New Synthetic Pathways from Gibberellins to Antheridiogens Isolated from the Fern Genus *Anemia*

Mark Furber, Lewis N. Mander,* and Graham L. Patrick

Research School of Chemistry, Australian National University, GPO Box 4, Canberra, ACT 2601, Australia

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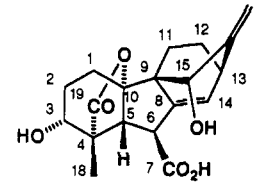
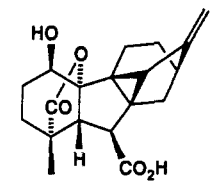
Gibberellin A_7 (4) was converted into the antheridiogens 2 and 3 isolated from cultured gametophytes of ferns belonging to the genus *Anemia* by two independent routes. The first of these established the 9,15-cyclogibberellane skeleton of 3 by means of an intramolecular alkylation on the 9-ene-1-iodo-16-one 8 which was obtained from the triene acid 7; the 1β-hydroxyl of 3 was introduced by syn-S_N2' substitution of the 3β-mesylate derived from 10. In a second, more efficient approach, lactone 17 was treated with an excess of *N*-bromosuccinimide to form dibromide 19, which was also readily converted to a cyclogibberellane derivative, 20. This could be converted into both antheridiogen 2 from *Anemia phyllitidis* and antheridiogen 3 from *Anemia mexicana*. Important features of these syntheses are the solvent-controlled modulation of the effect of the amidine base DBU in the preparation of 32 and the use of diphenyl- and dimethylboron bromide to effect the contrathermodynamic 1,3-allylic isomerization of lactones 9, 20, and 11,12-dihydro-32.

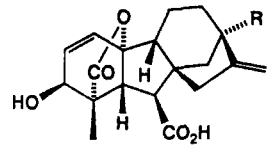
Following the discovery of an antheridium inducing substance in prothallia of the bracken fern, *Pteridium aquilinum*,[1,2] several discrete compounds (for which the term antheridiogen has been coined) have been isolated from the gametophytes of other fern species.[3] It was observed for members of the family Schizaeaceae that these substances possessed gibberellin-like reactivity[4] and, conversely, that gibberellins had antheridium-inducing properties.[5] Nakanishi et al. utilized this information in arriving at formula 1[6] for antheridic acid,[7] the major antheridiogen from *Anemia phyllitidis*, although this structure was later revised to 2 following total syntheses of the respective racemates by Corey and Myers.[8] Antheridic acid (2) has also been shown to be a natural antheridiogen in other members of the *Anemia genus*, i.e. *A. hirsuta*,[9] *A. rotundifolia*, and *A. flexuosa*.[10] It could not be detected in *A. mexicana*, but a new gibberellin-like antheridiogen was obtained from this last species,[11] for which structure 3 was deduced[12] and confirmed by synthesis from gibberellin A_7 ("GA_7") (4).[13] Structures of two antheridiogens from the related genus *Lygodium japonicum* have also been elucidated, the more potent of which was shown to be 9,11-didehydro-GA_9 methyl ester (6).[14,15] These substances induce extensive antheridia formation at concentrations as low as 10^{-14} M, and also initiate spore germination, but at higher concentrations (10^{-11}–10^{-10} M). Ester 6 has been shown to inhibit archegonia development in *Lygodium japonicum* at similar levels.[16]



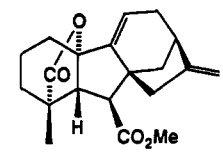
1 (3β)
2 (3α)



3



4 R = H
5 R = OH



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The range of gibberellin structural types as typified by 4 and 5 occurring naturally among the higher plants is surprisingly limited. The basic *ent*-norgibberellane formula is constant for ca. 60 metabolites, while the rest (ca. 20) are based on the full C_{20} skeleton, reflecting their origin from geranylgeranyl pyrophosphate.[17,18] The variations that account for the 80 known naturally occurring gibberellins stem mainly from different hydroxylation patterns, sometimes in combination with an olefinic bond in the A ring. The discovery of this new collection of compounds, i.e. 2, 3, and 6, provides a significant departure from the structural homogeneity associated with the higher plant gibberellins and leads to a number of fascinating conjectures concerning the evolutionary aspects of the biosynthesis and biological roles of the gibberellins in the plant Kingdom. It also leads to the enticing prospect that this structural variability will be extended among other fern species. However, given the tiny quantities of material which are likely to be available, it is clear that the search for new compounds will be arduous and that the role of synthesis in structure elucidations will be crucial, as has already been demonstrated for compounds 2,[8] 3,[13] and 6.[15] We have therefore mounted a major research program with

(1) Döpp, W. *Ber. Deut. Bot. Ges.* **1950**, *63*, 139–147.
(2) Döpp, W. *Ber. Deut. Bot. Ges.* **1959**, *72*, 11–24.
(3) Näf, U.; Nakanishi, K.; Endo, M. *Bot. Rev.* **1975**, *41*, 315–357.
(4) Sharp, P. B.; Keitt, G. W.; Clum, H. H.; Näf, U. *Physiol. Plant.* **1975**, *34*, 101–105.
(5) Schraudolf, H. *Nature* **1964**, *201*, 98–99. Voeller, B. *Science* **1964**, *143*, 373–375.
(6) Nakanishi, K.; Endo, M.; Näf, U.; Johnson, L. F. *J. Am. Chem. Soc.* **1971**, *93*, 5579–5581.
(7) Corey, E. J.; Myers, A. G.; Schraudolf, H.; Takahashi, N.; Yamane, H. *Tetrahedron Lett.* **1986**, *27*, 5083–5084.
(8) Corey, E. J.; Myers, A. G. *J. Am. Chem. Soc.* **1985**, *107*, 5574–5576.
(9) Zanno, P. R.; Endo, M.; Nakanishi, K.; Näf, U.; Stein, C. *Naturwissenschaften* **1972**, *512*, 12.
(10) Yamane, H.; Nohara, K.; Takahashi, N.; Schraudolf, H. *Plant Cell Physiol.* **1987**, *28*, 1203–1207.
(11) Nester, J. E.; Veysey, S.; Coolbaugh, R. C. *Planta* **1987**, *170*, 26–33.
(12) Furber, M.; Mander, L. N.; Nester, J. E.; Takahashi, N.; Yamane, H. *Phytochemistry* **1989**, *28*, 63–66.
(13) Preliminary account: Furber, M.; Mander, L. N. *J. Am. Chem. Soc.* **1988**, *110*, 4084–4085.
(14) Yamane, H.; Takahashi, N.; Takeno, K.; Furuya, M. *Planta* **1979**, *147*, 251–256.
(15) Yamane, H.; Satoh, Y.; Nohara, K.; Nakayama, M.; Murofushi, N.; Takahashi, N.; Takeno, K.; Furuya, M.; Furber, M.; Mander, L. N. *Tetrahedron Lett.* **1988**, *29*, 3959–3962.
(16) Takeno, K.; Yamane, H.; Yamaguchi, T.; Takahashi, N.; Furber, M.; Mander, L. N. *Plant Cell Physiol.* **1988**, *30*, 201–205.
(17) Takahashi, N.; Yamaguchi, I.; Yamane, H. In *Chemistry of Plant Hormones*; Takahashi, N., Ed.; CRC Press: Boca Raton, FL, 1986; pp 57–151.
(18) Mander, L. N. *Nat. Prod. Rep.* **1988**, *5*, 541–579.

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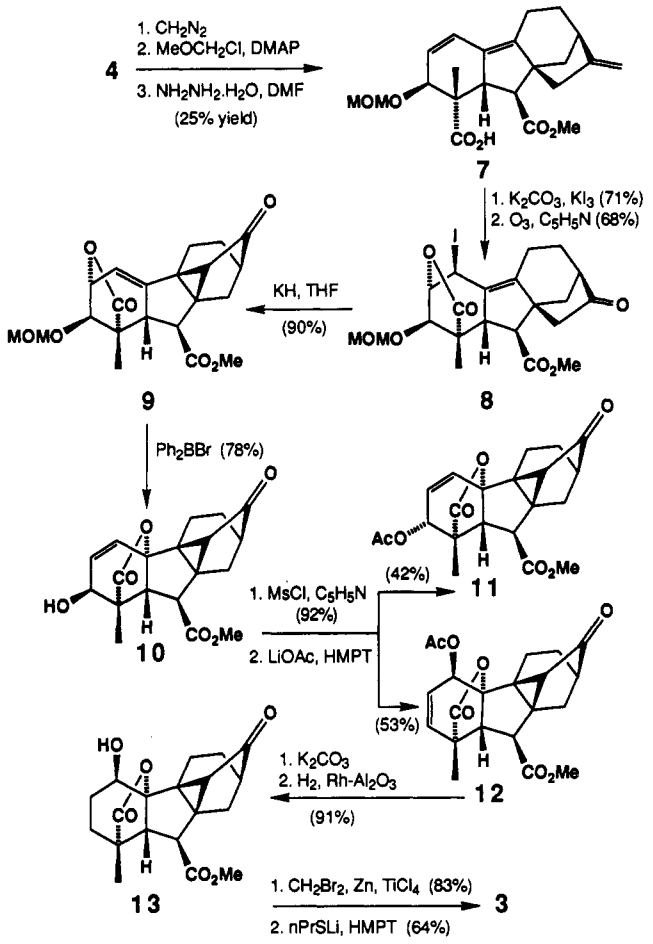
Scheme I



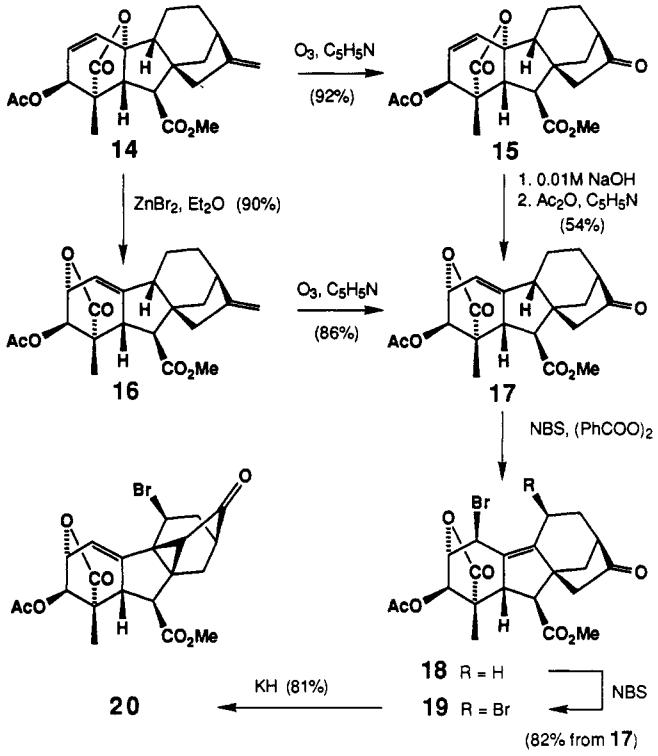
the objective of establishing efficient methods of access to these substances by synthetic conversions from the fungal gibberellins GA_7 (**4**) and GA_3 (**5**). Aspects of our more recent endeavors directed towards the *Anemia* antheridiogens **2** and **3** are described herein.

A detailed description of our first preparation of antheridic acid (**2**) from GA_7 (**4**) has been published.[19] As well as establishing improved access to this intriguing compound, the conversion provided intermediates with the same basic skeleton postulated for the major antheridiogen **3** from *Anemia mexicana*.[20] We were therefore well placed to probe the validity of the hypothesis and to show that not only was the carbon skeleton probably correct, but also that the hydroxy group should be in the 1β location.[12] These conclusions were then confirmed by the synthesis of **3** outlined in Scheme I.[13]

Second Generation Syntheses

The low-yield preparation of **7**[21] in the preceding synthesis created a major bottleneck in the accumulation of adequate supplies of the synthetic antheridiogens for the pursuit of more extensive biological and biosynthetic

Scheme II



studies. An improved route to Δ^9-ene-1-halides analogous to **8** which might serve as substrates in the pivotal intramolecular alkylation step was therefore sought. The successful solution to this quest is summarized in Scheme II.[22] Isomerization of the allylic A-ring lactone moiety with dilute sodium hydroxide in gibberellins like GA_7 (**4**) was known to afford the $\Delta^{1(10)}$-ene 19,2-lactones,[23] and we were similarly able to carry out the analogous conversion of the GA_7-17-nor-16-one derivative **15**[24] into its A-ring isomer, affording **17** after acetylation. Alternatively, a more efficient and experimentally convenient preparation of this compound was achieved by effecting the A-ring allylic rearrangement with zinc bromide on the GA_7 derivative **14**. Ozonolysis of the product then provided **17** in much higher overall yield. It was envisaged that allylic bromination of **17** would take place with migration of the alkene bond and give rise to **18**, which could then be used instead of the allylic iodide **8**. Unfortunately, it was difficult to obtain **18** in acceptable amounts because of further bromination to the 1,11-dibromide **19**. The reaction was therefore allowed to progress to this further stage in the expectation that the 11-bromo substituent would not interfere with the alkylation step and that it could be removed subsequently. In the event, treatment with potassium hydride afforded the cyclopropyl ketone **20** in high yield, although it should be noted that this reaction is capricious[25] and was only successful with selected batches of reagent, as had been found with **8** and its 3α-epimer in the earlier studies.[13,19]

A second synthesis of antheridic acid was then completed, based on the sequence outlined in Scheme III.

(19) Furber, M.; Mander, L. N. *J. Am. Chem. Soc.* **1987**, *109*, 6389–6396.

(20) Takahashi, N.; Yamane, H., personal communication.

(21) The parent acids undergo this reaction in ca. 40% yield (Grove, J.; Mulholland, T. P. C. *J. Chem. Soc.* **1960**, 3007–3022), but in the preparation of **7** the yield is reduced to 25% because of competing demethylation to the corresponding 7,19-dicarboxylic acid (20% yield). The other identified byproducts are cyclic 19,2-hydrazides, which account for a further 17% of material (see the Experimental Section). A further complicating aspect of this preparation is that preparative quantities of GA_7 are only available from commercial fermentation processes as a 1:1 mixture with the 1,2-dihydro derivative (GA_4).

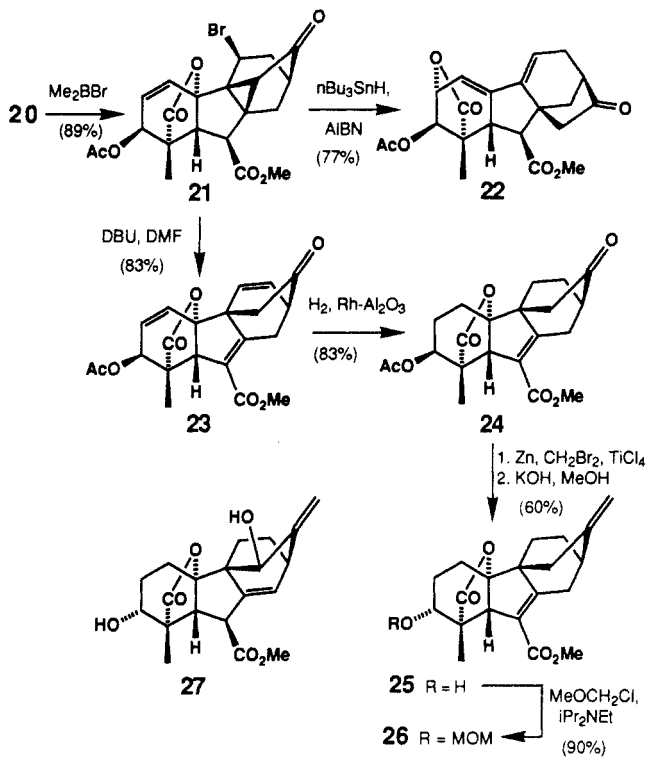
(22) Preliminary communication: Furber, M.; Mander, L. N. *Tetrahedron Lett.* **1988**, *29*, 3339–3342.

(23) Cross, B. E.; Grove, J. F.; Morrison, A. *J. Chem. Soc.* **1961**, 2498–2515. Kirkwood, P. S.; MacMillan, J.; Sinnott, M. L. *J. Chem. Soc., Perkin Trans. 1* **1980**, 2117–2121.

(24) Cross, B. E.; Galt, R. H. B.; Hanson, J. R. *Tetrahedron* **1962**, *18*, 451–459.

(25) Macdonald, T. L.; Natalie, K. J., Jr.; Prasad, G.; Sawyer, J. S. *J. Org. Chem.* **1986**, *51*, 1124–1126.

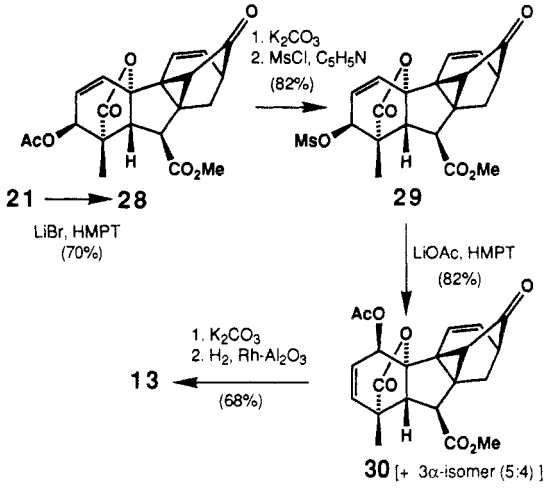
Scheme III



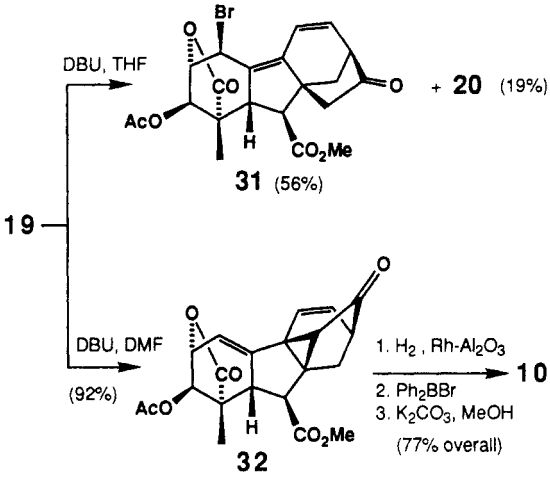
After isomerization of the A-ring allylic lactone moiety in **20** with dimethylboron bromide[26] to give **21**, attempts were made to remove the bromo substituent by reductive methods (e.g. n-Bu_3SnH or $CrCl_2$), but this led to cleavage of the newly formed C(9)–C(15) bond and reversion of the allylic A-ring lactone function to the $\Delta^{1(10)}$-19,2-isomer, affording **22**. However, elimination of HBr from **21** could be satisfactorily carried out with 1,8-diazabicyclo[5.4.0]-undec-7-ene (DBU), which also effected fission of the C(8)–C(15) bond. The resulting triene **23** was selectively hydrogenated to **24**, and after restoration of the 17-methylene group by the Lombardo procedure,[27] the 3β-acetate function was hydrolyzed under conditions which were sufficiently vigorous to effect epimerization at C(3) (retro-aldol/aldol reaction),[28] thereby furnishing the 3α-epimer **25**. After protecting this product as the 3-(methoxymethyl) ether **26**, the sequence was completed as described previously,[19] providing antheridic acid from GA_7 (**4**) in an overall yield of 10.7%. On this occasion the allylic hydroxylation at C(15) with SeO_2/*tert*-butyl peroxide gave rise to an isolable amount (10% yield) of the 15α-epimer (**27**) of methyl antheridate, allowing the assignment of stereochemistry at C(15) in the respective epimers to be made with greater confidence.[29]

The possibility of obtaining improved access to the *A. mexicana* antheridiogen **3** from cyclopropyl ketone **21** was examined next. This was successfully achieved by two approaches, the first of which is outlined in Scheme IV. It was found that **21** could be converted into diene **28** by treatment with the weaker base LiBr,[30] thereby avoiding

Scheme IV



Scheme V



fragmentation of the C(8)–C(15) bond which had accompanied DBU-induced elimination of HBr in the formation of **23**. Solvolysis of the derived mesylate **29** as for the mesylate of **10** gave the 1β-acetate **30** as the major product in a 5:4 mixture with the 3α-isomer. Hydrolysis of **30** followed by catalytic hydrogenation to **13** then allowed completion of the synthesis of **3** as indicated in the latter part of the previous sequence (Scheme I).

In a second study, the feasibility of removing the 11-bromo substituent from **19** by means of an elimination process prior to the intramolecular alkylation step with potassium hydride (**19** → **20**) was investigated (Scheme V). Treatment with DBU in tetrahydrofuran afforded the desired dienyl bromide **31**, but this product was also accompanied by a significant quantity of the cyclopropyl ketone **20** (19% yield), indicating that it might be possible to utilize DBU in the formation of 9,15-cyclogibberellins instead of the troublesome KH reagent. Thus, we found that the reaction of **19** with DBU with DMF as the solvent effected both cyclopropyl ketone formation and elimination of HBr in the C ring to furnish **32** in consistently good yields. Hydrogenation, isomerization with diphenyl boron bromide, and then hydrolysis gave carbinol **10** in an overall yield of 31% from GA_7 (**4**), thereby allowing better access to both **2** and **3**.

The new synthetic methodology which has been described, e.g. the reversible isomerization of the A-ring allylic lactone moiety, usefully extends the available options in

(26) Guindon, Y.; Yoakim, C.; Morton, H. E. *J. Org. Chem.* **1984**, *49*, 3912–3920.

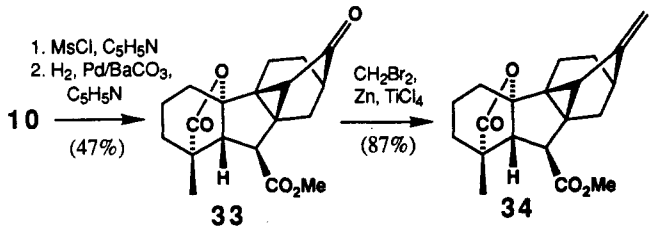
(27) Lombardo, L. *Tetrahedron Lett.* **1981**, *23*, 4293–4296. Cf.: Oshima, K.; Takai, K.; Hotta, Y.; Nozaki, H. *Tetrahedron Lett.* **1978**, 2417–2420.

(28) MacMillan, J.; Pryce, R. J. *J. Chem. Soc., Perkin Trans. 1* **1967**, 740–742.

(29) The isolation of the 3-*tert*-butyldimethylsilyl derivative of **27** as a minor product from reduction of the 15-oxo analogue has been reported: Myers, A. G. *Ph.*D. Dissertation, Harvard University, 1985.

(30) Parker, A. J. *Chem. Technol.* **1971**, *1*, 297–303.

Scheme VI



the manipulation of gibberellin structures,[31,32] while the availability of both of the *Anemia* antheridiogens by these improved procedures has facilitated several biological and biochemical investigations which would not otherwise have been practical. It has enabled the preparation of isotopically substituted derivatives and has allowed us to establish an extensive spectroscopic data base which should simplify the task of determining the structures of further growth substances of this general type. The synthesis of the parent system **34** (Scheme VI),[13] for example, originally enabled us to predict the location of the hydroxy group in **3**,[12] while in a more recent study, the *17,17'-d_2* acid corresponding to **34** was prepared and converted by prothallia of *Anemia phyllitidis* into *17,17'-d_2*-antheridic acid (**2**),[33] lending support to the earlier speculation[15,19] that the biosynthesis of **2** might occur via a 9,15-cyclogibberellin intermediate, rather than the more direct 1,2-bond shift as suggested by Nakanishi et al.[6]

Experimental Section

Chromatography was carried out on silica gel (Merck 9385) at normal pressures or on a Chromatotron Model 7924T with silica gel PF_{254} (Merck 7749). NMR spectra were measured on either JEOL FX200 or Varian XL 300 spectrometers with tetramethylsilane as an internal standard (δ = 0.0 ppm) for ^1H NMR or $CDCl_3$ (δ = 77.0 ppm) for ^{13}C NMR spectra.[34] ^{13}C NMR data for all numbered compounds are presented in Table I.

***ent*-3α-(Methoxymethoxy)-20-norgibberella-1,9,16-triene-7,19-dioic Acid 7-(Methyl ester) (7).** To a stirred solution of commercial GA_7/GA_4 mixture (4 g; containing 2.88 g, 11.9 mmol of GA_7) in EtOAc (50 mL), was added a solution of diazomethane in Et_2O until all of the starting material had been consumed according to TLC analysis. The solution was concentrated in vacuo, and the product was dissolved in dry CH_2Cl_2 (200 mL) and Hunig's base (diisopropylethylamine) (15 mL, 11.13 g, 86 mmol) and cooled to 0 °C. A solution of chloromethyl methyl ether (10 mL, 10.6 g, 131 mmol) in dry CH_2Cl_2 (20 mL) was added dropwise, followed by DMAP (0.1 g, 0.8 mmol). The mixture was allowed to warm to room temperature and stirred for 14 h. After recooling to 0 °C, the excess of chloromethyl methyl ether was destroyed by stirring with aqueous $NaHCO_3$ solution for 30 min. The mixture was diluted with Et_2O (500 mL), and the organic layer washed with 1 N HCl solution followed by brine, dried over $MgSO_4$, and concentrated in vacuo to give a mixture of 3-(methoxymethyl)gibberellin A_7/A_4 methyl esters. The mixture

Table I. ^{13}C NMR Data[a]

carbon	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
7	125.05	126.53	74.31	58.70	47.77	49.17	175.26	49.11	125.57	142.15	20.14	33.20	42.13	46.03	40.13	153.30	106.11	20.01	180.33
8	9.74	74.56	76.75	54.82	44.66	49.48	172.05	46.82	126.06	145.48	19.93	27.20	46.32	42.06	45.16	217.05		15.23	174.86
9	115.86	73.29	81.06	48.01	42.81	46.66	172.22	45.99*	45.17*	149.85	17.55	26.05	42.23	30.55	37.26	211.55		17.38	175.52
10	129.90	133.98	70.19	52.24	50.16	46.21	171.44	46.10*	44.35*	90.16	15.39	26.78	42.73	30.42	34.32	212.16		14.11	177.86
11	129.76	130.93	73.55	51.74	55.13	46.49	170.78	45.35*	44.21*	88.83	15.42	26.63	42.61	30.34	33.87	211.14		13.99	174.12
12	66.63	137.64	127.11	47.56	48.99	46.45	171.11	44.06*	43.41*	91.58	15.28	26.62	42.64	30.44	34.33	211.41		14.65	176.04
13	64.93	31.37	28.51	48.05	48.97	47.14	171.65	44.79*	43.72*	93.59	15.35	26.74	42.86	30.42	34.68	213.58		16.69	178.10
3	65.88	32.65	29.93	49.32	50.48	48.06	175.65	42.20*	38.74*	96.74	17.22	29.23	40.78	34.96	32.43	154.00	102.82	17.11	180.65
3-Me	65.34	31.33	28.43	48.02	49.01	46.53	172.78	40.85*	37.17*	94.60	16.11	27.89	39.14	33.66	30.73	152.17	102.69	16.59	178.69
16	112.86	75.51*	72.01*	47.42	46.31	48.85	175.31	51.13	46.35	152.65	20.68	30.49	41.55	41.55	40.36	152.36	106.52	17.14	175.08
17	113.38	74.86*	71.45*	47.07	46.17	48.65	174.58	48.70	45.55	150.73	17.50	27.13	45.55	39.07	46.84	218.17		17.17	174.00
19	36.86	73.70	73.70	54.93	45.85	49.84	171.96	47.01	130.35	147.52	33.64	39.89	46.11	43.16	46.75	215.23		15.31	173.80
20	116.92	73.17	71.34	51.41	43.51	46.78	171.34	47.54	50.28	147.19	42.68	40.39	40.99	31.01	37.94	207.23		17.17	174.12
21	129.44	132.45	70.02	50.63	50.63	45.55	170.12	48.79	50.43	89.28	42.64	41.44	41.20	30.52	34.72	206.91		13.61	175.44
22	118.22	75.34	71.98	48.82	46.31*	49.96	172.33	48.18	143.89	143.40	114.52	31.66	45.46*	37.20	50.08	210.30		18.20	174.49
23	132.74	131.08	71.25	52.06	58.55	121.00	464.85	161.27	56.91	85.96	130.78	130.05	49.70	30.89	39.07	206.64		15.92	175.31
24	22.89	25.32	72.27	52.71	55.74	122.64	164.89	161.15	53.61	90.05	21.29	21.00	42.95	30.40	43.63	211.02		15.89	175.34
25	25.00	29.06	73.44	53.76	60.36	120.92	166.00	165.56	50.87	90.31	21.93	25.00	36.71	34.40	35.00	147.57	107.86	13.70	176.48
28	130.26	132.16	70.11	50.69	51.33	46.08	170.88	45.20	42.98	88.18	127.37	123.81	44.65	28.09	25.43	208.43		13.55	175.58
29	129.91	133.82	76.50	51.54	51.39	46.28	170.79	45.29	42.98	88.27	127.81	123.75	44.91	28.27	25.64	208.37		14.43	174.88
30	67.19	137.79	127.16	47.69	50.14	46.28	171.20	43.66	43.36	89.82	126.52	124.71	45.35	28.44	26.02	209.07		14.66	175.66
31	50.52	73.88*	73.64*	53.58	49.87	45.82	173.82	42.9	125.41	146.06	121.29	132.36	35.25	39.63	42.90	206.7		15.95	172.13
32	116.2	75.6	71.6	47.5	45.9	45.1	172.4	46.4	43.9	146.6	126.4	123.9	43.9	28.85	28.91	209.2		17.4	174.3
33	26.94	18.98	34.94	47.85	55.42	46.99	171.73	46.63	45.20	92.67	15.43	26.63	42.72	30.45	34.28	212.22		16.70	178.19
34	27.08	19.14	35.07	47.84	55.62	46.35	172.95	42.70	39.48	93.81	16.15	27.90	39.13	33.74	30.60	152.15	102.48	16.69	178.84

[a] Nonskeletal carbons were observed in the following ranges (ppm): OCH_2OMe 95.83–95.93; OCH_2OCH_3 55.42–56.12; CO_2CH_3 50.93–52.71; $OCOCH_3$ 20.00–21.15; $OCOCH_3$ 169.37–170.48; OSO_2CH_3 38.72–38.78. *Assignments may be interchanged.

(31) Mander, L. N.; Patrick, G. L. *Tetrahedron Lett.* **1990**, *31*, 423–426.

(32) The borane mediated process is general for a wide range of gibberellin structures. It can be safely assumed that the reaction process is activated by coordination between the lactone function and the borane and proceeds by S_N2 substitution at C(2) followed by an intramolecular variant of S_N2' substitution at C(10) by the liberated carboxylate. The problem is to rationalize the contrathermodynamic nature of the process. We can only speculate that this is driven by selective complexation between the borane and the 19,2-lactone isomers and that the 19,10-lactone function is too sterically hindered to form an adduct.

(33) Takahashi, N.; Yamane, H.; Yamauchi, T., personal communication.

(34) ^1H NMR assignments were substantiated by ^1H–^1H COSY spectra while ^{13}C NMR assignments were based on DEPT and, in selected cases, 2D ^1H–^{13}C COSY (HETCOR) spectra.

was dissolved in DMF (40 mL) and heated to 100 °C under N_2. Hydrazine monohydrate was added with stirring until the solution became cloudy, and the resulting mixture heated under reflux at 120 °C for 3 h. The reaction was monitored by TLC analysis, and once complete, cooled to 0 °C, poured into H_2O (150 mL) and acidified to pH 3 with 6 N HCl. The product was immediately extracted with EtOAc, washed with brine, and dried over $MgSO_4$. Concentration in vacuo and chromatography on silica gel (Et_2O–hexane (1:1), then Et_2O, then Et_2O–MeOH (5:1) gave in order of elution:

***ent*-3α-(Methoxymethoxy)-20-norgibberella-1,9,16-triene-7,19-dioic acid 7-(methyl ester) (7)** (0.84 g, 25%): R_f 0.50 (Et_2O); $[\alpha]^{25}_D$ −53° (*c* 60.5 × 10^{-3}, CH_2Cl_2); IR ($CHCl_3$) ν_{max} 3600–2400 (m), 2940 (m), 1730 (s), 1080 (m) cm^{-1}; UV (EtOH) λ_{max} 256 nm (ε 15 340 dm^3 mol^{-1} cm^{-1}); ^1H NMR (300 MHz, $CDCl_3$) 6.43 (1 H, d, $J_{1,2}$ = 9.7 Hz, H1), 5.92 (1 H, dd, $J_{2,1}$ = 9.7 Hz, $J_{2,3}$ = 5.5 Hz, H2), 4.27 (1 H, d, $J_{3,2}$ = 5.5 Hz, H3), 4.93 (1 H, s, br, H17), 4.89 (1 H, s, br, H17′), 4.77, 4.27 (2 H, 2 AB d, *J* = 6.8 Hz, OCH_2O), 3.71 (3 H, s, CO_2CH_3), 3.62 (2 H, s, H5 + H6), 3.37 (3 H, s, OCH_2OCH_3), 2.76 (1 H, m, H13), 2.48 (1 H, dd, $J_{11\alpha,11\beta}$ = 16.3 Hz, $J_{11\alpha,12\alpha}$ = 5.7 Hz, H11α), 2.22 (1 H, br d, $J_{15\beta,15\alpha}$ = 16.0 Hz, H15β), 2.08 (1 H, dm, $J_{15\alpha,15\beta}$ = 16.0 Hz, H15α), 2.05 (1 H, ddd, $J_{14\beta,14\alpha}$ = 11.0 Hz, $J_{14\beta,13}$ = 4.5 Hz, *J* = 1 Hz, H14β), 2.10 (1 H, m, H11β), 1.65 (2 H, m, H12α and H12β), 1.56 (1 H, dd, $J_{14\alpha,14\beta}$ = 11.0 Hz, $J_{14\alpha,15\beta}$ = 2.3 Hz, H14α), 1.28 (3 H, s, H18); LRMS 388 (M^+, 13), 373 (3), 356 (39), 281 (77), 222 (63), 45 (100); HRMS found 388.1887 (M^+), $C_{22}H_{28}O_6$ requires 388.1886.

***ent*-3α-(Methoxymethoxy)-20-norgibberella-1,9,16-triene-7,19-dioic acid** (0.70 g, 21%): R_f 0.40 (Et_2O); $[\alpha]^{25}_D$ −78° (*c* 24.7 × 10^{-3}, CH_2Cl_2); IR ($CHCl_3$) ν_{max} 3600–2400 (m), 2940 (m), 1705 (s), 1080 (m) cm^{-1}; UV (EtOH) λ_{max} 256 nm (ε 14 740 dm^3 mol^{-1} cm^{-1}); ^1H NMR (300 MHz, $CDCl_3$) 6.44 (1 H, d, $J_{1,2}$ = 9.7 Hz, H1), 5.94 (1 H, dd, $J_{2,1}$ = 9.7 Hz, $J_{2,3}$ = 5.5 Hz, H2), 4.29 (1 H, d, $J_{3,2}$ = 5.5 Hz, H3), 4.95 (1 H, s, br, H17), 4.91 (1 H, s, br, H17′), 4.79, 4.68 (2 H, 2 AB d, *J* = 6.8 Hz, OCH_2O), 3.69 (1 H, $J_{6,5}$ = 9.0 Hz, H6), 3.58 (1 H, dd, $J_{5,6}$ = 9.0 Hz, $J_{5,11\beta}$ = 4.1 Hz, H5), 3.38 (3 H, s, OCH_3), 2.78 (1 H, m, H13), 2.50 (1 H, ddm, $J_{11\alpha,11\beta}$ = 16.0 Hz, $J_{11\alpha,12\alpha}$ = 5.6 Hz, H11α), 2.31 (1 H, dm, $J_{15\beta,15\alpha}$ = 16.4 Hz, H15β), 2.27 (1 H, d, $J_{15\alpha,15\beta}$ = 16.4 Hz, H15α), 2.10 (2 H, m, H14β and H11β), 1.66 (2 H, m, H12α and H12β), 11.58 (1 H, d, br, $J_{14\alpha,14\beta}$ = 11.5 Hz, H14α), 1.35 (3 H, s, H18); LRMS 374 (M^+, 6), 329 (24), 267 (52), 223 (13), 45 (100); HRMS found 374.1716 (M^+), $C_{21}H_{26}O_6$ requires 374.1729.

***ent*-2β-Hydrazino-3α-(methoxymethoxy)-20-norgibberella-1(10),16-diene-7,19-dioic acid 7-(methyl ester) 19,*N*′-lactam** (0.355 g, 10%): R_f 0.57 (Et_2O–MeOH, 5:1); $[\alpha]^{25}_D$ +32° (*c* 80.68 × 10^{-3}, CH_2Cl_2); IR ($CHCl_3$) ν_{max} 3400 (s), 1725 (s), 1655 (s), 1170 (m), 1149 (m), 1110 (m), 1040 (m), 920 (m), 910 (m) cm^{-1}; ^1H NMR (300 MHz, $CDCl_3$) 7.60 (1 H, s, br, CONH), 5.25 (1 H, s, br, H1), 4.85 (1 H, s, H17), 4.83 (1 H, s, H17′), 4.74, 4.67 (2 H, AB d, *J* = 7.0 Hz), 4.4 (1 H, br, NH), 3.80 (2 H, m, H2 and H3), 3.67 (3 H, s, CO_2CH_3), 3.34 (3 H, s, OCH_3), 3.34 (1 H, m, obscured, H5), 3.15 (1 H, d, $J_{6,5}$ = 5.3 Hz, H6), 2.69 (1 H, s, br, H9), 2.48 (1 H, s, br, H13), 2.39 (1 H, d, $J_{15\alpha,15\beta}$ = 15.7 Hz, H15α), 2.18 (1 H, d, br, $J_{15\beta,15\alpha}$ = 15.7 Hz, H15β), 1.72 (2 H, m, H11α and H11β), 1.6–1.3 (2 H, m, H12α and H12β), 1.28 (2 H, m, H14α and H14β), 1.20 (3 H, s, H18); LRMS 402 (M^+, 8), 370 (8), 325 (8), 309 (23), 308 (25), 223 (12), 45 (100); HRMS found 402.2136 (M^+), $C_{22}H_{30}O_5N_2$ requires 402.2155.

***ent*-2β-Hydrazino-3α-(methoxymethoxy)-20-norgibberella-1(10),16-diene-7,19-dioic acid 19,*N*′-lactam** (0.20 g, 7%): identified by its conversion into the methyl ester above with diazomethane.

***ent*-2β-Hydroxy-1α-iodo-3α-(methoxymethoxy)-20-norgibberella-9,16-diene-7,19-dioic Acid 7-(Methyl ester) 19,2-Lactone.** To a stirred solution of acid 7 (0.245 g, 0.63 mmol) in THF (10 mL) was added a 1 M aqueous solution of K_2CO_3 (5 mL). After the mixture was stirred at room temperature for 10 min, a solution of KI_3 (1 M in THF–H_2O, 1:1, 10 mL, 10 mmol) was added, followed by Et_2O (10 mL), and the mixture stirred for 15 min, when TLC analysis indicated reaction was complete. The mixture was diluted with Et_2O, washed with saturated aqueous sodium thiosulfate solution followed by brine, and dried over $MgSO_4$. Concentration in vacuo and chromatography on silica gel (Et_2O–hexane, 1:1) gave iodolactone (0.230 g, 71%) as a white solid. A small sample was recrystallized from Et_2O–hexane as colorless rectangular rods: mp 131–3 °C dec; R_f 0.56 (Et_2O–hexane, 2:1); $[\alpha]^{25}_D$ −370° (*c* 96.2 × 10^{-3}, CH_2Cl_2); IR ($CHCl_3$) ν_{max} 2940 (s), 1780 (s), 1730 (s), 1660 (m), 1480 (s), 1380 (s), 1340 (s), 1325 (s), 1270 (s), 1160 (s), 1055 (s), 995 (s), 920 (m), 890 (m) cm^{-1}; ^1H NMR (200 MHz, $CDCl_3$) 5.06 (1 H, d, br, $J_{1,2}$ = 3.1 Hz, H1), 4.78 (1 H, dd, $J_{2,3}$ = 5.0 Hz, $J_{2,1}$ = 3.1 Hz, H2), 4.26 (1 H, d, $J_{3,2}$ = 5.0 Hz, H3), 4.96 (1 H, s, H17), 4.90 (1 H, s, H17′), 4.92, 4.74 (2 H, AB d, *J* = 6.9 Hz, OCH_2O), 3.90 (1 H, dd, $J_{5,6}$ = 9.0 Hz, $J_{5,11\beta}$ = 3.9 Hz, H5), 3.73 (3 H, s, CO_2CH_3), 3.47 (3 H, s, OCH_3), 2.98 (1 H, d, $J_{6,5}$ = 9.0 Hz, H6), 2.74 (1 H, m, H13), 2.39 (1 H, m, H14α), 2.13 (1 H, d, br, $J_{15\beta,15\alpha}$ = 16.1 Hz, H15β), 1.96 (1 H, dt, $J_{15\alpha,15\beta}$ = 16.1 Hz, *J* = *ca* 2.5 Hz), 1.36 (1 H, dd, $J_{14\alpha,14\beta}$ = 11.0 Hz, $J_{14\alpha,15\beta}$ = 2.0 Hz, H14α), 2.1–1.58 (4 H, m), 1.16 (3 H, s, H18); LRMS 483 (M^+ − OCH_3, 3), 387 (12), 355 (21), 281 (89), 222 (100); HRMS found 483.0669 (M^+ − OCH_3), $C_{21}H_{24}O_5I$ requires 483.0669. Anal. Found: C, 51.12; H, 5.34. Calcd for $C_{22}H_{27}O_6I$: C, 51.37; H, 5.29.

***ent*-2β-Hydroxy-1α-iodo-3α-(methoxymethoxy)-16-oxo-17,20-dinorgibberell-9-ene-7,19-dioic Acid 7-(Methyl ester) 19,2-Lactone (8).** A solution of the diene iodolactone prepared above (0.228 g, 0.44 mmol) in dry CH_2Cl_2 (25 mL) and dry pyridine (4 mL) was added in one portion to a saturated solution of ozone in dry CH_2Cl_2 (200 mL), vigorously stirred at −78 °C. After ca. 5 s the reaction was quenched by addition of dimethyl sulfide (5 mL, 4.23 g, 68 mmol), and the solution was concentrated in vacuo. Chromatography on silica gel (hexane–Et_2O, 2:1 then 1:1) gave the 17-nor-16-one 8 (0.155 g, 68%), which crystallized from the collection tubes as colorless rectangular rods: mp 131–3 °C dec; R_f 0.40 (Et_2O–hexane, 3:1); $[\alpha]^{25}_D$ −361° (*c* 87.6 × 10^{-3}, CH_2Cl_2); IR ($CHCl_3$) ν_{max} 2960 (m), 1785 (s), 1740 (s), 1670 (w), 1160 (s), 1150 (s), 1050 (s), 995 (s) cm^{-1}; ^1H NMR (300 MHz, $CDCl_3$) 5.03 (1 H, d, br, $J_{1,2}$ = 3.1 Hz, H1), 4.92, 4.74 (2 H, 2 AB d, *J* = 7.0 Hz, OCH_2O), 4.81 (1 H, dd, $J_{2,3}$ = 5.0 Hz, $J_{2,1}$ = 3.1 Hz, H2), 4.29 (1 H, d, $J_{3,2}$ = 5.0 Hz, H3), 3.94 (1 H, dd, $J_{5,6}$ = 9.2 Hz, $J_{5,11\beta}$ = 4.5 Hz, H5), 3.76 (3 H, s, CO_2CH_3), 3.48 (3 H, s, OCH_3), 3.03 (1 H, d, $J_{6,5}$ = 9.2 Hz, H6), 2.60–2.50 (2 H, m, H11α and H13), 2.35 (1 H, ddd, $J_{14\beta,14\alpha}$ = 11.7 Hz, $J_{14\beta,13}$ = 5.8 Hz, $J_{14\beta,12\beta}$ = 1.3 Hz, H14β), 2.05 (1 H, dd, $J_{15\beta,15\alpha}$ = 17.8 Hz, $J_{15\beta,14\alpha}$ = 3.3 Hz, H15β), 2.03 (1 H, m, H13), 1.93 (1 H, dd, $J_{15\alpha,15\beta}$ = 17.8 Hz, *J* = 1.2 Hz, H15α), 1.86–1.6 (2 H, m, H11β and H12α), 1.66 (1 H, dd, $J_{14\alpha,14\beta}$ = 11.7 Hz, $J_{14\alpha,15\beta}$ = 3.2 Hz, H14α), 1.18 (3 H, s, H18); LRMS 485 (M^+ − OCH_3, 5), 389 (15), 329 (15), 283 (45), 224 (43), 155 (53), 45 (100); HRMS found 485.0461 (M^+ − OCH_3), $C_{20}H_{22}O_6I$ requires 485.0461. Anal. Found: C, 49.12; H, 4.81. Calcd for $C_{21}H_{25}O_7I$: C, 48.85; H, 4.88.

***ent*-2β-Hydroxy-3α-(methoxymethoxy)-16-oxo-17,20-dinor-9α,15α-cyclogibberell-1(10)-ene-7,19-dioic Acid 7-(Methyl ester) 19,2-Lactone (9).** A solution of iodo ketone 8 (0.643 g, 1.25 mmol) in dry THF (20 mL) was added dropwise to a stirred suspension of KH (1.0 g, 25 mmol, washed with dry hexane) in THF (80 mL), under N_2 at 0 °C. The solution was allowed to warm to room temperature over 45 min, at which stage TLC analysis indicated that reaction was complete. The mixture was diluted with Et_2O and filtered through Celite under N_2. The reaction flask and potassium hydride were rinsed with Et_2O, and the washings were filtered. Concentration and chromatography on silica gel (Et_2O–hexane, 1:1 then 2:1) gave the desired cyclopropyl ketone 9 as a white solid, which was recrystallized from Et_2O–hexane as colorless plates (0.435 g, 90%): mp 167–8 °C; R_f 0.21 (Et_2O–hexane, 4:1); $[\alpha]^{25}_D$ −153° (*c* 93.7 × 10^{-3}, CH_2Cl_2); IR ($CHCl_3$) ν_{max} 2950 (m), 1775 (s), 1735 (s), 1665 (w), 1175 (m), 1165 (m), 1150 (m), 1125 (m), 1050 (s), 995 (m), 950 (m) cm^{-1}; UV (EtOH) λ_{max} 222 nm (ε 9200 dm^3 mol^{-1} cm^{-1}); ^1H NMR (300 MHz, $CDCl_3$) 5.79 (1 H, dm, $J_{1,2}$ = 5.4 Hz, H1), 4.79 (1 H, dd, $J_{2,1}$ = 5.4 Hz, $J_{2,3}$ = 5.0 Hz, H2), 4.71, 4.66 (2 H, 2 AB d, *J* = 7.0 Hz, OCH_2O), 3.95 (1 H, d, $J_{3,2}$ = 5.0 Hz, H3), 3.74 (3 H, s, CO_2CH_3), 3.33 (3 H, s, OCH_3), 2.96 (2 H, s, H5 + H6), 2.33 (1 H, ddd, $J_{14\beta,14\alpha}$ = 11.8 Hz, $J_{14\beta,13}$ = 6.0 Hz, $J_{14\beta,12\beta}$ = 1.2 Hz, H14β), 2.30 (1 H, d, $J_{15,13}$ = 1.5 Hz, H15), 2.28–2.17 (2 H, m, H13 and H11α), 2.03 (1 H, m, H11β), 1.86 (1 H, d, $J_{14\alpha,14\beta}$ = 11.8 Hz, H14α), 1.78–1.88 (2 H, m, H12α and 12β), 1.16 (3 H, s, H18); LRMS 388 (M^+, 11), 356 (3), 343 (22), 329 (24), 328 (24), 296 (47), 283 (33), 269 (35), 203 (100); HRMS found 388.1522 (M^+), $C_{21}H_{24}O_7$ requires 388.1522. Anal. Found: C, 65.15; H, 6.53. Calcd for $C_{21}H_{24}O_7$: C, 64.93; H, 6.23.

***ent*-3α,10β-Dihydroxy-16-oxo-17,20-dinor-9α,15α-cyclogibberell-1-ene-7,19-dioic Acid 7-(Methyl ester) 19,10-Lactone**

(10). **Preparation 1.** To a stirred solution of methoxymethyl ether **9** (435 mg, 1.12 mmol) in dry CH_2Cl_2 (20 mL) at −30 °C was added a solution of Ph_2BBr (1.2 g, 5.0 mmol) in dry CH_2Cl_2 (2 mL). TLC analysis indicated that all of the starting material has been consumed and been replaced by a mixture of two products. The temperature was allowed to rise to −15 °C, and additional Ph_2BBr was added dropwise until all of the more polar (fluorescence quenching) material had been converted into the less polar (nonfluorescence quenching) component. Aqueous (1 M) K_2CO_3 solution was added, and, after stirring for 5 min, the product was extracted into Et_2O. The combined organic extracts were washed with brine, dried over $MgSO_4$, and concentrated in vacuo. Chromatography on silica gel (Et_2O–hexane, 3:1 then Et_2O) gave the desired rearranged alcohol **10** (301 mg, 78%) as a colorless oil: R_f 0.62 (Et_2O–MeOH, 8:1); $[\alpha]^{25}_D$ −41° (*c* 23.1 × 10^{-3}, CH_2Cl_2); IR ($CHCl_3$) ν_{max} 2960 (w), 1780 (s), 1735 (s), 1160 (m), 1130 (m), 1040 (m), 1000 (m), 920 (m) cm^{-1}; ^1H NMR (300 MHz, $CDCl_3$) 6.48 (1 H, dd, $J_{1,2}$ = 9.4 Hz, J = 0.9 Hz, H1), 5.94 (1 H, dd, $J_{2,1}$ = 9.4 Hz, $J_{2,3}$ = 3.7 Hz, H2), 4.20 (1 H, dd, $J_{3,OH}$ = 6.5, $J_{3,2}$ = 3.7 Hz, H3), 3.75 (3 H, s, CO_2CH_3), 3.04 (1 H, d, $J_{6,5}$ = 9.4 Hz, H6), 2.67 (1 H, d, $J_{5,6}$ = 9.4 Hz, H5), 2.42 (1 H, dd, $J_{14\beta,14\alpha}$ = 11.8 Hz, $J_{14\beta,13}$ = 5.7 Hz, H14β), 2.26–2.38 (2 H, m, H11α and H13), 2.12 (1 H, m, H11β), 2.09 (1 H, d, $J_{15,13}$ = 1.5 Hz, H15), 1.95 (1 H, d, $J_{14\alpha,14\beta}$ = 11.8 Hz, H14α), 1.96–1.86 (2 H, m, H12α and H12β), 1.30 (3 H, s, H18); LRMS 344 (M^+, 6), 326 (2), 312 (4), 298 (5), 285 (12), 284 (12), 283 (10), 282 (10), 241 (19), 223 (12), 195 (24); HRMS found 344.1259 (M^+), $C_{19}H_{20}O_6$ requires 344.1260.

Preparation 2. A solution of diene **32** (0.248 g, 0.65 mmol) in EtOAc (40 mL) containing rhodium–alumina (5%, 82 mg) was vigorously stirred at 24 °C under an atmosphere of hydrogen for 3 h. The filtered solution was reduced to dryness, and the residue was crystallized from EtOAc–Et_2O to give ***ent*-3α-acetoxy-2β-hydroxy-16-oxo-17,20-dinor-9α,15α-cyclogibberell-1(10)-ene-7,19-dioic acid 7-(methyl ester) 19,2-lactone** (two crops, 128 and 97 mg, total 90%): mp 195–198 °C; IR ν_{max} 1784 (s), 1750–1720 (s), 1662 (m), 1445 (m), 1238 (s), 1070 (s), 950 (s) cm^{-1}; ^1H NMR (200 MHz, $CDCl_3$) 5.70 (1 H, dm, $J_{1,2}$ = 5.0 Hz, H1), 4.95 (1 H, dd, $J_{2,1}$ = 5.0 Hz, $J_{2,3}$ = 5.2 Hz, H2), 4.89 (1 H, d, $J_{2,3}$ = 5.2 Hz, H3), 3.78 (3 H, s, CO_2CH_3), 2.85 (1 H, dd, $J_{5,6}$ = 9.7 Hz, $J_{5,1}$ = 2.4 Hz, H5), 2.94 (1 H, d, $J_{6,5}$ = 9.7 Hz, H6), 2.25 (1 H, s, H15), 1.18 (3 H, s, H18); LRMS 386 (M^+, 9), 358 (3), 344 (3), 327 (9), 300 (18), 299 (20), 285 (42), 283 (31), 282 (42), 254 (26), 241 (28), 213 (42), 195 (100), 181 (28) 165 (25), 155 (17), 153 (15), 141 (14), 129 (13), 115 (11), 43 (30), 42 (100). Anal. Found: C, 65.12; H, 5.54. Calcd for $C_{21}H_{22}O_7$: C, 65.27; H, 5.74.

A solution of this product (50 mg, 0.13 mmol) in CH_2Cl_2 (10 mL) was treated with Ph_2BBr (0.60 g, 2.4 mmol), and the mixture was stirred under nitrogen at −10 °C for 2 h. A solution of $NaHCO_3$ was then added, and after 10 min the product was extracted into EtOAc. After drying ($MgSO_4$), the solvent was removed in vacuo, and the residue was chromatographed on silica gel. ***ent*-3α-Acetoxy-10β-hydroxy-16-oxo-17,20-dinor-9α,15α-cyclogibberell-1-ene-7,19-dioic acid 7-(methyl ester) 19,10-lactone** was eluted with Et_2O as a white solid: mp 204–206 °C (45 mg, 90%); IR ($CHCl_3$) ν_{max} 1783 (s), 1748 (s), 1733 (s), 1280 (m), 1228 (s), 1210 (s), 1155 (m), 970 (m), 910 (m), 740 (m) cm^{-1}; ^1H NMR (200 MHz, $CDCl_3$) 6.53 (1 H, d, $J_{1,2}$ = 9.6 Hz), 5.89 (1 H, dd, $J_{2,1}$ = 9.6 Hz, $J_{2,3}$ = 3.7 Hz, H2), 5.37 (1 H, d, $J_{3,2}$ = 3.7 Hz, H3), 3.76 (3 H, s, CO_2CH_3), 3.02 (1 H, d, $J_{6,5}$ = 9.3 Hz, H6), 2.76 (1 H, d, $J_{5,6}$ = 9.3 Hz, H5), 2.09 (1 H, d, $J_{15,13}$ = 1.5 Hz, H15), 2.12 (3 H, s, $OCOCH_3$), 1.19 (3 H, s, H18); LRMS 383 (M^+, 6), 300 (20), 282 (57), 254 (28), 241 (15), 223 (42), 213 (30), 195 (80), 181 (21), 165 (20), 155 (14), 153 (14), 141 (14), 128 (15), 115 (15), 91 (14), 43 (100). Anal. Found: C, 65.48; H, 5.51. Calcd for $C_{21}H_{22}O_7$: C, 65.27; H, 5.74.

A stirred solution of this acetate (10 mg, 0.026 mmole in methanol (1 mL) was treated dropwise with 0.5 M K_2CO_3 (0.15 mL, 0.075 mmol) over 30 s. After 6 min the cooled solution was diluted with brine and extracted into EtOAc. Removal of solvent from the dried extract afforded carbinol **10** as a colorless oil (8.5 mg, 95%), the TLC and ^1H NMR spectrum of which were identical with the sample prepared above.

***ent*-10β-Hydroxy-3α-((methylsulfonyl)oxy)-16-oxo-17,20-dinor-9α,15α-cyclogibberell-1-ene-7,19-dioic Acid 7-(Methyl ester) 19,10-Lactone.** To a stirred solution of alcohol **10** (301 mg, 0.87 mmol) in dry CH_2Cl_2 (50 mL) and dry Et_3N (3 mL) at 0 °C was added freshly distilled methanesulfonyl chloride (1 mL, 1.5 g, 13 mmol), and the mixture was stirred at 0 °C for 6 h. The solution was poured into Et_2O and washed with aqueous $NaHCO_3$ solution followed by brine. After drying over $MgSO_4$, the solution was concentrated in vacuo, and the product was chromatographed on silica gel (Et_2O–hexane, 3:1) to give the desired mesylate (340 mg, 92%) as a colorless oil: R_f 0.62 (Et_2O–MeOH, 8:1); $[\alpha]^{25}_D$ +41° (*c* 15.8 × 10^{-3}, CH_2Cl_2); IR ($CHCl_3$) ν_{max} 2960 (w), 1780 (s), 1735 (s), 1180 (s), 1160 (m), 1130 (m), 920 (m) cm^{-1}; ^1H NMR (300 MHz, $CDCl_3$) 6.65 (1 H, dd, $J_{1,2}$ = 9.3 Hz, J = 0.8 Hz, H1), 6.04 (1 H, dd, $J_{2,1}$ = 9.3 Hz, $J_{2,3}$ = 3.8 Hz, H2), 5.11 (1 H, d, $J_{3,2}$ = 3.8 Hz, H3), 3.78 (3 H, s, CO_2CH_3), 3.11 (3 H, s, OSO_2CH_3), 3.05 (1 H, d, $J_{6,5}$ = 9.3 Hz, H6), 2.74 (1 H, d, $J_{5,6}$ = 9.3 Hz, H5), 2.45 (1 H, dd, $J_{14\beta,14\alpha}$ = 11.8 Hz, $J_{14\beta,13}$ = 6.0 Hz, H14β), 2.28–2.40 (2 H, m, H11α and H13), 2.18 (1 H, m, H11β), 2.11 (1 H, d, $J_{15,13}$ = 1.5 Hz, H15), 1.97 (1 H,m d, $J_{14\alpha,14\beta}$ = 11.8 Hz, H14α), 1.88–1.97 (2 H, m, H12α and H12β), 1.34 (3 H, s, H18); LRMS 422 (M^+, 2), 363 (2), 282 (10), 195 (31), 44 (100); HRMS found 422.1035 (M^+), $C_{20}H_{22}O_8S$ requires 422.1035.

***ent*-1α-Acetoxy-10β-hydroxy-16-oxo-17,20-dinor-9α,15α-cyclogibberell-2-ene-7,19-dioic Acid 7-(Methyl ester) 19,10-Lactone (12).** A solution of the mesylate prepared above (341 mg, 0.81 mmol) and dry LiOAc (0.5 g, 7.6 mmol) in dry HMPT (10 mL) was stirred under N_2 at 4 °C for 72 h. The solution was diluted with Et_2O (100 mL) and washed with H_2O (2 × 25 mL) followed by brine. After being dried over $MgSO_4$, the solution was concentrated in vacuo, and the product was chromatographed on silica gel (Et_2O–hexane, 2:1 then 3:1) to give the desired 1β-acetate **12** (165 mg, 53%) as a colorless oil: R_f 0.54 (Et_2O); $[\alpha]^{21}_D$ −280° (*c* 15.0 × 10^{-3}, CH_2Cl_2); IR ($CHCl_3$) ν_{max} 2960 (w), 1785 (s), 1737 (s), 1375 (m), 1280 (m), 1160 (m), 1130 (m), 1112 (m), 1035 (m) cm^{-1}; ^1H NMR (200 MHz, $CDCl_3$) 5.97 (1 H, dd, $J_{3,2}$ = 9.2 Hz, $J_{3,1}$ = 0.8 Hz, H3), 5.79 (1 H, dd, $J_{2,3}$ = 9.2 Hz, $J_{2,1}$ = 3.5 Hz, H2), 5.62 (1 H, dd, $J_{1,2}$ = 3.5 Hz, $J_{1,3}$ = 0.8 Hz, H1), 3.74 (3 H, s, CO_2CH_3), 2.92 (1 H, dd, $J_{6,5}$ = 8.9 Hz, J = 0.5 Hz, H6), 2.51 (1 H, d, $J_{5,6}$ = 8.9 Hz, H5), 2.40 (1 H, dd, br, $J_{14\beta,14\alpha}$ = 11.8 Hz, $J_{14\beta,13}$ = 6.0 Hz, H14β), 2.40–2.04 (3 H, m, H11β, H13, H11α), 2.17 (3 H, s, $OCOCH_3$), 2.13 (1 H, d, $J_{15,13}$ = 1.5 Hz, H15), 11.92 (1 H, d, $J_{14\alpha,14\beta}$ = 11.8 Hz, H14α), 1.84 (2 H, m, H12α, H12β), 1.28 (3 H, s, H18); LRMS 386 (M^+, 4), 358 (1), 344 (1), 327 ( ), 316 (7), 300 (11), 282 (97), 271 (28), 254 (56), 223 (48), 213 (34), 195 (100); HRMS found 386.1364 (M^+), $C_{21}H_{22}O_7$ requires 386.1366.

In addition, the 3α-acetate **11** was obtained (131 mg, 42%): R_f 0.40 (Et_2O); $[\alpha]^{21}_D$ −190° (*c* 11.6 × 10^{-3}, CH_2Cl_2); IR ($CHCl_3$) ν_{max} 2960 (w), 1785 (s), 1737 (s), 1440 (m), 1372 (m), 1245 (m), 1172 (m), 1130 (m), 1020 (m), 990 (m), 970 (m), 915 (m) cm^{-1}; ^1H NMR (300 MHz, $CDCl_3$) 6.47 (1 H, dd, $J_{1,2}$ = 9.5 Hz, $J_{1,3}$ = 1.8 Hz, H1), 5.80 (1 H, dd, $J_{2,1}$ = 9.5 Hz, $J_{2,3}$ = 2.8 Hz, H2), 5.49 (1 H, dd, $J_{3,2}$ = 2.8 Hz, $J_{3,1}$ = 1.8 Hz, H3), 3.74 (3 H, s, CO_2CH_3), 3.01 (1 H, d, $J_{6,5}$ = 9.3 Hz, H6), 2.48 (1 H, d, $J_{5,6}$ = 9.3 Hz, H5), 2.42 (1 H, dd, $J_{14\beta,14\alpha}$ = 11.7 Hz, $J_{14\beta,13}$ = 5.9 Hz, H14β), 2.38 (1 H, m, H11α), 2.29 (1 H, dtd, $J_{13,14\beta}$ = 5.9 Hz, $J_{13,12(12')}$ = 3.2 Hz, $J_{13,15}$ = 1.7 Hz, H13), 2.16 (1 H, m, H11β), 2.11 (3 H, s, $OCOCH_3$), 1.99 (1 H, d, $J_{15,13}$ = 1.7 Hz, H15), 1.94 (1 H, d, $J_{14\alpha,14\beta}$ = 11.7 Hz, H14α), 1.90 (2 H, m, H12α, H12β), 1.21 (3 H, s, H18); LRMS 386 (M^+, 4), 355 (2), 344 (3), 327 (13), 300 (72), 283 (60), 282 (76), 271 (12), 254 (20), 241 (34), 223 (34), 195 (100); HRMS found 383.1364 (M^+), $C_{21}H_{22}O_7$ requires 386.1366.

***ent*-1α,10β-Dihydroxy-16-oxo-17,20-dinor-9α,15α-cyclogibberellane-7,19-dioic Acid 7-(Methyl ester) 19,10-Lactone (13). Preparation 1.** A solution of acetate **12** (165 mg, 0.43 mmol) in MeOH (30 mL) was treated with an aqueous solution of K_2CO_3 (0.25 M, 10 mL, 2.5 mmol), and the mixture was stirred at room temperature for 15 min. The solution was diluted with brine and extracted with Et_2O, and the combined organic extracts were dried over $MgSO_4$ and concentrated in vacuo. The crude product was dissolved in EtOAc (5 mL) and stirred over 5% Rh/alumina (25 mg) under a hydrogen atmosphere for 6 h. The catalyst was removed by filtration (Whatman GF/A), and the product was concentrated in vacuo. Recrystallization of the crude product from Et_2O–EtOAc gave the desired 1β-alcohol **13** (136 mg, 91%) as colorless needles: mp 220–1 °C; R_f 0.66 (Et_2O–MeOH, 20:1); $[\alpha]^{25}_D$ −103° (*c* 12.6 × 10^{-3}, CH_2Cl_2); IR ($CHCl_3$) ν_{max} 3600–3200 (m), 2960 (w), 1780 (s), 1735 (s), 1380 (m), 1175 (m), 1125 (s), 1020 (m), 990 (m), 920 (m) cm^{-1}; ^1H NMR (300 MHz, $CDCl_3$) 4.37 (1 H, s, br, H1), 3.75 (3 H, s, CO_2CH_3), 3.08 (1 H, s, br, O*H*), 2.98

(1 H, d, $J_{6,5}$ = 9.0 Hz, H6), 2.72 (1 H, d, $J_{5,6}$ = 9.0 Hz, H5), 2.43 (1 H, d, $J_{15,13}$ = 1.7 Hz, H15), 2.42 (1 H, ddd, $J_{14\beta,14\alpha}$ = 11.7 Hz, $J_{14\beta,13}$ = 7.5 Hz, $J_{14\beta,12\beta}$ = 1.5 Hz, H14β), 2.31 (1 H, m, H11α), 2.27 (1 H, dtd, $J_{13,14\beta}$ = 7.5 Hz, $J_{13,12(12')}$ = 3.3 Hz, $J_{13,15}$ = 1.7 Hz, H13), 2.12 (1 H, m, H11β), 1.93 (1 H, d, $J_{14\alpha,14\beta}$ = 11.7 Hz, H14α), 1.90–1.72 (5 H, m), 1.61 (1 H, m, H2α), 1.15 (3 H, s, H18); LRMS 346 (M^+, 32), 331 (5), 318 (14), 314 (43), 304 (27), 287 (80), 284 (43), 275 (100), 259 (12), 225 (36), 197 (26); HRMS found 346.1416 (M^+), $C_{19}H_{22}O_6$ requires 346.1416. Anal. Found: C, 66.10; H, 642. Calcd for $C_{19}H_{22}O_6$: C, 65.88; H, 6.40.

Preparation 2. A solution of 1β-acetate (**30**) (20.4 mg, 53 μmol) in MeOH (5 mL) was treated with an aqueous solution of $KHCO_3/K_2CO_3$ (1/1, 0.5 M, 0.1 mL), and the mixture was stirred at room temperature for 5 min. EtOAc was added, and the organic layer was washed with brine, dried over $MgSO_4$, and concentrated in vacuo. The crude hydrolysis product was redissolved in EtOAc (5 mL) and stirred with 5% Rh/alumina (5 mg) under a H_2 atmosphere for 6 h. Filtration (Whatman GF/A), concentration in vacuo, and chromatography on silica gel (Et_2O) gave the desired hydroxy ketone **13** (12 mg, 68%), identical in all respects with the sample prepared above from **12**. In addition, the corresponding 1β,16ξ-diol resulting from over-reduction was obtained (2 mg, 11%) as a colorless oil: ^{1}H NMR (200 MHz, $CDCl_3$) 4.41 (1 H, m, H1), 4.24 (1 H, s, br, H16), 3.73 (3 H, s, CO_2CH_3), 2.80 (1 H, d, $J_{6,5}$ = 9.0 Hz, H6), 2.64 (1 H, d, $J_{5,6}$ = 9.0 Hz, H5), 2.2–1.2 (14 H, m), 1.10 (3 H, s, H18); LRMS 348 (M^+, 32), 330 (23), 316 (66), 289 (66), 277 (100), 271 (26), 257 (47), 227 (95); LRMS (bis-TMS ether) 492 (M^+, 7), 477 (4), 421 (5), 402 (19), 73 (100).

***ent*-1α,10β-Dihydroxy-20-nor-9α,15α-cyclogibberell-16-ene-7,19-dioic Acid 19,10-Lactone (3) Methyl Ester. Preparation 1.** A stock solution of methylidenetriphenylphosphorane was prepared from dry methyltriphenylphosphonium bromide (1 g, 2.8 mmol) and *n*-BuLi (1.5 M, 1.8 mL, 2.7 mmol) in dry THF (10 mL). A portion of this solution (0.4 mL, 85 μmol) was added dropwise to a stirred solution of ketone **13** (8.1 mg, 23.5 μmol) in dry THF (5 mL) at −20 °C. TLC analysis indicated that all of the starting material had been consumed and replaced by a very polar product, believed to be a betaine. The mixture was allowed to warm to 0 °C and quenched with saturated aqueous NH_4Cl solution. The mixture was diluted with H_2O and washed with EtOAc. The product remained in the aqueous phase. The H_2O was evaporated in vacuo, the product was dissolved in EtOH, and the insoluble NH_4Cl was filtered off. The ethanolic solution was heated under reflux with DBU (1 mL) for 20 min, concentrated in vacuo, diluted with EtOAc, and washed with 1 N HCl followed by brine. After the mixture was dried over $MgSO_4$, the product was concentrated in vacuo and chromatographed on a preparative TLC plate (Et_2O) to give the desired olefin (1.2 mg, 15%) as a colorless oil; for spectroscopic details see below.

Preparation 2. To a stirred suspension of activated zinc dust (5.75 g, 88 mmol) in dry THF (50 mL) and CH_2Br_2 (2.0 mL, 28 mmol) at −40 °C was added $TiCl_4$ (2.3 mL, 21 mmol) dropwise over 10 min. The mixture was then stirred under N_2 at 4 °C for 14 h; 4 mL of this suspension was added dropwise to a stirred solution of ketone **13** (0.136 g, 0.39 mmol) in dry THF (15 mL) at room temperature, under N_2. Reaction was judged to be complete by TLC analysis after 5 min. Aqueous $NaHCO_3$ solution was added, and, after 5 min, the product was extracted with Et_2O, washed with brine, and dried over $MgSO_4$. Concentration in vacuo and chromatography on silica gel (Et_2O–hexane, 4:1) gave the desired olefin (0.112 g, 83%) as a foam: R_f 0.59 (Et_2O); $[\alpha]^{21}_D$ −50° (c 3 × 10^{-3}, CH_2Cl_2); IR ($CHCl_3$) ν_{max} 2958 (w), 1775 (s), 1732 (s), 1666 (w), 1455 (w), 1439 (w), 1385 (w), 1280 (m), 1260 (m), 1175 (m), 1138 (m), 999 (m), 920 (m), 910 (m), 880 (w) cm^{-1}; ^{1}H NMR (300 MHz, $CDCl_3$), 4.80 (1 H, s, H17), 4.76 (1 H, s, H17′), 4.29 (1 H, s, br, H1), 3.72 (3 H, s, CO_2CH_3), 2.95 (1 H, d, $J_{6,5}$ = 8.9 Hz, H6), 2.72 (1 H, d, $J_{5,6}$ = 8.9 Hz, H5), 2.41 (1 H, m, H13), 2.37 (1 H, s, br, H15), 2.16 (1 H, m, H11α), 2.02 (1 H, ddd, $J_{14\beta,14\alpha}$ = 11.9 Hz, $J_{14\beta,13}$ = 5.8 Hz, $J_{14\beta,12\beta}$ = 1.5 Hz, H14β), 1.95 (1 H, m, H11β), 1.87–1.70 (3 H, m, H3α, H3β, H2β), 1.64 (1 H, d, $J_{14\alpha,14\beta}$ = 11.9 Hz, H14α), 1.63–1.50 (4 H, m, H12α, H12β, H2α, OH), 1.12 (3 H, s, H18); LRMS 344 (M^+, 58), 329 (2), 312 (7), 285 (27), 282 (34), 223 (100), 195 (25); LRMS TMS ether 416 (M^+, 35), 401 (3), 384 (2), 357 (15), 345 (9), 285 (32), 282 (31), 272 (12), 259 (18), 223 (51), 213 (28), 73 (100); HRMS found 344.1622 (M^+), $C_{20}H_{24}O_5$ requires 344.1624.

In addition, **1β,10α-dihydroxyantherida-6(8),16-diene-7,19-dioic acid 19,10-lactone methyl ester** (5 mg, 4%) was obtained: R_f 0.54 (Et_2O); IR ($CHCl_3$) ν_{max} 3700–3200 (m), 2950 (m), 1770 (s), 1705 (s), 1640 (w), 1438 (m), 1260 (m), 1139 (m), 1004 (m), 920 (m); ^{1}H NMR (300 MHz, $CDCl_3$) 4.84 (1 H, dt, $J_{17,17'}$ = 3.8 Hz, J = 2.4 Hz, H17), 4.65 (1 H, dt, $J_{17,17'}$ = 3.8 Hz, J = 2.0 Hz, H17′), 4.30 (1 H, m, H1), 3.77 (1 H, dd, $J_{5,14}$ = 3.7 Hz, $J_{5,14'}$ = 2.2 Hz, H5), 3.72 (3 H, s, CO_2CH_3), 2.75 (1 H, dm, $J_{14,14'}$ = 18.9 Hz, H14), 2.58–2.42 (3 H, m), 2.16 (1 H, m), 2.0–1.5 (8 H, m), 1.22 (3 H, s, H18); LRMS 344 (M^+, 32), 326 (5), 316 (17), 313 (29), 312 (30), 300 (50), 285 (15), 284 (26), 252 (36), 238 (100), 223 (36); HRMS found 344.1630 (M^+), $C_{20}H_{24}O_5$ requires 344.1624.

***ent*-1α,10β-Dihydroxy-20-nor-9α,15α-cyclogibberell-16-ene-7,19-dioic Acid 19,10-Lactone (3).** To a stirred solution of the ester prepared above (0.06 g, 0.175 mmol) in dry HMPT (5 mL) at room temperature was added freshly prepared lithium propane-1-thiolate (0.20 g, 2.4 mmol), and the mixture was stirred under N_2 for 90 min. The mixture was diluted with H_2O (10 mL) and 1 M aqueous $NaHCO_3$ solution (1 mL) and washed with EtOAc. The aqueous phase was acidified to pH 3 with 1 N HCl and extracted with EtOAc, washed with 1 N HCl followed by 1 M aqueous $CuSO_4$ solution, and finally saturated aqueous NH_4Cl solution. The product was dried over $MgSO_4$, concentrated in vacuo, and chromatographed on silica gel (Et_2O–MeOH, 8:1) to give the desired carboxylic acid as an oil, which crystallized as needles on addition of Et_2O (37 mg, 64%): mp 213–4 °C; R_f 0.61 (Et_2O–MeOH, 8:1); $[\alpha]^{21}_D$ −72° (c 12.75 × 10^{-3}, MeOH); IR ($CHCl_3$) ν_{max} 3600–2300 (m), 2950 (m), 2870 (m), 1770 (s), 1725 (m), 1712 (m), 1670 (w), 1455 (w), 1385 (w), 1282 (m), 1182 (m), 1138 (m), 990 (m), 912 (m) cm^{-1}; ^{1}H NMR (300 MHz, $CDCl_3$) 4.82 (1 H, s, H17), 4.78 (1 H, s, H17′), 4.30 (1 H, m, H1), 2.99 (1 H, d, $J_{6,5}$ = 8.9 Hz, H6), 2.70 (1 H, d, $J_{5,6}$ = 8.9 Hz, H5), 2.44 (1 H, m, H13), 2.38 (1 H, s, H15), 2.24–2.10 (2 H, m, H11α and H14α), 1.96 (1 H, m, H11β), 1.87–1.70 (3 H, m, H2β, H3α, and H3β), 1.67 (1 H, d, $J_{14\alpha,14\beta}$ = 11.3 Hz, H14α), 1.68–1.53 (3 H, m, H12α, H12β, and H2α), 1.17 (3 H, s, H18); LRMS 330 (M^+, 7), 312 (1), 286 (1), 285 (1), 284 (1), 271 (5), 269 (2), 268 (7), 259 (2), 240 (3), 239 (3), 223 (18), 195 (8), 181 (7), 107 (26), 105 (24), 91 (100); HRMS found 330.1468 (M^+), $C_{19}H_{22}O_5$ requires 330.1467. Anal. Found: C, 68.79; H, 6.82. Calcd for $C_{19}H_{22}O_5$: C, 69.07; H, 6.71.

***ent*-3α-Acetoxy-2β-hydroxy-16-methylene-20-norgibberell-1(10)-ene-7,19-dioic Acid 7-(Methyl ester) 19,2-Lactone (16).** Gibberellin A_7 3-acetate methyl ester (**14**) (0.240 g, 0.622 mmol), prepared from GA_3 (**5**) by the method of Dolan and MacMillan,[35] was dissolved in dry ether (20 mL) and treated with zinc(II) bromide (1.1 g). After stirring at 22 °C for 24 h, the reaction was 50% complete (estimated from ^{1}H NMR spectra), so further zinc(II) bromide was added and stirring was continued for a further 22 h (ca. 95% reaction). Ice-cold 1 M HCl was then added, and the organic phase was separated, washed with brine, and dried ($MgSO_4$). Removal of solvent and crystallization of the residue from Et_2O–hexane gave colorless crystals of **16** (219 mg, 90%): mp 112–114 °C; IR ($CHCl_3$) ν_{max} 1783 (s), 1763 (s), 1732 (s), 1068 (m), 950 (m), 895 (m) cm^{-1}; ^{1}H NMR (200 MHz, $CDCl_3$) 5.71 (1 H, m, H1), 5.32 (1 H, dd, $J_{2\beta,3\alpha}$ = 6.4 Hz, $J_{2\beta,1}$ = 2.6 Hz, H2β), 4.99 (1 H, m, H3α), 4.90 (2 H, br s, H17,17′), 3.74 (3 H, s, CO_2CH_3), 3.39 (1 H, dd, $J_{5,6}$ = 6.6 Hz, $J_{5,11\beta}$ = 2.4 Hz, H5), 2.75 (1 H, m, H13), 2.63 (1 H, d, $J_{6,5}$ = 6.6 Hz, H6), 2.12 (3 H, s, $OCOCH_3$), 1.21 (3 H, s, H18); LRMS 386 (M^+, 5), 368 (5), 354 (6), 326 (13), 294 (30), 281 (63), 266 (14), 251 (12), 239 (12), 223 (40), 222 (50), 221 (55), 193 (22), 179 (18), 155 (30), 143 (15), 129 (14), 115 (13), 43 (100). Anal. Found: C, 68.76; H, 6.64. Calcd for $C_{22}H_{26}O_6$: C, 68.38; H, 6.78.

***ent*-3α-Acetoxy-2β-hydroxy-16-oxo-17,20-dinorgibberell-1(10)-ene-7,19-dioic Acid 7-(Methyl ester) 19,2-Lactone (17). Preparation 1.** Gibberellin A_7 17-nor-16-one methyl ester[24] (prepared by ozonolysis as described below on **16**) (5.17 g, 14.94 mmol) was stirred at room temperature with 0.01 N NaOH solution (2.5 L). The substrate gradually dissolved over a period of ca. 30 min, and the reaction was judged to be complete after 2 h according to TLC analysis. The aqueous solution was saturated with NaCl, and the product was extracted with EtOAc, dried over $MgSO_4$, and concentrated in vacuo. The aqueous phase was acidified to pH 3 with 2 N HCl and reextracted with EtOAc, to

(35) Dolan, S. C.; MacMillan, J. *J. Chem. Soc., Chem. Commun.* **1985**, 1588–1589.

give the corresponding dihydroxy acid. After drying over $MgSO_4$ and concentration, this product was combined with the previously isolated hydroxy lactone, and the mixture was dissolved in dry CH_2Cl_2 (100 mL) and treated with Et_3N (5 mL) and acetic anhydride (5 mL). After 30 min at room temperature, DMAP (0.1 g) was added, and the mixture was stirred for an additional 5 min. H_2O (100 mL) was added, and the mixture was stirred vigorously for a further 30 min to destroy the excess of acetic anhydride. The product was extracted with Et_2O and the combined extracts washed successively with saturated aqueous $NaHCO_3$ solution, 1 N HCl, and brine and then dried over $MgSO_4$. Concentration in vacuo and chromatography on silica gel (Et_2O–hexane, 2:1 then 1:1) gave, after recrystallization from Et_2O, the desired 19,2-lactone **17** (3.13 g, 54%) as a colorless solid: mp 151–2 °C; R_f 0.25 (Et_2O–hexane, 2:1); $[\alpha]^{24}$ +186° (c 4.85 × 10^{-3}, CH_2Cl_2); IR ($CHCl_3$) ν_{max} 2960 (m), 2880 (w), 1780 (s), 1740 (s), 1675 (w), 1365 (m), 1337 (m), 1177 (m), 1075 (m), 950 (m) cm^{-1}; ^1H NMR (200 MHz, $CDCl_3$) 5.79 (1 H, m, H1), 5.03 (2 H, m, H2 and H3), 3.74 (3 H, s, CO_2CH_3), 3.39 (1 H, dd, $J_{5,6}$ = 6.6 Hz, $J_{5,11\beta}$ = 2.4 Hz, H5), 2.75 (1 H, m, H13), 2.63 (1 H, d, $J_{6,5}$ = 6.6 Hz, H6), 2.35 (2 H, m), 2.12 (3 H, s, $OCOCH_3$), 2.12 (1 H, m), 1.9–1.5 (6 H, m), 1.23 (3 H, s, H18); LRMS 388 (M^+, 1), 356 (2), 329 (6), 328 (25), 310 (17), 296 (57), 284 (23), 283 (62), 225 (70), 224 (100); HRMS found 388.1522 (M^+), $C_{21}H_{24}O_7$ requires 388.1522. Anal. Found: C, 65.18; H, 6.49. Calcd for $C_{21}H_{24}O_7$: C, 64.93; H, 6.23.

Preparation 2. A solution of the iso-GA_7 derivative **16** (6.82 g, 17.67 mmol) in a mixture of EtOH (600 mL) and pyridine (3 mL) at −15 °C was treated with a stream of ozonized oxygen until TLC showed equal intensities for starting material and product (4 min), indicating >80% reaction. Acetic acid (15 mL), water (24 mL), and zinc powder (5 g) were added, and after stirring for 30 min the filtered solution was reduced to a small volume and extracted with EtOAc (3 × 50 mL). After washing with $NaHCO_3$ and brine and then drying ($MgSO_4$), the combined organic layers were reduced to dryness, and the residue was crystallized from EtOAc to give **17** (2.47 g). Chromatography (EtOAc–hexane, 1:1) of the mother liquor afforded recovered starting material (0.87 g, 12.7%) and further product (3.46 g) (total yield 86%), mp 150–2 °C, identical in all respects with material from procedure 1.

***ent*-3α-Acetoxy-1α,11α-dibromo-2β-hydroxy-16-oxo-17,20-dinorgibberell-9-ene-7,19-dioic Acid 7-(Methyl ester) 19,2-Lactone (19).** A solution of ketone **17** (2.7 g, 6.96 mmol), *N*-bromosuccinimide (3.72 g, 21 mmol), and dibenzoyl peroxide (20 mg, 80 μmol) in dry CCl_4 (75 mL) was heated at reflux, under N_2, for 1 h, or until all of the initially formed monobromide had been replaced by the corresponding dibromide according to TLC analysis (on TLC analysis, the monobromide is observed as a higher R_f spot, whereas the corresponding dibromide has the same R_f as the starting material). The mixture was cooled, diluted with Et_2O, and washed with saturated aqueous sodium thiosulfate solution and then brine. After drying over $MgSO_4$ and concentration in vacuo, the product was chromatographed on silica gel (Et_2O–hexane, 2:1, then Et_2O) and recrystallized from Et_2O to give dibromide **19** (3.1 g, 82%) as colorless rectangular rods: mp 131–2 °C; R_f 0.25 (Et_2O–hexane, 2:1); $[\alpha]^{22}$ −6° (c 6.4 × 10^{-3}, CH_2Cl_2); IR ($CHCl_3$) ν_{max} 3010 (w), 2960 (w), 1795 (s), 1745 (s), 1235 (m), 1162 (m), 1082 (m), 1060 (m), 985 (m), 910 (m) cm^{-1}; ^1H NMR (200 MHz, $CDCl_3$) 5.05 (3 H, m, H1 + H2 + H11), 4.84 (1 H, br d, $J_{1,2}$ = 3.1 Hz, H1), 4.05 (1 H, d, $J_{5,6}$ = 8.8 Hz, H5), 3.78 (3 H, s, CO_2CH_3), 3.09 (1 H, d, $J_{6,5}$ = 8.8 Hz, H6), 2.82 (1 H, dd, $J_{15\beta,15\alpha}$ = 17.8 Hz, $J_{15\beta,14\alpha}$ = 3.7 Hz, H15β), 2.60 (2 H, m), 2.35 (2 H, m), 2.21 (3 H, s, $OCOCH_3$), 2.04 (1 H, d, $J_{15\alpha,15\beta}$ = 17.8 Hz, H15α), 1.60 (1 H, dd, $J_{14\alpha,14\beta}$ = 11.7 Hz, $J_{14\alpha,15\beta}$ = 3.7 Hz, H14α), 1.16 (3 H, s, H18); LRMS 467, 465 (M^+ − Br, 0.5), 386 (M^+ − Br_2, 2.5), 282 (17), 240 (15), 223 (25), 195 (21), 181 (53), 180 (100), 179 (70); HRMS found 465.0551 (M^+ − Br), $C_{21}H_{22}O_7Br^{79}$ requires 465.0549. Anal. Found: C, 45.88; H, 4.05. Calcd for $C_{21}H_{22}O_7Br_2$: C, 46.17; H, 4.06.

When the reaction was carried out as above, but with 1.3 molar equiv of *N*-bromosuccinimide, ***ent*-3α-acetoxy-1α-bromo-2β-hydroxy-16-oxo-17,20-dinorgibberell-9-ene-7,19-dioic acid 7-(methyl ester) 19,2-lactone (18)** was obtained as an oil in ca. 30% yield: R_f 0.31 (Et_2O–hexane, 2:1); ^1H NMR (200 MHz, $CDCl_3$) 5.08 (1 H, A of ABX, $J_{3,2}$ = 5.1 Hz, H3), 4.98 (1 H, A of ABX, $J_{2,3}$ = 5.1 Hz, $J_{2,1}$ = 3.1 Hz, H2), 4.84 (1 H, d, $J_{1,2}$ = 3.1 Hz, H1), 3.96 (1 H, dd, $J_{5,6}$ = 8.9 Hz, $J_{5,11\alpha}$ = 4.3 Hz, H5), 3.77 (3 H, s, CO_2CH_3), 3.05 (1 H, d, $J_{6,5}$ = 8.9 Hz, H6), 2.60 (2 H, m), 2.35 (1 H, m), 2.21 (3 H, s, $OCOCH_3$), 2.05 (4 H, m), 1.65 (2 H, m), 1.16 (3 H, s, H18); LRMS 468, 466 (M^+, 0.5), 437, 435 (0.8), 423, 425 (1.5), 387 (M^+ − Br, 3), 327 (13), 283 (21), 267 (8), 251 (11), 241 (17), 224 (37), 195 (27), 181 (35), 155 (49), 43 (100); HRMS found 466.0629 (M^+), $C_{21}H_{23}O_7Br^{79}$ requires 466.0627.

***ent*-3α-Acetoxy-11α-bromo-2β-hydroxy-16-oxo-17,20-dinor-9α,15α-cyclogibberell-1(10)-ene-7,19-dioic Acid 7-(Methyl ester) 19,2-Lactone (20).** A solution of ketone **19** (3.1 g, 5.68 mmol) in dry THF (20 mL) was added dropwise to a stirred suspension of KH (1.0 g, 25 mmol, washed with dry hexane) in THF (80 mL), under N_2. After being stirred at room temperature for 3 h, the mixture was warmed to 30 °C for 30 min to drive the reaction to completion. The mixture was diluted with Et_2O (100 mL) and filtered through Celite under N_2. The reaction flask was rinsed with Et_2O, and the washings were also filtered. Concentration in vacuo and chromatography on silica gel (Et_2O), followed by recrystallization from Et_2O, gave the desired cyclopropyl ketone **20** (2.15 g, 81%) as colorless plates: mp 187–9 °C; R_f 0.46 (Et_2O); $[\alpha]^{24}$ −0.9° (c 28.9 × 10^{-3}, CH_2Cl_2); IR ($CHCl_3$) ν_{max} 3020 (w), 2960 (w), 1780 (s), 1740 (s), 1662 (w), 1520 (m), 1440 (m), 1080 (m), 1050 (m), 955 (m), 930 (m), 627 (m) cm^{-1}; ^1H NMR (200 MHz, $CDCl_3$) 6.23 (1 H, br d, $J_{1,2}$ = 5.3 Hz, H1), 5.00 (2 H, m, H2 and H3), 4.70 (1 H, dd, $J_{11\alpha12\alpha}$ = 7.3 Hz, $J_{11\alpha12\beta}$ = 2.9 Hz, H11α), 3.78 (3 H, s, CO_2CH_3), 2.99 (2 H, br s, H5 + H6), 2.55 (1 H, s, H15), 2.60–2.30 (4 H, m), 2.13 (3 H, s, $OCOCH_3$), 1.80 (1 H, dm, $J_{14\alpha,14\beta}$ = 11.7 Hz, H14α), 1.17 (3 H, s, H18); LRMS 466 (M^+, 1), 464 (M^+, 1), 407 (11), 405 (11), 385 (5), 281 (32), 221 (27), 193 (48), 179 (48), 43 (100); HRMS found 464.0469 (M^+), $C_{21}H_{21}O_7Br^{79}$ requires 464.0471. Anal. Found: C, 54.48; H, 4.30. Calcd for $C_{21}H_{21}O_7Br$: C, 54.20; H, 4.55.

***ent*-3α-Acetoxy-11α-bromo-10β-hydroxy-16-oxo-17,20-dinor-9α,15α-cyclogibberell-1-ene-7,19-dioic Acid 7-(Methyl ester) 19,10-Lactone (21).** To a stirred solution of lactone **20** (2.10 g, 4.5 mmol) in dry CH_2Cl_2 (40 mL) at −15 °C, was added dropwise dimethylboron bromide (1 g, 8.3 mmol), and the mixture was maintained at this temperature for 1 h, at which stage TLC analysis indicated complete conversion to a slightly more polar (UV inactive) compound. A solution of 1 M aqueous $NaHCO_3$ was added, and, after stirring for 5 min, the solution was diluted with Et_2O, washed with brine, and dried over $MgSO_4$. Concentration in vacuo and filtration through a short plug of silica gel (Et_2O), followed by recrystallization from Et_2O, gave the rearranged lactone **21** (1.86 g, 89%) as colorless hexagons: mp 171–2 °C; R_f 0.39 (Et_2O); $[\alpha]^{24}$ +12.8° (c 17.8 × 10^{-3}, CH_2Cl_2); IR ($CHCl_3$) ν_{max} 2960 (w), 1785 (s), 1740 (s), 1455 (m), 1440 (m), 1372 (m), 1280 (m), 1160 (m), 1130 (m), 972 (m), 920 (m) cm^{-1}; ^1H NMR (200 MHz, $CDCl_3$) 7.19 (1 H, dd, $J_{1,2}$ = 9.5 Hz, $J_{1,3}$ = 0.7 Hz, H1), 5.83 (1 H, dd, $J_{2,1}$ = ..5 Hz, $J_{2,3}$ = 3.7 Hz, H2), 5.35 (1 H, dd, $J_{3,2}$ = 3.7 Hz, $J_{3,1}$ = 0.7 Hz, H3), 4.97 (1 H, dd, $J_{11\alpha,12\alpha}$ = 8.0 Hz, $J_{11\alpha,12\beta}$ = 2.4 Hz, H11α), 3.74 (3 H, s, CO_2CH_3), 2.98 (1 H, d, $J_{6,5}$ = 9.5 Hz, H6), 2.83 (1 H, d, $J_{5,6}$ = 9.5 Hz, H5), 2.63 (1 H, ddd, $J_{12\alpha,12\beta}$ = 15.6 Hz, J = 8.3 Hz, J = 2.4 Hz, H12β), 2.57–2.32 (3 H, m), 2.33 (1 H, s, H15), 2.09 (3 H, s, $OCOCH_3$) 1.82 (1 H, d, $J_{14\alpha,14\beta}$ = 11.7 Hz, H14α), 1.16 (3 H, s, H18); LRMS 466, 464 (M^+, 2), 386 (26), 385 (M^+ − Br, 32), 281 (51), 221 (32), 193 (100), 179 (60); HRMS found 464.0469 (M^+), $C_{21}H_{21}O_7Br^{79}$ requires 464.0471. Anal. Found: C, 54.33; H, 4.65. Calcd for $C_{21}H_{21}O_7Br$: C, 54.20; H, 4.55.

***ent*-3α-Acetoxy-10β-hydroxy-16-oxo-17,20-dinorgibberella-1(10),9(11)-diene-7,19-dioic Acid 7-(Methyl ester) 19,10-Lactone (22).** A solution of bromo ketone **21** (50 mg, 0.09 mmol) in dry toluene (2 mL) was treated with *n*-Bu_3SnH (0.095 mL, 0.35 mmol) and AIBN (3 mg); the mixture was heated under reflux for 5 min, reduced to a small volume, and chromatographed directly on silica gel. Diene **22** (32 mg, 77%) was eluted with ether–hexane (2:1) and obtained as an oil: R_f 0.44 (Et_2O); ^1H NMR (200 MHz, $CDCl_3$) 6.22 (1 H, m, H11), 6.00 (1 H, m, H1), 5.02 (2 H, m, H2, H3), 3.76 (3 H, s, CO_2CH_3), 3.35 (1 H, dd, $J_{5,6}$ = 12.2 Hz, $J_{5,1}$ = 3.1 Hz, H5), 3.33 (m, 1 H, H13) 2.65 (1 H, d, $J_{6,5}$ = 12.2 Hz, H6), 2.12 (3 H, s, $COCH_3$), 1.25 (3 H, s, H18); LRMS 386 (6, M^+), 282 (17), 223 (17), 195 (15), 180 (52), 165 (23), 152 (6), 141 (6), 128 (9), 115 (11), 84 (44), 43 (100); HRMS found 386.1364 (M^+), $C_{21}H_{22}O_7$ requires 386.1366.

3β-Acetoxy-10α-hydroxy-16-oxo-17-norantherida-1,6-(8),11-triene-7,19-dioic Acid 7-(Methyl ester) 19,10-Lactone

(23). A solution of bromo cyclopropyl ketone **21** (0.40 g, 0.86 mmol) in dry DMF (10 mL) and DBU (2.5 mL) was gradually heated under N_2, over a 1-h period, from 70 °C to 120 °C. The mixture was cooled, diluted with Et_2O, and then washed with 1 N HCl followed by brine. After drying over $MgSO_4$, the solution was concentrated in vacuo, and the product was chromatographed on silica gel (Et_2O–hexane, 4:1) to give triene **23** (0.274 g, 83%) as a foam: R_f 0.36 (Et_0); $[\alpha]^{30}$ −180° (*c* 7.65 × 10^{-3}, CH_2Cl_2); IR ($CHCl_3$) ν_{max} 3045 (w), 3010 (w), 2955 (w), 1780 (s), 1730 (s), 1715 (s), 1640 (w), 1440 (m), 1372 (m), 1240 (m), 1170 (m), 1150 (m), 1130 (m), 1010 (m), 980 (m), 910 (m) cm^{-1}; UV (EtOH) λ_{max} 231 nm (ϵ 11 300 dm^3 mol^{-1} cm^{-1}); ^1H NMR (200 MHz, $CDCl_3$) 6.68 (1 H, d, $J_{11,12}$ = 8.3 Hz, H11), 6.53 (1 H, d, $J_{1,2}$ = 9.3 Hz, H1), 6.51 (1 H, dd, $J_{12,11}$ = 8.3 Hz, $J_{12,13}$ = 6.4 Hz, H12), 5.99 (1 H, dd, $J_{2,1}$ = 9.3 Hz, $J_{2,3}$ = 3.6 Hz, H2), 5.44 (1 H, d, $J_{3,2}$ = 3.6 Hz, H3), 4.02 (1 H, dd, $J_{5,14}$ = 3.8 Hz, $J_{5,14'}$ = 2.3 Hz, H5), 3.76 (3 H, s, CO_2CH_3), 3.42 (1 H, dm, $J_{13,12}$ = 6.4 Hz, H13), 3.01 (1 H, dt, $J_{14,14'}$ = 19.3 Hz, $J_{14,5}$ = 2.3 Hz, H14), 2.58 (1 H, dm, $J_{14',14}$ = 19.3 Hz, H14'), 2.26 (1 H, d, $J_{15,15'}$ = 17.2 Hz, H15), 2.15 (3 H, s, $OCOCH_3$), 1.90 (1 H, d, $J_{15',15}$ = 17.2 Hz, H15'), 1.33 (3 H, s, H18); LRMS 384 (M^+, 0.01), 353 ($M^+ - OCH_3$, 1), 280 (2), 254 (2), 195 (11), 179 (100); HRMS found 384.1211 (M^+), $C_{21}H_{20}O_7$ requires 384.1209.

3β-Acetoxy-10α-hydroxy-16-oxo-17-norantherid-6(8)-ene-7,19-dioic Acid 7-(Methyl ester) 19,10-Lactone (24). To a solution of triene **23** (0.274 g, 0.71 mmol) in EtOAc (15 mL) was added 5% Rh on alumina (30 mg). The mixture was stirred under an atmosphere of H_2 for 20 h, diluted with EtOAc, filtered (Whatman GF/A), and concentrated in vacuo. Filtration through a short column of silica gel (Et_2O) gave α,β-unsaturated ester **24** (0.230 g, 83%) as a foam: R_f 0.33 (Et_2O); $[\alpha]^{32}$ −1.5° (*c* 5.5 × 10^{-3}, CH_2Cl_2); IR ($CHCl_3$) ν_{max} 3010 (w), 2955 (w), 1780 (s), 1730 (s), 1712 (s), 1640 (w), 1440 (m), 1268 (m), 1245 (m), 1180 (m), 1140 (m), 1020 (m), 970 (m) cm^{-1}; UV (EtOH) λ_{max} 228 nm (ϵ 10 950 dm^3 mol^{-1} cm^{-1}); ^1H NMR (200 MHz, $CDCl_3$) 5.02 (1 H, t, *J* = 2.8 Hz, H3), 3.77 (1 H, dd, $J_{5,14}$ = 3.9 Hz, $J_{5,14'}$ = 2.2 Hz, H5), 3.73 (3 H, s, CO_2CH_3), 3.00 (1 H, dm, $J_{14,14'}$ = 19.5 Hz, H14), 2.72 (1 H, dm, $J_{14',14}$ = 19.5 Hz, H14'), 2.59 (1 H, m, H13), 2.34 (1 H, d, $J_{15,15'}$ = 17.8 Hz, H15), 2.3 (1 H, m), 2.15 (3 H, s, $OCOCH_3$), 2.15–1.6 (8 H, m), 1.21 (3 H, s, H18); LRMS 388 (M^+, 0.05), 357 (8), 284 (100); HRMS found 388.1522 (M^+), $C_{21}H_{24}O_7$ requires 388.1522.

3α,10α-Dihydroxyantherida-6(8),16-diene-7,19-dioic Acid 7-(Methyl ester) 19,10-Lactone (25). To a stirred suspension of activated zinc dust (5.75 g, 88 mmol) in dry THF (50 mL) and CH_2Br_2 (2.0 mL, 28 mmol) at −40 °C was added $TiCl_4$ (2.3 mL, 21 mmol) dropwise over 10 min. The mixture was then stirred under N_2 at 4 °C for 14 h; 4 mL of this suspension was added dropwise to a stirred solution of ketone **24** (0.230 g, 5.93 mmol) in dry THF (6 mL) at room temperature, under N_2. Reaction was judged to be complete after 5 min according to TLC analysis. Aqueous $NaHCO_3$ solution was added dropwise and, after 5 min, the product was extracted with Et_2O, washed with brine, and dried over $MgSO_4$. Concentration in vacuo and chromatography on silica gel (Et_2O–hexane, 5:3) gave, after recrystallization from Et_2O–hexane, **3β-acetoxy-10α-hydroxyantherida-6(8),16-diene-7,19-dioic acid 7-(methyl ester) 19,10-lactone** (0.181 g, 79%) as colorless rectangles: mp 196–7 °C; R_f 0.44 (Et_2O–hexane, 5:3); $[\alpha]^{30}$ +9° (*c* 7.2 × 10^{-3}, CH_2Cl_2); IR ($CHCl_3$) ν_{max} 3020 (w), 2955 (w), 1775 (s), 1740 (s), 1710 (s), 1635 (w), 1440 (m), 1270 (m) cm^{-1}; ^1H NMR (200 MHz, $CDCl_3$) 5.00 (1 H, t, *J* = 2.8 Hz, H3), 4.89 (1 H, s, br, H17), 4.66 (1 H, s, br, H17'), 3.74 (1 H, dd, $J_{5,14}$ = 3.7 Hz, $J_{5,14'}$ = 2.2 Hz, H5), 3.70 (3 H, s, CO_2CH_3), 2.75 (1 H, dm, $J_{14,14'}$ = 19.3 Hz, H14), 2.53 (1 H, dm, $J_{14',14}$ = 19.3 Hz, H14'), 2.49 (1 H, m, H13), 2.37 (1 H, d, br, $J_{15,15'}$ = 16.1 Hz, H15), 2.13 (3 H, s, $OCOCH_3$), 2.2–1.5 (9 H, m), 1.18 (3 H, s, H18); LRMS 386 (M^+, 1), 355 (8), 326 (9), 283 (23), 282 (100); HRMS found 386.1730 (M^+), $C_{22}H_{26}O_6$ requires 386.1729. Anal. Found: C, 68.56; H, 6.74. Calcd for $C_{22}H_{26}O_6$: C, 68.38; H, 6.78.

A solution of this acetate (0.181 g, 0.47 mmol) in MeOH (20 mL) and water (4 mL) was treated with KOH (70 mg), and the mixture was stirred at room temperature for 14 h and then at 40 °C for 4 h, under N_2. The solution was diluted with EtOAc, washed with brine, dried over $MgSO_4$, and concentrated in vacuo. Chromatography on silica gel (Et_2O) gave the desired 3α-alcohol **25** as the major component, along with the corresponding 3β-isomer. The 3β-isomer was re-treated under the above conditions. After two cycles the 3α-alcohol **25** (total product: 0.122 g, 76%) was obtained as a foam: R_f 0.43 (Et_2O–MeOH, 20:1); $[\alpha]^{30}$ −23° (*c* 18.5 × 10^{-3}, CH_2Cl_2); IR ($CHCl_3$) ν_{max} 3500 (w, br), 3010 (w), 2950 (w), 1770 (s), 1710 (s), 1640 (m), 1440 (m), 1360 (m), 1265 (m), 1150 (m), 1060 (m) cm^{-1}; ^1H NMR (200 MHz, $CDCl_3$) 4.85 (1 H, s, br, H17), 4.64 (1 H, s, br, H17'), 3.78 (3 H, s, CO_2CH_3), 3.70 (1 H, m, H3), 2.99 (1 H, m, H5), 2.71 (1 H, dm, $J_{14,14'}$ = 19.3 Hz, H14), 2.51 (1 H, dm, $J_{14',14}$ = 19.3 Hz, H14'), 2.47 (1 H, m, H13), 2.36–2.20 (2 H, m), 2.20–1.30 (9 H, m), 1.27 (3 H, s, H18); LRMS 344 (M^+, 40), 326 (46), 312 (100), 298 (45), 284 (57), 270 (36), 256 (51), 243 (33), 228 (27), 197 (24); HRMS found 344.1622 (M^+), $C_{20}H_{24}O_5$ requires 344.1624.

10α-Hydroxy-3α-(methoxymethoxy)antherida-6(8),16-(17)-diene-7,19-dioic Acid 7-(Methyl ester) 19,10-Lactone (26). Chloromethyl methyl ether (0.11 mL, 1.5 mmol) was added dropwise to a stirred solution of alcohol **25** (0.122 g, 0.355 mmol) in dry CH_2Cl_2 (10 mL) and Hunig's base (0.28 mL, 1.6 mmol) at 0 °C under N_2. DMAP (10 mg) was then added, and the solution was stirred at room temperature for 14 h. Saturated aqueous $NaHCO_3$ solution was added to destroy the excess of chloromethyl methyl ether, and, after stirring for 10 min, the product was extracted with Et_2O. The combined organic extracts were washed with 1 N HCl followed by brine, dried over $MgSO_4$, concentrated in vacuo, and chromatographed on silica gel (Et_2O–hexane, 2:1) to give ether **26** (0.124 g, 90%) as an oil: R_f 0.52 (Et_iO); $[\alpha]^{25}$ −4° (*c* 0.51 × 10^{-3}, CH_2Cl_2); ^1H and ^{13}C NMR spectra identical with those of the sample prepared previously.[19]

3a,10α,15α-Trihydroxyantherida-8(14),16-diene-7,19-dioic Acid 19,10-Lactone (27) Methyl Ester [Methyl 15-*epi*-Antheridate]. During the repeat preparation of antheridic acid **2** methyl ester,[19] a small amount of the more polar 15α-epimer **27** was obtained (8% yield): R_f 0.48 (Et_2O–MeOH, 9:1); ^1H NMR (200 MHz, $CDCl_3$) 6.18 (1 H, dd, $J_{14,13}$ = 6.3 Hz, $J_{14,6}$ = 2.7 Hz, H14), 4.93 (2 H, s, H17, 17'), 3.92 (1 H, br s, H15), 3.78 (3 H, s, CO_2CH_3), 3.72 (1 H, dd, $J_{3,2\alpha}$ = 11 Hz, $J_{3,2\alpha}$ = 5.5 Hz, H3), 3.42 (1 H, dd, $J_{6,5}$ = 10 Hz, $J_{6,14}$ = 2.7 Hz, H6), 3.13 (1 H, br d, $J_{13,14}$ = 6.3 Hz, H13), 2.77 (1 H, d, $J_{5,6}$ = 10 Hz, H5) 2.37 (1 H, dt, *J* = 15, 15, 5.7 Hz, H1β), 1.24 (3 H, s, H18); LRMS 360 (M^+, 9), 342 (10), 328 (17), 316 (19), 310 (10), 298 (20), 283 (20), 272 (10), 264 (17), 256 (21), 237 (16), 213 (29), 183 (32), 167 (24), 149 (45), 141 (25), 129 (30), 115 (31), 105 (23), 91 (43), 57 (100).

***ent*-3α-Acetoxy-10β-hydroxy-16-oxo-17,20-dinor-9α,15α-cyclogibberella-1,11-diene-7,19-dioic Acid 7-(Methyl ester) 19,10-Lactone (28).** To a stirred solution of bromide **21** (0.10 g, 0.215 mmol) in dry HMPT (8 mL) at room temperature was added anhydrous LiBr (0.2 g, 2.3 mmol). The mixture was then warmed to 50 °C and stirred at this temperature, under N_2, for 24 h. The solution was diluted with Et_2O, washed with $CuSO_4$ solution (3×) followed by brine, and then dried over $MgSO_4$. Concentration in vacuo and chromatography on silica gel (Et_2O–hexane, 2:1) gave the desired diene **28** (59 mg, 71%) as a colorless oil: R_f 0.52 (Et_2O); $[\alpha]^{24}_D$ −175° (*c* 22.4 × 10^{-3}, CH_2Cl_2); IR ($CHCl_3$) ν_{max} 3030 (w), 2958 (w), 2940 (w), 1782 (s), 1740 (s), 1633 (w), 1612 (w), 1455 (m), 1440 (m), 1371 (m), 1159 (m), 1138 (m), 1121 (m), 1010 (m), 915 (m) cm^{-1}; ^1H NMR (200 MHz, $CDCl_3$) 6.63 (1 H, d, $J_{1,2}$ = 9.3 Hz, H1), 6.30 (1 H, d, $J_{11,12}$ = 7.8 Hz, H11), 6.09 (1 H, t, $J_{12(11,13)}$ = 7.8 Hz, H12), 5.93 (1 H, dd, $J_{2,1}$ = 9.3 Hz, $J_{2,3}$ = 3.7 Hz, H2), 5.41 (1 H, d, $J_{3,2}$ = 3.7 Hz, H3), 3.79 (3 H, s, CO_2CH_3), 2.99 (2 H, s, H5, H6), 2.90 (1 H, m, H13), 2.45 (1 H, dd, $J_{14\beta,14\alpha}$ = 11.5 Hz, $J_{14\beta,13'}$ = 5.12 Hz, H14β), 2.13 (3 H, s, $OCOCH_3$), 1.97 (1 H, s, H15), 1.44 (1 H, d, $J_{14\alpha,14\beta}$ = 11.5 Hz, H14α), 1.22 (3 H, s, H18); LRMS 384 (M^+, 1), 280 (26), 233 (44), 221 (24), 193 (55), 179 (73), 43 (100); HRMS found 384.1211 (M^+), $C_{21}H_{20}O_7$ requires 384.1209.

***ent*-10β-Hydroxy-3α-((methylsulfonyl)oxy)-16-oxo-17,20-dinor-9α,15α-cyclogibberella-1,11-diene-7,19-dioic Acid 7-(Methyl ester) 19,10-Lactone (29).** To a stirred solution of acetate **28** (0.057 g, 0.15 mmol) in MeOH (5 mL) was added a solution of $KHCO_3/K_2CO_3$ (1:1, 0.5 M, 0.1 mL) at room temperature. After stirring for 5 min, the solution was diluted with EtOAc and washed with brine. The organic layer was dried over $MgSO_4$, concentrated in vacuo, and then redissolved in dry CH_2Cl_2 (10 mL) and Et_3N (0.5 mL). After cooling in an ice bath, methanesulfonyl chloride (0.3 mL) was added, and the mixture was stirred at 4 °C for 14 h. The solution was then diluted with EtOAc and washed with $NaHCO_3$ solution followed by brine.

After drying over $MgSO_4$ and concentration in vacuo, the product was chromatographed on silica gel (Et_2O) to give, after recrystallization from CH_2Cl_2–Et_2O, the desired mesylate **29** (0.051 g, 82%) as colorless plates: mp 170–1 °C; R_f 0.52 (Et_2O–MeOH, 20:1); $[\alpha]^{24}_D$ –175 (*c* 8 × 10^{-3}, CH_2Cl_2); IR ($CHCl_3$) ν_{max} 2960 (w), 2940 (w), 1785 (s), 1745 (s), 1455 (w), 1440 (w), 1370 (m), 1158 (s), 920 (s) cm^{-1}; ^1H NMR (200 MHz, $CDCl_3$) 6.74 (1 H, d, $J_{1,2}$ = 9.5 Hz, H1), 6.29 (1 H, d, $J_{11,12}$ = 8.3 Hz, H11), 6.13–6.03 (2 H, m, H2 and H12), 5.13 (1 H, d, $J_{3,2}$ = 3.7 Hz, H3), 3.79 (3 H, s, CO_2CH_3), 3.11 (3 H, s, OSO_2CH_3), 3.01 and 2.93 (2 H, AB d, *J* = 9.5 Hz, H5 and H6), 2.91 (1 H, m, H13), 2.45 (1 H, dd, $J_{14\beta,14\alpha}$ = 1.5 Hz, $J_{14\beta,13}$ = 5.1 Hz, H14β), 1.96 (1 H, s, H15), 1.44 (1 H, d, $J_{14\alpha,14\beta}$ = 11.5 Hz, H14α)8 1.36 (3 H, s, H18); LRMS 420 (M^+, 0.2), 361 (0.2), 324 (0.7), 280 (7), 252 (12), 238 (23), 221 (37), 193 (100), 192 (42), 179 (99), 178 (70); HRMS found 420.0880; $C_{20}H_{20}O_8S$ requires 420.0879. Anal. Found: C, 57.48; H, 4.64. Calcd for $C_{20}H_{20}O_8S$: C, 57.18; H, 4.80.

***ent*-1α-Acetoxy-10β-hydroxy-16-oxo-17,20-dinor-9α,15α-cyclogibberella-2,11-diene-7,19-dioic Acid 7-(Methyl ester) 19,10-Lactone (30).** A solution of mesylate **29** (0.05 g, 0.12 mmol) and dry LiOAc (0.1 g, 1.5 mmol) in dry HMPT (8 mL), was stirred under N_2 at 4 °C for 72 h and then at room temperature for a further 4 h. The solution was diluted with Et_2O (100 mL) and washed with aqueous $CuSO_4$ solution (3×) followed by brine. After drying over $MgSO_4$, the solution was concentrated in vacuo, and the product was chromatographed on silica gel (Et_2O–hexane, 2:1) to give, after recrystallization from Et_2O–hexane, the desired 1β-acetate **30** (20.4 mg, 45%) as colorless plates: mp 183–4 °C; R_f 0.50 (Et_2O); $[\alpha]^{25}_D$ –542 (*c* 9 × 10^{-3}, CH_2Cl_2); IR ($CHCl_3$) ν_{max} 2970 (w), 2960 (w), 2940 (w), 1790 (s), 1740 (s), 1450 (w), 1440 (w), 1370 (w), 1160 (m), 1112 (m), 1038 (m), 975 (m), 923 (m) cm^{-1}; ^1H NMR (200 MHz, $CDCl_3$) 6.29 (1 H, d, $J_{11,12}$ = 8.0 Hz, H11), 6.01 (1 H, dd, $J_{3,2}$ = 9.0 Hz, $J_{3,1}$ = 0.7 Hz, H3), 6.00 (1 H, dd, $J_{12,11}$ = 8.0 Hz, $J_{12,13}$ = 7.0 Hz, H12), 5.85 (1 H, dd, $J_{2,3}$ = 9.0 Hz, $J_{2,1}$ = 3.4 Hz, H2), 5.73 (1 H, dd, $J_{1,2}$ = 3.4 Hz, $J_{1,3}$ = 0.7 Hz, H1), 3.77 (3 H, s, CO_2CH_3), 2.90 (1 H, d, $J_{6,5}$ = 9.0 Hz, H6), 2.83 (1 H, m, H13), 2.68 (1 H, d, $J_{5,6}$ = 9.0 Hz, H5), 2.42 (1 H, dd, $J_{14\beta,14\alpha}$ = 11.5 Hz, $J_{14\beta,13}$ = 5.1 Hz, H14β), 2.10 (3 H, s, $OCOCH_3$), 1.99 (1 H, s, H15), 1.43 (1 H, d, $J_{14\alpha,14\beta}$ = 11.5 Hz, H14α), 1.31 (3 H, s, H18); LRMS 384 (M^+, 9), 325 (5), 280 (36), 221 (35), 220 (26), 193 (100), 192 (44), 179 (96), 178 (43); HRMS found 384.1211 (M^+), $C_{21}H_{20}O_7$ requires 384.1209. Anal. Found: C, 65.20; H, 5.47. Calcd for $C_{21}H_{20}O_7$: C, 65.61; H, 5.24.

In addition, the corresponding 3α-acetate (17 mg, 37%) was obtained and recrystallized from Et_2O–hexane as colorless needles: mp 198–9 °C; R_f 0.45 (Et_2O); $[\alpha]^{26}_D$ –426° (*c* 5.05 × 10^{-3}, CH_2Cl_2); IR ($CHCl_3$) ν_{max} 2960 (w), 1780 (s), 1740 (s), 1440 (w), 1372 (w), 1180 (m), 1126 (m), 1032 (m), 1019 (m), 989 (m), 949 (m), 918 (m) cm^{-1}; ^1H NMR (200 MHz, $CDCl_3$) 6.58 (1 H, dd, $J_{1,2}$ = 9.3 Hz, $J_{1,3}$ = 1.7 Hz, H1), 6.32 (1 H, d, $J_{11,12}$ = 7.8 Hz, H11), 6.08 (1 H, dd, $J_{12,11}$ = 7.8 Hz, $J_{12,13}$ = 7.3 Hz, H12), 5.85 (1 H, dd, $J_{2,1}$ = 9.3 Hz, $J_{2,3}$ = 2.7 Hz, H2), 5.54 (1 H, dd, $J_{3,2}$ = 2.7 Hz, $J_{3,1}$ = 1.7 Hz, H3), 3.77 (3 H, s, CO_2CH_3), 2.99 (1 H, d, $J_{6,5}$ = 9.3 Hz, H6), 2.89 (1 H, m, H13), 2.68 (1 H, d, $J_{5,6}$ = 9.3 Hz, H5), 2.44 (1 H, dd, $J_{14\beta,14\alpha}$ = 9.5 Hz, $J_{14\beta,13}$ = 5.1 Hz, H14β), 2.12 (3 H, s, $OCOCH_3$), 1.85 (1 H, s, H15), 1.44 (1 H, d, $J_{14\alpha,14\beta}$ = 9.5 Hz, H14α), 1.25 (3 H, s, H18); LRMS 384 (M^+, 5), 356 (2), 343 (3), 325 (7), 324 (6), 296 (5), 281 (5), 280 (5), 238 (15), 221 (23), 219 (26), 193 (44), 179 (70), 178 (25), 43 (100); HRMS found 384.1211 (M^+), $C_{21}H_{20}O_7$ requires 384.1209. Anal. Found: C, 65.46; H, 5.33. Calcd for $C_{21}H_{20}O_7$: C, 65.61; H, 5.24.

***ent*-3α-Acetoxy-1α-bromo-2β-hydroxy-16-oxo-17,20-dinor-gibberella-9,11-diene-7,19-dioic Acid 7-(Methyl ester) 19,2-Lactone (31).** A solution of dibromide **19** (0.101 g, 0.185 mmol) in dry THF (5.0 mL) under nitrogen at 0 °C was treated with DBU (30.0 μL, 0.20 mmol) and then stirred at 22 °C for 3 h. EtOAc (50 mL) was then added, and the solution was washed with 1 M HCl and brine and dried ($MgSO_4$). After removal of solvent, the residue was chromatographed on silica gel and diene **31** was eluted with Et_2O–hexane (3:1) as a colroless oil (35 mg, 41%): ^1H NMR (200 MHz, $CDCl_3$) 6.37 (1 H, d, $J_{11,12}$ = 9 Hz, H11), 6.15 (1 H, br t, *J* = 8 Hz), 5.10–4.95 (3 H, m, H1 + H2 + H3), 4.08 (1 H, d, $J_{5,6}$ = 9.4 Hz, H5), 3.04 (1 H, d, $J_{6,5}$ = 9.4 Hz, H6), 3.22 (1 H, m, H13), 2.22 (3 H, s, $COCH_3$), 1.17 (3 H, s, H18). Further elution afforded diene **31** (15 mg, 17.4%) contaminated with the cyclopropyl ketone **20**, followed by pure **20** (16 mg, 18.6%).

***ent*-3α-Acetoxy-2β-hydroxy-16-oxo-17,20-dinor-9α,15α-cyclogibberella-1(10),11-diene-7,19-dioic Acid 7-(Methyl ester) 19,2-Lactone (32).** A solution of dibromide **19** (1.317 g, 2.41 mmol) in carefully dried DMF (25 mL) at 0 °C under nitrogen was treated with dry DBU (3.62 mL, 24.2 mmol) and then stirred at 20 °C for 16 h. The solution was diluted with Et_2O, washed with $CuSO_4$ solution (3×), followed by brine, and then dried over $MgSO_4$. Concentration in vacuo and chromatography on silica gel (Et_2O–hexane, 2:1) gave **32** as an oil (0.67 g, 72%). Crystallization from ether gave material mp 171–173.5 °C; IR ν_{max} 1780 (s), 1750–1730 (s), 1660 (m), 1230 (s), 1170 (m), 1078 (m), 953 (m), 840 (m), 755 (m) cm^{-1}; ^1H NMR (200 MHz, $CDCl_3$) 6.2 (1 H, d, $J_{11,12}$ = 7.6 Hz, H11), 6.1 (1 H, m overlapped, H1), 6.05 (1 H, br t, *J* = 7.6 Hz, H12), 5.04 (t, $J_{2,1(2,3)}$ = 5.4 Hz, H2), 4.99 (1 H, d, $J_{3,2}$ = 5.4 Hz, H3), 3.80 (3 H, s, OCH_3), 3.11 (1 H, dd, $J_{5,6}$ = 9.9 Hz, $J_{5,1}$ = 2.3 Hz, H5), 2.96 (1 H, d, $J_{5,6}$ = 9.9 Hz, H6), 2.84 (1 H, m, H13), 2.38 (1 H, dd, $J_{14,14'}$ = 11.6 Hz, $J_{14,13}$ = 5.1 Hz, H14), 2.18 (1 H, s, H15), 1.45 (1 H, d, $J_{14,14'}$ = 11.6 Hz), 1.21 (3 H, s, H18); LRMS 384 (1), 356 (1), 324 (7), 251 (17), 238 (25), 219 (75), 193 (30), 179 (80), 165 (19), 152 (11), 141 (10), 128 (8), 115 (12), 43 (100). Anal. Found: C, 65.36; H, 5.34. Calcd for $C_{21}H_{20}O_7$: C, 65.62; H, 5.24.

Continued elution gave the corresponding 3-carbinol (0.2 g, 24%): ^1H NMR (200 MHz, $CDCl_3$) 6.22 (1 H, d, $J_{11,12}$ = 7.9 Hz, H11), 6.08 (1 H, dd, $J_{1,2}$ = 5.2 Hz, $J_{1,5}$ = 2.3 Hz, H1), 6.01 (1 H, br t, *J* = 7.9 Hz, H12), 4.77 (t, $J_{2,1(2,3)}$ = 5.2 Hz, H2), 4.24 (1 H, m, H3), 3.78 (3 H, s, OCH_3), 3.15 (1 H, dd, $J_{5,6}$ = 9.9 Hz, $J_{5,1}$ = 2.3 Hz, H5), 2.94 (1 H, d, $J_{5,6}$ = 9.9 Hz, H6), 2.83 (1 H, m, H13), 2.35 (1 H, dd, $J_{14,14'}$ = 11.6 Hz, $J_{14,13}$ = 5.1 Hz, H14), 2.19 (1 H, s, H15), 1.42 (1 H, d, $J_{14,14'}$ = 11.6 Hz), 1.18 (3 H, s, H18). This product was reacetylated (Ac_2O, Et_3N) to give further **32** (0.21 g).

***ent*-10β-Hydroxy-16-oxo-17,20-dinor-9α,15α-cyclogibberellane-7,19-dioic Acid 7-(Methyl ester) 19,10-Lactone (33). Preparation 1.** A solution of the 3-mesylate prepared from **10** (13 mg, 31 μmol) in EtOAc (5 mL) and pyridine (0.1 mL) was stirred with 5% Pd/$BaCO_3$ (13 mg) under an atmosphere of hydrogen. After stirring at room temperature for 14 h, the solution was diluted with EtOAc and filtered (Whatman GF/A). Concentration in vacuo and chromatography on silica gel (Et_2O–hexane, 3:1) gave the saturated ketone **33** (4.6 mg, 47%) as a colorless oil: R_f 0.45 (Et_2O); $[\alpha]^{25}_D$ –81° (*c* 6.3 × 10^{-3}, CH_2Cl_2); IR ($CHCl_3$) ν_{max} 2960 (m), 1780 (s), 1735 (s), 1650 (w), 1440 (m), 1280 (m), 1260 (m), 1175 (m), 1130 (m), 980 (m), 920 (m) cm^{-1}; ^1H NMR (200 MHz, $CDCl_3$) 3.72 (3 H, s, CO_2CH_3), 2.95 (1 H, d, $J_{6,5}$ = 8.9 Hz, H6), 2.02 (1 H, d, $J_{5,6}$ = 8.8 Hz, H5), 2.38 (1 H, dd, $J_{14\beta,14\alpha}$ = 11.7 Hz, $J_{14\beta,13}$ = 6.0 Hz, H14β), 2.30 (2 H, m, H13, H11α), 1.92 (1 H, d, $J_{14\alpha,14\beta}$ = 11.7 Hz, H14α), 1.92 (1 H, s, br, H15), 2.17–1.4 (9 H, m), 1.12 (3 H, s, H18); LRMS 330 (M^+, 2), 312 (13), 302 (3), 286 (67), 271 (41), 258 (23), 244 (30), 243 (100), 226 (41), 217 (38), 199 (68); HRMS found 330.1468 (M^+), $C_{19}H_{22}O_5$ requires 330.1467.

Preparation 2. A solution of the 3-mesylate from **10** (45 mg, 0.107 mmol) in dry degassed benzene (10 mL) and *n*-Bu_3SnH (1.5 mL) was heated at reflux under N_2, and a solution of AIBN (3 mg) in benzene (1 mL) was added dropwise over 30 min. After 1 h at reflux, the reaction was judged to be complete according to TLC analysis. The solution was concentrated in vacuo, and the product was chromatographed on silica gel (Et_2O–hexane, 1:1, then 3:1) to give a mixture of isomeric Δ^1 and Δ^2 olefins. The mixture was dissolved in EtOAc (10 mL) and stirred with 5% Rh/alumina (10 mg) under a H_2 atmosphere for 6 h. The solution was filtered (Whatman GF/A), concentrated in vacuo, and chromatographed on silica (Et_2O–hexane, 1:1) to give the desired cyclopropyl ketone **33** (23 mg, 65%) as an oil; spectroscopic details as for preparation 1.

***ent*-10β-Hydroxy-20-nor-9α,15α-cyclogibberell-16-ene-7,19-dioic Acid 19,10-Lactone (34).** A solution of the Lombardo–Oshima reagent (1 mL), freshly prepared as described for the preparation of **3** methyl ester, was added dropwise to a stirred solution of ketone **33** (22 mg, 67 μmol) in dry THF (3 mL) at room temperature. After 5 min the reaction was quenched with aqueous $NaHCO_3$ solution, and the product was extracted with Et_2O, washed with brine, dried over $MgSO_4$, and concentrated in vacuo. Chromatography on silica gel (Et_2O–hexane, 1:1) yielded the desired olefin **34** (19 mg, 87%) as a colorless oil: R_f 0.52 (Et_2O–

hexane, 1:1); $[\alpha]^{21}_D$ −65° (c 7.65 × 10^{-3}, CH_2Cl_2); IR ($CHCl_3$) ν_{max} 2955 (s), 2870 (s), 1770 (s), 1732 (s), 1669 (m), 1439 (m), 1385 (m), 1282 (s), 1265 (s), 1175 (s), 1138 (s), 980 (m), 920 (s), 877 (m) cm^{-1}; ^1H NMR (300 MHz, $CDCl_3$) 4.76 (1 H, s, H17), 4.74 (1 H, s, H17′), 3.71 (3 H, s, CO_2CH_3), 2.93 (1 H, d, $J_{6,5}$ = 8.8 Hz, H6), 2.40 (1 H, dt, $J_{13,14\beta}$ = 5.7 Hz, $J_{13,12(12')}$ = 3.5 Hz, H13), 2.15 (1 H, m, H11α) 2.06 (1 H, d, $J_{5,6}$ = 8.8 Hz, H5), 2.05 (1 H, m, H1), 2.0 (1 H, m, H14β), 1.95 (1 H, s, br, H15), 1.9 (1 H, m, H11β), 1.82 (1 H, m, H2), 1.70 (1 H, m, H3), 1.62 (1 H, d, $J_{14\alpha,14\beta}$ = 11.5 Hz, H14α), 1.65–1.40 (5 H, m), 1.09 (3 H, s, H18); LRMS 328 (M^+, 12), 296 (2), 284 (44), 269 (31), 255 (13), 225 (100), 224 (45); HRMS found 328.1675 (M^+), $C_{20}H_{24}O_4$ requires 328.1675.

The *17,17-d_2* derivative of **34** (5.0 mg) was prepared with CD_2Br_2 in a completely analogous manner. The ^1H NMR spectrum was identical, except for the absence of signals from the 17-methylene gorup: LRMS 330 (M^+ 53), 286 (46), 271 (33), 257 (16), 243 (10), 227 (100), 226 (48). This material (2.0 mg) was demethylated with *n*-PrSLi/HMPT by the method described for the preparation of **3**.

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Registry No. **2**, 34327-25-8; **3**, 114596-77-9; **3** methyl ester, 114596-83-7; **4**, 510-75-8; **4** MOM ether, methyl ester, 127472-82-6; **7**, 114596-78-0; **7** diacid, 127472-84-8; **8**, 114596-79-1; **8** (16-methylene derivative), 114613-99-9; **9**, 114673-20-0; **10**, 114614-20-9; **10** acetate, 127515-26-8; **10** mesylate, 114614-21-0; **11**, 114614-24-3; **12**, 114596-81-5; **13**, 114596-82-6; **13** (1,16-diol), 127472-70-2; **14**, 5508-48-5; **15**, 100769-73-1; **16**, 127472-74-6; **17**, 122054-19-7; **18**, 122054-20-0; **19**, 122054-21-1; **20**, 122054-22-2; **21**, 122054-23-3; **22**, 127472-75-7; **23**, 122054-24-4; **24**, 122054-26-6; **24** (16-methylene derivative), 122054-25-5; **26**, 110374-12-4; **27**, 127515-25-7; **28**, 127472-76-8; **29**, 127472-77-9; **30**, 127472-78-0; 3α-**30**, 127515-27-9; **31**, 127472-79-1; **32**, 127472-80-4; **32** (11,12-dihydro derivative), 127472-73-5; **32** 3-carbinol, 127472-85-9; **33**, 114614-22-1; **34**, 114614-23-2; **34**-17,17′-d_2, 127472-86-0; GA_4, 468-44-0; *ent*-2β-hydrazino-3α-(methoxymethoxy)-20-norgiberella-1(10),16-diene-7,19-dioic acid 7-(methyl ester) 19,*N*′-lactam, 127472-71-3; *ent*-2β-hydrazino-3α-(methoxymethoxy)-20-norgiberella-1(10),16-diene-7,9-dioic acid 19,*N*′-lactam, 127472-72-4; 1β,10α-dihydroxyantherida-6(8),16-diene-7,19-dioic acid 19,10-lactone methyl ester, 127472-81-5; 3-(methoxymethoxy)gibberellin A_4 methyl ester, 127472-83-7.

Supplementary Material Available: A table of more complete ^{13}C NMR spectral data (i.e. including unnumbered compounds) and copies of ^1H and ^{13}C NMR spectra for compounds **3** (methyl ester), **10–12**, **18**, **22–24**, **27**, **28**, **31**, **33**, **34**, and *17,17′-d_2*-**34** (37 pages). Ordering information is given on any current masthead page.

Synthesis of 2-Phenyldecahydroquinolin-4-ones via Imino Diels–Alder Reaction: Influence of the Imine Nitrogen Substituent on the Reaction Course and on the Heterocycle Conformation

Linda Le Coz,† Christine Veyrat-Martin,† Lya Wartski,*,† Jacqueline Seyden-Penne,*,† Claudette Bois,‡ and Michèle Philoche-Levisalles‡

Laboratoire des Carbocycles, Unité Associée au C.N.R.S. 0478, Institut de Chimie Moléculaire d'Orsay, Université de Paris-Sud, 91405 Orsay, France, and Laboratoire de Chimie des Métaux de Transition, Unité Associée au C.N.R.S. 0419, Université Pierre et Marie Curie, 75252 Paris, France

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Reaction of acetylcyclohexene trimethylsilyl enol ether (1) with N-substituted phenyl imines **2** takes place in the presence of Lewis acids. When the N-substituent in **2** is phenyl, *p*-tolyl, or *p*-methoxyphenyl, the cycloaddition gives exo and endo enoxysilanes **5a–c** and **6a–c** in a 70/30 ratio under kinetic control and <2/98 under thermodynamic control, via a Diels–Alder ⇄ retro-Diels–Alder process. Starting from the *p*-(dimethylamino)phenyl, benzyl, or trimethylsilyl analogues, no stereoselection is observed whatever the conditions. Protonation of the enoxysilanes **5** and **6** by MeOH–Et_3N takes place from the exo side, leading to cis ring-fused N-substituted *exo*- or *endo*-2-phenyldecahydroquinolin-4-ones **7** and **8**; their conformation as determined by NMR and X-ray crystallography, as well as their stability in the case of endo isomers **8**, strongly depends on the planarity or pyramidality of nitrogen. Unexpectedly, the preferred conformation of the heterocycle, both in solution and in the crystal, of *N*-phenyl- and *N*-*p*-tolyl-substituted exo isomers **7a** and **7b** whose N atoms are planar is a boat with a quasi-axially located 2-phenyl substituent.

The synthetic utility of the Diels–Alder reaction has been increased through the use of the readily available silyloxy dienes, which exhibit high regioselectivity in their reactions with unsymmetrical dienophiles.[1] In the hetero-Diels–Alder field,[2] the condensation of these dienes with carbonyl compounds[3] continues to be an area of great synthetic activity, but there are few reports of their reactions with unactivated imines.[4]

Trimethylsilyl enol ether **1** of acetylcyclohexene is an interesting partner in Diels–Alder cycloadditions as it can lead to bicyclic compounds; recent papers are devoted to its reaction with carbon dienophiles.[5] Besides the problem

† Laboratoire des Carbocycles.
‡ Laboratoire de Chimie des Métaux de transition.

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