 H, m, 4a-H), 3.12 (1 H, d, *J* 12, 12-H), 2.68 (1 H, d, *J* 2, 11-H) and 1.68–2.60 (7 H, m) $\nu_{max}(CHCl_3)/cm^{-1}$ 1705; *m/z* 271 (M^+) (Found: C, 70.6; H, 6.3; N, 5.0. Calc. for $C_{16}H_{17}NO_3$: C, 70.83; H, 6.32; N, 5.16%).

8,9-*Methylenedioxy*-2β- *and* -2α-*methylsulfonyloxy*-5,11-*methanomorphanthridine* **26** *and* **27**.—A solution of ketone **5** (200 mg, 0.738 mmol) and $NaBH_4$ (27.8 mg, 0.735 mmol) in methanol (5 cm^3) was stirred at 0 °C for 10 min. The reaction was quenched with water and the mixture was extracted with chloroform. The organic extract was washed with brine, dried (K_2CO_3), and evaporated under reduced pressure to give 5,11-methanomorphanthridin-2-ol **25** (201 mg, 99.8%) as a mixture of diastereoisomers, m.p. 181–183 °C (from ethyl acetate–hexane); $\delta_H(CDCl_3)$ 6.46 and 6.42 (each 1 H, s, 2 × ArH), 5.84 (2 H, s, OCH_2O), 4.00–4.21 (1 H, m, 2-H), 4.32, 4.27, 3.75 and 3.71 (each 0.5 H, d, *J* 17.1, 6-H_2), 2.80–3.29 (3 H, m, 4a-H and 12-H_2), 2.50–2.68 (1 H, m, 11-H) and 1.00–2.40 (7 H, m, 1-, 3- and 4-H_2 and 11a-H); $\nu_{max}(CHCl_3)/cm^{-1}$ 3200–3650; *m/z* 273 (M^+) (Found: M^+, 273.1360. Calc. for $C_{16}H_{19}NO_3$: *M*, 273.1366).

To an ice-cold, stirred solution of the alcohols **25** (201 mg, 0.738 mmol) and Et_3N (239.4 mg, 2.37 mmol) in chloroform (5 cm^3) was added dropwise methanesulfonyl chloride (178.2 mg, 1.56 mmol). After 15 min, similar work-up as described above left an oily residue. Chromatography of this residue on silica gel [(1:3) methanol–ethyl acetate and then (1:20) methanol–chloroform] afforded mesates **26** (120.4 mg, 46.6%) and **27** (125.4 mg, 48.5%). For compound **26**: m.p. 46–48 °C; $\delta_H(CDCl_3)$ 6.44 and 6.41 (each 1 H, s, 2 × ArH), 5.85 (2 H, s, OCH_2O), 4.78 (1 H, br s, $w_{\frac{1}{2}}$ 20, 2-H), 4.28 and 3.72 (each 1 H, d, *J* 17.1, 6-H_2), 3.18 (1 H, dd, *J* 2 and 12, 12-H), 3.00 (3 H, s, Me), 2.72–3.06 (2 H, m, 4a- and 12-H), 2.63 (1 H, d, *J* 2, 11-H) and 1.36–2.40 (7 H, m, 1-, 3- and 4-H_2 and 11a-H); $\nu_{max}(CHCl_3)/cm^{-1}$ 1480; *m/z* 351 (M^+) (Found: M^+ 351.1146. Calc. for $C_{17}H_{21}NO_5S$: *M*, 351.1139). For compound **27**: m.p. 50–51 °C; $\delta_H(CDCl_3)$ 6.48 and 6.43 (each 1 H, s, 2 × ArH), 5.85 (2 H, s, OCH_2O), 5.07 (1 H, br s, $w_{\frac{1}{2}}$ 20, 2-H), 4.31 and 3.76 (each 1 H, d, *J* 17.1, 6-H_2), 2.96 (3 H, s, Me), 2.84–3.36 (3 H, m, 4a- and 12-H_2), 2.56 (1 H, d, *J* 2, 11-H) and 1.10–2.32 (7 H, m, 1-, 3- and 4-H_2 and 11a-H); $\nu_{max}(CHCl_3)/cm^{-1}$ 1470; *m/z* 351 (M^+) (Found: M^+, 351.1129).

Alternative Synthesis of Mesate **26**.—A solution of 2β-benzyloxy-8,9-methylenedioxy-3β-methylsulfonyloxy-5,11-methanomorphanthridine (59.0 mg, 0.129 mmol) and $NaBH_4$ (39.0 mg, 1.03 mmol) in DMSO[22] (1.5 cm^3) was heated at 150 °C for 0.5 h. After addition of water, the mixture was extracted with diethyl ether. The extract was dried (K_2CO_3), and evaporated under reduced pressure to give an oily residue. PLC of this oil with (1:20) methanol–chloroform as developing solvent afforded 2β-benzyloxy-8,9-methylenedioxy-5,11-methanomorphanthridine (20.3 mg, 43.3%) as an oil, $\delta_H(CDCl_3)$ 7.26 (5 H, s, Ph), 6.47 and 6.43 (each 1 H, s, 2 × ArH), 5.84 (2 H, s, OCH_2O), 4.44 (2 H, s, $PhCH_2$), 4.34 and 3.78 (each 1 H, d, *J* 17.1, 6-H_2), 3.60–3.92 (1 H, m, 2-H), 3.18 (1 H, dd, *J* 2 and 12, 12-H), 2.94 (1 H, d, *J* 12-H), 2.84–3.34 (1 H, m, 4a-H), 2.59 (1 H, d, *J* 2, 11-H), 2.44–2.76 (1 H, m, 11a-H), 1.72–2.27 (3 H, m) and 1.04–1.66 (3 H, m); $\nu_{max}(CHCl_3)/cm^{-1}$ 1485; *m/z* 363 (M^+) (Found: M^+, 363.1833. Calc. for $C_{23}H_{25}NO_3$: *M*, 363.1833).

A suspension of the benzyl ether obtained above (18.3 mg, 0.05 mmol), charcoal (30 mg) and 2% aq. $PdCl_2$ (0.5 cm^3) in methanol (2 cm^3) was stirred under hydrogen at room temperature for 8 h. The mixture was then filtered and the filtrate was made alkaline with saturated aq. Na_2CO_3. The mixture was extracted with chloroform. The organic extract was washed with brine, dried (K_2CO_3), and evaporated under reduced pressure to give 8,9-methylenedioxy-5,11-methanomorphanthridin-2β-ol **25a** (13.1 mg, 95.2%) as crystals, m.p. 194–196 °C; $\delta_H(CDCl_3)$ 6.46 and 6.42 (each 1 H, s, 2 × ArH), 5.84 (2 H, s, OCH_2O), 4.28 and 3.72 (each 1 H, d, *J* 16, 6-H_2), 4.00–4.26 (1 H, m, 2-H), 3.08 (1 H, dd, *J* 3 and 12, 12-H), 2.90 (1 H, d, *J* 12, 12-H), 2.90–3.26 (1 H, m, 4a-H) 2.53 (1 H, d, *J* 3, 11-H), 2.41–2.61 (1 H, m, 11a-H) and 1.00–2.28 (6 H, m) $\nu_{max}(CHCl_3)/cm^{-1}$ 3050–3600 and 1475; *m/z* 273 (M^+) (Found: M^+ 273.1366. Calc. for $C_{16}H_{19}NO_3$: *M*, 273.1366).

To an ice-cold, stirred solution of the alcohol **25a** (8.0 mg, 0.029 mmol) and Et_3N (8.2 mg, 0.081 mmol) in chloroform (1

cm^3) was added methanesulfonyl chloride (6.0 mg, 0.052 mmol). After the mixture had been stirred at room temperature for 0.5 h, work-up in the usual manner afforded the required mesate **26** (7.2 mg, 70.0%), the spectra (^1H NMR, IR) of which were identical with those of the mesate obtained from mixed diastereoisomers **25** (see above).

8,9-*Methylenedioxy*-2α- *and* -2β-*phenylythio*-5,11-*methanomorphanthridine* **32** *and* **33**.—A solution of alcohols **25** (136.5 mg, 0.5 mmol), diphenyl disulfide (1.094 g, 5 mmol) and Bu_3P (1.3 cm^3, 5 mmol) in DME (8 cm^3) was refluxed for 4 h. The reaction was quenched with 3 mol dm^{-3} NaOH and the mixture was extracted with chloroform. The organic extract was washed with brine, dried (K_2CO_3), and evaporated under reduced pressure to give an oily residue. Chromatography of this residue on silica gel [(1:30) methanol–chloroform] afforded α-sulfide **32** (84.6 mg, 46.4%) and β-sulfide **33** (90.4 mg, 49.5%). For compound **32**: oil; $\delta_H(CDCl_3)$ 7.12–7.44 (5 H, m, 5 × ArH), 6.41 and 6.44 (each 1 H, s, 2 × ArH), 5.84 (2 H, s, OCH_2O), 4.27 and 3.69 (each 1 H, d *J* 16.4, 6-H_2), 2.76–3.40 (2 H, m, 2- and 4a-H), 3.12 (1 H, dd, *J* 3 and 12, 12-H), 2.89 (1 H, d, *J* 12-H), 2.56 (1 H, d, *J* 3, 11-H) and 1.16–2.44 (7 H, m, 1-, 3- and 4-H_2 and 11a-H); *m/z* 365 (M^+) (Found: M^+, 365.1445. Calc. for $C_{22}H_{23}NO_2S$: *M*, 365.1448). For compound **33**: m.p. 119.5–120.5 °C; $\delta_H(CDCl_3)$ 7.12–7.40 (5 H, m, 5 × ArH), 6.46 and 6.42 (each 1 H, s, 2 × ArH), 5.85 (2 H, s, OCH_2O), 4.28 and 3.72 (each 1 H, d, *J* 16, 6-H_2), 3.48–3.80 (1 H, m, 2-H), 3.08 (1 H, dd, *J* 3 and 11, 12-H), 2.90 (1 H, d, *J* 11, 12-H), 2.88–3.22 (1 H, m, 4a-H), 2.48 (1 H, d, *J* 3, 11-H) and 1.00–2.32 (7 H, m, 1-, 3- and 4-H_2 and 11a-H); *m/z* 365 (M^+) (Found: M^+, 365.1449).

Synthesis of Sulfide **32** *from* 2β-*Alcohol* **25a**.—A solution of 2β-alcohol **25a** (15.0 mg, 0.055 mmol), diphenyl disulfide (12.1 mg, 0.55 mmol) and Bu_3P (0.14 cm^3, 0.55 mmol) in DME (1 cm^3) was refluxed for 4 h. Similar work-up as described above gave sulfide **32** (29.3 mg, 93.6%), the ^1H NMR spectrum of which was identical with that of the authentic sample obtained above.

2,3- *and* 1,2-*Didehydro*-8,9-*methylenedioxy*-5,11-*methanomorphanthridine* **28** *and* **29**.—(a) *From* β-*Mesate* **26**. (i) *With Bu^{t}OK*. A mixture of mesate **26** (35.5 mg, 0.1 mmol) and Bu^{t}OK (24.8 mg, 0.22 mmol) in DMSO (0.5 cm^3) was stirred at room temperature for 10 h. The reaction was quenched with water. After extraction with diethyl ether, the extract was washed with brine, dried (K_2CO_3), and evaporated under reduced pressure to give an oily residue. PLC with (1:15) methanol–chloroform as developing solvent yielded $\Delta^{2,3}$-product **28** (10.9 mg, 42.3%) and $\Delta^{1,2}$-product **29** (10.2 mg, 39.5%), each as an oil. For compound **28**: $\delta_H(CDCl_3)$ 6.48 and 6.44 (each 1 H, s, 2 × ArH), 5.86 (2 H, s, OCH_2O), 5.64–6.01 (2 H, m, CH=CH), 4.33 and 3.74 (each 1 H, d, *J* 17.1, 6-H_2), 3.24 (1 H, dd, *J* 3 and 12, 12-H), 2.94 (1 H, d, *J* 12, 12-H), 2.90–3.26 (1 H, m, 4a-H), 2.67 (1 H, d, *J* 3, 11-H) and 1.56–2.60 (5 H, m, 1- and 4-H_2 and 11a-H); $\nu_{max}(CHCl_3)/cm^{-1}$ 1480; *m/z* 255 (M^+) (Found: M^+, 255.1255. Calc. for $C_{16}H_{17}NO_2$: *M*, 255.1257). For compound **29**: $\delta_H(CDCl_3)$ 6.52 and 6.44 (each 1 H, s, 2 × ArH), 5.86 (2 H, s, OCH_2O), 5.76–6.04 and 5.52–5.74 (each 1 H, m, CH=CH), 4.23 and 3.74 (each 1 H, d, *J* 17.1, 6-H_2), 3.00–3.22 (1 H, m, 4a-H), 2.96 (1 H, dd, *J* 2 and 10, 12-H), 2.89 (1 H, d, *J* 10, 12-H), 2.69 (1 H, d, *J* 2, 11-H) and 1.36–2.20 (5 H, m, 3- and 4-H_2 and 11a-H); $\nu_{max}(CHCl_3)/cm^{-1}$ 1475; *m/z* 255 (M^+) (Found: M^+ 255.1256).

(ii) *With DBU*. A mixture of mesyl derivative **26** (17.6 mg, 0.05 mmol) and DBU (14.9 mg, 0.098 mmol) in toluene (2 cm^3) was refluxed for 3 h. After evaporation of the solvent under reduced pressure, the oily residue was purified by PLC with (1:10) methanol–chloroform as developing solvent to yield compounds **28** (1.7 mg, 13.3%) and **29** (5.0 mg, 39.1%), each as an oil.

(b) *From* α-*mesate* **27**. A mixture of mesate **27** (88.1 mg, 0.25 mmol) and Bu^{t}OK (61.6 mg, 0.55 mmol) in DMSO (3 cm^3) was stirred at room temperature for 4 h. Similar work-up as described above gave $\Delta^{1,2}$-product **29** (56.7 mg, 88.6%), the spectra (^1H NMR, IR) of which were identical with those of the authentic sample obtained in method (a) above.

(c) *From* α-*sulfide* **32**. To a solution of the sulfide **32** (45.0 mg, 0.123 mmol) in methanol (1 cm^3) was added an aqueous solution of sodium periodate (30.9 mg, 0.144 mmol in 0.2 cm^3). After 7 h, 3 mol dm^{-3} NaOH and chloroform were added to the mixture. After the organic phase had been separated, the aqueous phase was extracted with chloroform. The combined organic phases were washed with brine, dried (K_2CO_3), and evaporated under reduced pressure to give an oily residue. Chromatography of this residue on silica gel [(1:10) methanol–chloroform] afforded sulfoxides (44.7 mg, 95.2%) as 1.3:1 mixture of oily diastereoisomers (estimated by the height of peaks due to the methylenedioxy group in the ^1H NMR spectrum), $\delta_H(CDCl_3)$ 7.28–7.72 (5 H, m, 5 × ArH), 6.52, 6.51, 6.40 and 6.39 (2 H, each s, 2 × ArH), 5.86 and 5.84 (2 H, each s, OCH_2O), 4.27 and 3.69 (each 1 H, d, *J* 16.4, 6-H_2), 2.76–3.40 (2 H, m, 2- and 4a-H), 3.12 (1 H, dd, *J* 3 and 12, 12-H), 2.89 (1 H, d, *J* 12, 12-H), 2.56 (1 H, d, *J* 3, 11-H) and 1.16–2.44 (7 H, m, 1-, 3- and 4-H_2 and 11a-H); *m/z* 381 (M^+) (Found: M^+ 381.1397. Calc. for $C_{22}H_{23}NO_3S$: *M*, 381.1397).

A solution of these sulfoxides (43.9 mg, 0.12 mmol) in toluene (1 cm^3) was refluxed for 1.5 h. The solvent was evaporated off under reduced pressure to give an oily residue, which was purified on PLC with (1:15) methanol–chloroform as developing solvent to yield $\Delta^{2,3}$-compound **28** (14.3 mg, 48.7%) and $\Delta^{1,2}$-compound **29** (12.0 mg, 40.8%), each as an oil. The ^1H NMR spectra of products **28** and **29** were identical with those of authentic samples obtained above.

(d) *From* β-*sulfide* **33**. To a solution of the sulfide **33** (30.0 mg, 0.082 mmol) in methanol (1 cm^3) was added an aqueous solution of sodium periodate (20.2 mg, 0.094 in 0.2 cm^3). Similar work-up as described above gave the sulfoxide of compound **33** (29.3 mg, 93.6%) as a 1.2:1 mixture of oily diastereoisomers (estimated by the height of peaks due to the methylenedioxy group in the ^1H NMR spectrum); $\delta_H(CDCl_3)$ 7.36–7.68 (5 H, m, 5 × ArH), 6.42 and 6.40 (2 H, each s, 2 × ArH), 5.84 and 5.83 (2 H, each s, OCH_2O), 4.26 and 3.67 (each 1 H, d, *J* 17, 6-H_2), 2.52–3.20 (2 H, m, 2- and 4a-H), 3.07 (1 H, dd, *J* 2 and 12, 12-H), 2.88 (1 H, d, *J* 12, 12-H), 2.60 (1 H, d, *J* 2, 11-H) and 1.12–2.44 (7 H, m, 1-, 3- and 4-H_2 and 11a-H); *m/z* 381 (M^+) (Found: M^+, 381.1389. Calc. for $C_{22}H_{23}NO_3S$: *M*, 381.1397).

A solution of the sulfoxides of compound **33** (24.8 mg, 0.065 mmol) in toluene (1 cm^3) was refluxed for 5 h. The solvent was evaporated off under reduced pressure to give an oily residue, which was purified by PLC with (1:15) methanol–chloroform as developing solvent to yield compounds **28** (6.9 mg, 41.6%) and **29** (8.5 mg, 51.3%), each as an oil.

(e) *From* p-*tosylhydrazone* **30**. A solution of ketone **5** (54.4 mg, 0.2 mmol) and *p*-tosylhydrazine (100.6 mg, 0.6 mmol) in methanol (2 cm^3) was refluxed for 1 h. Evaporation of the solvent, followed by chromatography on silica gel [(1:50) and then (1:10) methanol–chloroform], produced p-tosylhydrazone **30** (80.2 mg, 91.0%), m.p. 158–160 °C (from ethyl acetate–hexane): $\delta_H(CDCl_3)$ 7.80 and 7.28 (each 2 H, d, *J* 8, C_6H_4Me), 6.40 (2 H, s, 2 × ArH), 5.85 (2 H, s, OCH_2O), 4.29 and 3.70 (each 1 H, d, *J* 17.1, 6-H_2), 3.09 (1 H, dd, *J* 2 and 12, 12-H), 2.92 (1 H, d, *J* 12, 12-H), 2.88–3.28 (1 H, m, 4a-H), 2.62 (1 H, d, *J* 2, 11-H), 2.41 (3 H, s, Me) and 1.46–2.54 (7 H, m): $\nu_{max}(CHCl_3)/cm^{-1}$ 1480; *m/z* 439 (M^+) (Found: M^+, 439.1363. Calc. for $C_{23}H_{25}N_3O_4S$: *M*, 439.1363).

A solution of hydrazone **30** (65.7 mg, 0.15 mmol) and

Bu^{t}OK (52.5 mg, 0.468 mmol) in DMSO (2 cm^3) was heated at 100 °C for 2 h. After the reaction had been quenched with water, the mixture was extracted with diethyl ether. The organic extract was washed with brine, dried (K_2CO_3), and evaporated under reduced pressure to give an oily residue. PLC with (1:20) methanol–chloroform as developing solvent afforded compounds **28** (13.1 mg, 34.3%) and **29** (10.4 mg, 27.3%), which were identified by comparison of their respective spectral data (^{1}H NMR, IR) with those of authentic samples obtained above.

2,3-*Benzylidenedioxy*-8,9-*methylenedioxy*-5,11-*methanomorphanthridine* **31**.—A mixture of olefin **28** (25.4 mg, 0.1 mmol), OsO_4 (15×10^{-3} cm^3, 0.003 mmol; 0.02 mol dm^{-3} in 1,4-dioxane) NMNO[25] (12.6 mg, 0.11 mmol), 1,4-dioxane (1.6 cm^3) and water (0.4 cm^3) was stirred at room temperature for 1 h. Then 10% aq. $Na_2S_2O_3$ and 3 mol dm^{-3} NaOH were added to the mixture, which was then extracted with chloroform. The organic extract was washed with brine, dried (K_2CO_3), and evaporated under reduced pressure to give a solid, which was treated with benzaldehyde dimethyl acetal (20.8 mg, 0.14 mmol) in the presence of *p*-TsOH monohydrate (19.7 mg, 0.10 mmol) in chloroform (2 cm^3) at room temperature for 1 h. After dilution with chloroform, the organic phase was washed successively with saturated aq. $NaHCO_3$ and brine, dried (K_2CO_3), and evaporated under reduced pressure to give an oily residue, which was purified by PLC with (1:15) methanol–chloroform as developing solvent to afford compound **31** (28.1 mg, 74.8%). ^{1}H NMR and IR spectra were identical with those of an authentic sample.[6]

1,11a-*Didehydro*-8,9-*methylenedioxy*-5,11-*methanomorphanthridin*-2-*one* **34**.—A mixture of ketone **5** (100 mg, 0.37 mmol) and DDQ (250.1 mg, 1.10 mmol) in 1,4-dioxane (8 cm^3) was refluxed for 0.5 h. The mixture was diluted with chloroform. The organic phase was washed successively with saturated aq. $NaHCO_3$ and brine, dried (K_2CO_3) and evaporated under reduced pressure to leave an oily residue. PLC of the oil with (1:15) methanol–chloroform as developing solvent afforded enone **34**[9] (75.0 mg, 75.6%); m.p. 49–50 °C; $\delta_H(CDCl_3)$ 6.53 and 6.47 (each 1 H, s, 2 × ArH), 5.89 and 5.86 (each 1 H, d, *J* 2, OCH_2O), 5.72–5.94 (1 H, m, 1-H), 4.40 and 3.84 (each 1 H, d, *J* 17, 6-H_2), 3.36–3.68 (1 H, m, 4a-H), 3.43 (1 H, br s, 11-H), 4.16 (2 H, br s, $w_{\frac{1}{2}}$ 3.4, 12-H_2) and 1.60–2.56 (4 H, m, 3- and 4-H_2); $\nu_{max}(CHCl_3)/cm^{-1}$ 1660; *m/z* 269 (M^+) (Found: M^+, 269.1049. Calc. for $C_{16}H_{15}NO_3$: *M*, 269.1050).

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