X-RAY STRUCTURAL CHARACTERIZATION OF DISORDERED EPIFRIEDELIN-3-OL AND FRIEDELIN -3-ONE

Auphatham Phothikanith and Kenneth J. Haller*

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Abstract

Structure correlation to examine the hybridization of carbon C3 in friedalane and oleanane triterpene structures revealed one anomalous compound in the structure database. Redetermination of the structure of the anomalous compound clearly demonstrates that the oxygen at C3 is disordered. The major component of the structure is epifriedelin-3-ol with a refined occupancy of 0.680(3). The minor component is friedelin-3-one, the only difference being the ketone at C3. The bond lengths of the disordered components are d[C-O] = 1.426(5) and d[C=O] = 1.251(6) Å, giving occupancy weighted averages of 1.370 Å and 341.4° for d[C-O], nearly the same as the 1.33 7.33 A° and 343.1° values reported in the anomalous structure. Refinement converged with a conventional *R* of 0.0563 and the highest peak on the electron density difference map of 0.22(3) e Å^{-3}.

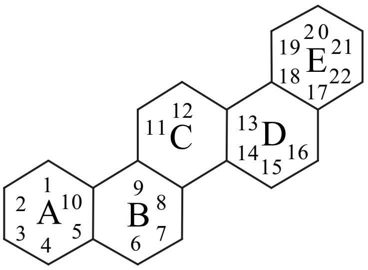
Keywords: X-ray crystallography, structure correlation, disordered structure, natural product, friedelane

Introduction

Today about a quarter million structures of organic compounds are stored in the Cambridge Structure Database (CSD). With the assistance of powerful computers and software this resource has been exploited in what has been called data mining. In this enterprise scientists have established favored conformations, intermolecular interactions, and reactivities of classes of compounds or functional groups (Burgi and Dunitz, 1994). Other workers have established the stereochemistry of various supramolecular synthons, weak interaction building blocks for extended solid state structure (Desiraju, 1991). The vast data available on first row transition metal-carbonyl complexes has been analyzed to characterize the structures, and thus help predict reactivities (Braga *et al.,* 1995; Paquette *et al.,* 1996). Additional work to establish the geometrical parameters of C-H···O weak hydrogen bonds in organic compounds has also been reported (Steiner and Desiraju, 1998).

Friedelin and it derivatives are primarily natural products that contain the saturated five fused six-membered ring system with an oxygen functional group at position 3 and substituents at positions 4, 5, 9, 13, 14, 17, and 20 (two substituents at position 20) illustrated following schematic diagram:

School of Chemistry, Institute of Science, Suranaree University of Technology, Nakhon Ratchasima 30000 Thailand, E-mail:haller@sut.ac.th
**Corresponding author*



Numbering schematic of the friedelin ring system.

The conventional numbering system for the pentacyclic skeleton is indicated on the diagram, as is the conventional letter labeling of each of the five rings. Compounds of this family exhibit antileukemic activity (Lee *et al.,* 1984), cytotoxicity, (Zheng, 1994), and antiviral activity (Chen *et al.*, 1992). The oxygen substituent can be either an oxy-functional group such as hydroxyl as in epifreidelin Figure 1(a)) (Laing *et al.,* 1977), or a carbonyl as in friedelin (Figure 1(b)) (Mo *et al.*, 1989). Accurate structural work and *ab initio* molecular orbital calculations in the latter case indicate the molecular packing interactions in friedelin and it derivatives are relatively weak intermolecular forces. The carbonyl and oxy groups contain acceptor oxygen atoms that can form weak C-H···O hydrogen bond interactions, or carbonyl-carbonyl interactions of the >C(δ^+)···O(δ^-) type (Allen *et al.,* 1998). The weakness of the intermolecular interactions should make the friedelane system a good candidate for structural correlation to investigate its conformational space.

Methods

Structure Correlation:

Structure data were retrieved from the Cambridge Structural Database (CCDC, 2001, 233,218 entries) in *cif* form for all 55 triterpene (class No. 56) structures containing the saturated five fused six-member ring search fragment. The 34 entries (Table 1.) with oxygen bound at C3 wereutilized for the structure correlation. Distances, angles, and displacements from the mean plane of six carbon atoms in a ring were derived from the structure data, and the sum of the C2-C3-C4, C2-C3-O3, and C4-C3-O3 angles, $\Sigma\angle$C3, was calculated. The scatterplot of $\Sigma\angle$C3 vs C3-Odistance was produced using version 1.2 of the DPLOT program (USAE, 1999).

X-ray Crystallography:

The single crystal used for x-ray data collection was selected from an unknown sample, isolated from a Thai source (Phaopongthai, 1995), and recrystallized from dichloromethane/hexane. The transparent colorless plate shaped crystal was mounted on a hollow fiber with cyanoacrylate glue. Data were collected using the COLLECT software (Nonius, 2000) on a Bruker Nonius KappaCCD diffractometer equipped with a graphite monochromated fine focus Mo $K\alpha$ x-radiation source and a 0.5 mm *ifg* focusing collimator. Data reduction was carried out with DENZO and scaling and merging with SCALEPACK (Otwinowski and Minor, 1997). The structure was solved by direct methods using SIR92 (Altomare *et al.,* 1994). SHELXTL (Sheldrick, 1997) was used for full matrix least-squares structure refinement, electron density difference maps, and table preparation. Distances and angles for the nonbonding interactions, and the perspective drawings were obtained from ORTEP III (Burnett and Johnson, 1996; Farrugia, 1997). Details of the crystal data and data collection parameters are given in Table 2.

The direct methods solution provided positions for the hydroxy oxygen atom and all 30 carbon atoms. A difference electron density map, calculated after preliminary isotropic refinement of the ordered epifriedelin-3-ol model, clearly revealed a second position about 0.7 Å from the first for the oxygen atom. The two positions were modeled as partial isotropic oxygen atoms assigned O3H (hydroxyl) and O3C (carbonyl) with the single constraint that their occupancies sum to unity. All other nonhydrogen atoms in the refinement model were reasonably well behaved as ordered anisotropic atoms. The hydrogen atoms, including those associated with the partially occupied hydroxyl group, could be located from the electron density difference map calculated at this stage, but were included as geometrically idealized isotropic contributors riding on the atoms to which they are attached. The hydroxy and methyl hydrogen atoms were constrained to the approximate tetrahedral positions as rigid groups allowed to rotate about the C-Me or C-O axis. Each of the three types of carbon bound hydrogen atoms were given a common refined atomic displacement parameter, while that for the hydroxy hydrogen was fixed at 0.06 Å^2. Occupancies of the partial hydrogen atoms associated with the hydroxy oxygen, O3H, were adjusted to match the oxygen occupancy.

Refinement converged with $R_1 = 0.0563$, $wR_2 = 0.1161$, and estimated error in an observation of unit weight of 1.053. Refined occupancies are 0.680(5) for the hydroxy form and 0.320(5) for the keto form. Refined atomic displacement parameters for the hydrogen atoms are $U_{iso}[\mathrm{H}_{\mathrm{methine}}] = 0.037(2)$, $U_{iso}[\mathrm{H}_{\mathrm{methylene}}] = 0.054(2)$, and $U_{iso}[\mathrm{H}_{\mathrm{methyl}}] = 0.076(2)$ Å^2. The highest peak on the final electron density difference map is 0.22(3) e Å^{-3}. Refinement of the Flack (1983) parameter for determination of absolute configuration was inconclusive. Atomic coordinates *(x, y, z)* and equivalent isotropic atomic displacement parameters *(Ueq)* for the nonhydrogen atoms are given in Table 3.

Results and Discussion

Structure Correlation:

The structure correlation scatterplot of $\Sigma\angle$C3 *vs* d[C3-O] is given in Figure 1 for the 34 polycyclic triterpene molecules with oxygen at position C3 listed in Table 1. The oxygen atom should be bound by either a single bond or a double bond as shown in Figure 2.

The scatterplot obviously characterizes the hybridization of the carbon atom for all but one of the compounds (labeled 'anomalous' in Figure 1). Ideal angles about carbon for sp^2 and sp^3 hybridization are 120° and 109.5°, giving expected values for the sum of the nonhydrogen angles of ~360° and ~329° respectively. Expected d[C-O] for a C_2-CH-OR single bond (hydroxyl or ester) is 1.43Å and d[C=O] for cyclohexanones is 1.21 Å (Orpen *et al.,* 1994). The average values of the two clusters are 1.445 Å / 331.2° and 1.218 Å / 359.7° for the hydroxyl and carbonyl types, respectively; the small increases in both d[C-O] values and in the hydroxyl $\Sigma\angle$C3 are consistent with expectations based on the increased steric volume of ring carbon atoms. The anomalous structure, EPFRED01 (Shi *et al.*, 1992), previously identified as epifriedelin-3-ol and indicated by a hexagonal symbol on Figure 2, falls on the scatterplot at d[C-O] = 1.33 Å and $\Sigma\angle$C3 = 343.1°, almost at the midpoint between the centroids of the two most probable value clusters. A second, apparently isomorphous, independent determination of epifreidelin-3-ol, EPFRED (Laing *et al.,* 1977), while a poor structure, based on the high R value, falls within the cluster. Inspection of the crystal data for these and other known related structures given in Table 4 show that with the interchange of the *a* and *b* axes the cells have the nearly the same metrics, suggesting that the packing of epifriedelin-3-ol and the closely related friedelin-3-one, differing only in the nature of the oxygen functional group at C3, are apparently the same.

Structure Description:

A new sample of epifriedelin-3-ol, isolated from a Thai source (Phaopongthai, 1995), was available for redetermination of the single crystal X-ray structure. The redetermined structure of the anomalous compound is illustrated in Figure 3 with the major occupancy O3H hydroxyl group represented as an unshaded ellipsoids and the minor occupancy O3C carbonyl group as a shaded ellipsoid. It should be noted that for any given molecule in the lattice it is either the hydroxyl form or the carbonyl form. The refined occupancy indicates that 68% of the molecules are hydroxyl form and 32% are carbonyl form. Interatomic bond distances and angles are given in Tables 5 and 6, mean planes and atomic displacements from the planes in Table 7, andselected torsional angles in Table 8.

The bond distances and endocyclic bond angles for the five ring skeleton are normal for a friedelin system. The endocyclic bond angles of the skeleton average 1.544(19) Å. The ring junction bonds, identified by * in Table 5, d[C5-C10] = 1.564(2), d[C8-C9] = 1.562(2), d[C13-C14] = 1.574(2), and d[C17-C18]= 1.583(3) Å are long for C-C single bonds due to steric effects from the predominance of axial substituents on one side of the skeleton. These axial groups cause the pentacyclic ring skeleton to be significantly bowed (as seen from the dihedral angles of

14.49(9), 14.52(5), 14.15(6), and 8.22(9)° between planes A and B, B and C, C and D, and D and E, respectively) due to the repulsive interactions between the axial methyl groups. This can also be seen in the positioning of the methyl groups where the position of the C24 methyl group is determined by a C-H···O interaction to the hydroxy oxygen (d[C24-O3H] = 2.979(4); d[O3H···H24a] = 2.490(14) Å), the C25 methyl group is 'geared' to the C24 methyl group (d[C24-C25] = 3.185 Å), and the C27 methyl group is 'geared' to the C25 methyl group (d[C25-C27] = 3.133 Å).

Examination of the displacements from the respective least squares mean planes given in Table 7 shows the conformations of rings A, B, and C are chair forms (displacement pattern, + - + - + -) and rings D and E are boat forms (+ - + + - +) (Masaki *et al*., 1975; Rogers *et al.,* 1980). The values of the displacements are similar to those previously reported for friedelin structures.

Torsion angles across the ring junctions (*trans* positions) in Table 6 illustrate the difference between chair/chair and boat/boat junctions for which the ideal values are 180° and 120°, respectively. The average deviation of 8.3° for the chair/chair junction is due to the steric interactions discussed above. The boat/boat junction only deviates 4.1° from the ideal value due to greater distances between the axial ligands of rings E and F. The chair/boat ring junction between C and D includes trans methyl substituents and exhibits torsion angles about C13-C14 of 174°, corresponding to a 6° rotation from an ideal trans-geometry.

The present sample, as well as the anomalous compound, crystallize in space group C2 and are isomorphous with the authentic sample of epifriedelin-3-ol previously reported (Laing *et al.,* 1977). The O3 sites on adjacent molecules are related pairwise across the 2-fold axis. The major component is present in more than 50% of the sites and does hydrogen bond across the 2-fold, d[O3H···O3H] = 2.895 Å. Similarly, the major and minor occupancy components can also hydrogen bond across the 2-fold, d[O3H···O3C] = 2.902 Å. However, d[O3C···O3C] = 2.760 Å, without an intervening hydrogen precludes the possibility of two minor component molecules coexisting across this 2-fold. The shortest C-H···O contact of 3.41° shows no C-H···O hydrogen bond interactions.

Comparing the anomalous structure identified in Figure 1 with the current structure shows a strong similarity. In the anomalous compound, d[C3-O] = 1.33 Å and the sum of the nonhydrogen angles about C3 = 343.1°. The refinement of the disordered model reported herein has occupancies of 0.680(3) for the hydroxy form and 0.320(3) for the keto form. If it were refined modeling the oxygen atom as a single anisotropic atom, the atomic displacement parameters of the oxygen will extend in the direction of the two positions given here as O3H and O3C and the apparent atomic position should lie quite close to the occupancy weighted center between the two peaks, *i.e.* mathematically,

$$\begin{aligned} d[\text{C3-O}] &= (\alpha)(d[\text{C3-O3H}]) + (1-\alpha) \\ &\qquad (d[\text{C3-O3C}]) = 1.370\ \text{Å} \\ \Sigma\angle\text{C3} &= (\alpha)(\Sigma\angle[\text{C(3-OH)}]) + (1-\alpha) \\ &\qquad (\Sigma\angle[\text{C(3=O)}]) = 341.4^{\circ} \end{aligned}$$

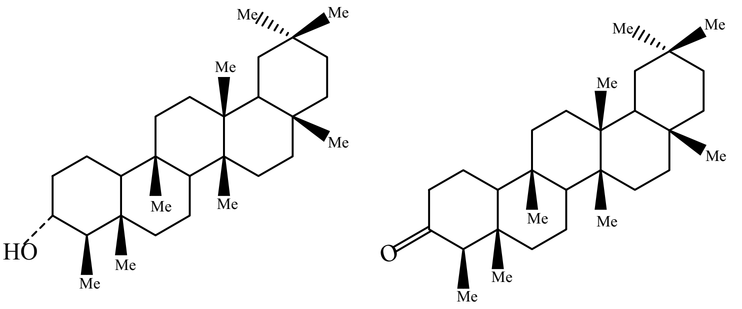
where α is the occupancy of hydroxy atoms and $(1 - \alpha)$ is the occupancy of the keto atom. The good agreement between the values for the anomalous structure and the occupancy weighted averages in the current structure strongly indicate that the structures are the same and the reason for the anomalous value in the literature is the failure to model the disorder.

Conclusion

Structure correlation, examining the hybridization of the oxygen atom attached to C3 of ring A of all known friedelane structures, showed the expected bimodal distribution for carbon-oxygen bond length versus bond angles about C3, except for one structure. Redetermination and correction of the anomalous structure shows it contains two different friedelane species, epifriedelin-3-ol and friedelin-3-one, demonstrating the ability of structure correlation methods to identify an incorrect structure entry in the crystallographic database.

Supplementary Material

CCDC 280086 contains supplementary crystallographic data for this paper. These data



Epifriedelin-3-ol Friedelin-3-one

Figure 1. Structure Diagram of Epifriedelin-3-ol and Friedelin-3-one. The hydroxy bond is indicated as a dashed line because the hydroxy group can be either above or below the plane

Table 1. The Compounds for Structure Correlation

	Compound	Reference Code	Reference
1	3-O-Acetyl-16-O-p-bromobenzoyl-pachysandiol B	ABPACH10	Masaki *et al.* (1975)
2	28,29-Dihydroxy-friedelan-3-one	BITSOM	Nozaki *et al.* (1982)
3	Stictane-3β,22α-diol	BIZKUO	Corbett *et al.* (1982)
4	5β,6β-Epoxy-alnusan-3β-yl acetate	BUKKEN10	Tori *et al.* (1984)
5	17-Perhydroxy-28-norfriedelan-3-one	CERCEH	Lee *et al.* (1984)
6	Orthosphenic acid monohydrate	CEYVAD	Gonzalez *et al.* (1983)
7	5α,10α-Epoxyalnusan-3β-yl acetate	CITFIU10	Takai *et al.* (1985)
8	Campanulin	CMPANL01	Mo (1977)
9	Taraxasterol	DATJOX	Reynolds *et al.* (1985)
10	Echinocystic acid diacetate bromolactone	ECHABL10	Carlisle *et al.* (1976)
11	Epifriedelinol	EPFRED	Laing *et al.* (1977)
12	Longan triterpene-A	EPFRED01	Shi *et al.* (1992)
13	5β,24-Cyclofriedelan-3-one	FADGEW	Connolly *et al.* (1986)
14	Methyl 3β,16α-dihydroxy-12-oxo-13α-olenan-28-oate dihydrate	FAWXUM	Dhaneshwar *et al.* (1987)
15	12α-Hydroxy-3-oxo-oleanano-28,13-lactone	FITVOT	Eggleston *et al.* (1987)
16	3β-Acetoxy-ursane-28,20β-olide	FOLVUX	Druet *et al.* (1987)
17	Friede-26β-ol-1,3-dione	FRDLON	Rogers *et al.* (1980)
18	22α-Hydroxystictan-3-one	FUYNUI	Wilkins *et al.* (1988)
19	29-Hydroxyfriedelan-3-one acetate	HFRDAC	Betancor *et al.* (1980)
20	28-Hydroxyfriedelan-3-one	JAMPOC	Subramanian *et al.* (1989)
21	11α,12α-Epoxy-13-hydroxy-3-oxoursan-28-oic acid-*y*-lactone	LILDAL	Tkachev *et al.* (1994)
22	Oleanolic acid diacetate bromolactone	OLDABL	van Schalkwyk *et al.* (1974)
23	Methyl 22β-hydroxy-3,21-dioxo-D:A-friedo-29-norleanan-24-oate	PAPGAO	Kutney *et al.* (1992)
24	2β-Bromo-19β,28-epoxy-18α-oleana-3-one	PIKMAX	Novotny *et al.* (1993)
25	Platycodigenin bromolactone benzene solvate	PLAGBL10	Akiyama *et al.* (1970)
26	Prionostemmadione	PRISEM	Monache *et al.* (1979)
27	6β-Hydroxyfriedelan-3,16,21-trione	SOXNUA	Nozaki *et al.* (1991)
28	3β-Hydroxy-D:A-friedo-oleanan-27-oic acid	VAGCUB	Tanaka *et al.* (1988)
29	Methyl 3-oxofriedelan-20α-oate	VEFNID	Cota *et al.* (1990)
30	Allobetulene	VEPBEX	Klinot *et al.* (1989)
31	Salaspermic acid monohydrate	YACNEV	Chen *et al.* (1992)
32	Dimethyl 3β-hydroxy-D:A-friedo-oleanan-27,29-dicarboxylate	YEGYOY	Gibbons *et al.* (1993)
33	D:A-friedo-oleanan-3-one	ZZZQAI02	Declercq *et al.* (1991)
34	Friedelan-3-one	ZZZQAI11	Mo *et al.* (1989)

Table 2. Crystal data and crystallographic experimental details

Crystal data			
Disorder component	epifriedelin-3-ol		friedelin-3-one
Chemical formula	$C_{30}H_{52}O$		$C_{30}H_{50}O$
Chemical formula weight	428.75		426.73
Refined occupancy factor	0.680(5)		0.320(5)
Chemical formula sum		$C_{30}H_{51.36}O$	
Chemical formula weight sum		428.08	
Crystal color and habit		transparent colorless plate	
Crystal size (mm)		0.12 × 0.40 × 0.42	
Crystal system and Space group		monoclinic *C2* (No. 5)	
Unit cell a (Å)		13.4372(27)	
b (Å)		6.4300(13)	
c (Å)		29.5987(59)	
β (°)		91.973(30)	
V (Å^3)		2552.54	
Z		4	
D_{calc} (Mg m^{-3})		1.114	
Radiation type		Mo $K\alpha$	
Wavelength (Å)		0.71073	
Temperature (K)		298	
μ (mm^{-1})		0.064	
Data collection			
Diffractometer		Bruker Nonius KappaCCD	
Absorption correction		multiscan	
Generator settings (kV/mA)		40 / 25	
Data collection method		ω-scans, and φ-scans with κ-offsets	
No. of integrated reflections		13490	
R_{merge}(*1* symmetry, 3662 multiples)		0.027	
No. of unique reflection		6672	
θ range (°)		2.75-30.05	
Range of *h, k, l*	$-18 \leq h \leq 18$, $-8 \leq k \leq 8$, $-41 \leq l \leq 41$		
Refinement			
Refinement on		F^2	
No. of unique reflection		6672	
R_{sym} (*2/m* symmetry,)		0.027	
No. of observed reflections $(F > 4\sigma F)$		5157	
No. of parameters / constraints used		291 / 1	
R_1 for 5157 $F > 4\sigma F$		0.0563	
wR_2 for 5157 $F > 4\sigma F$		0.1161	
R_1 for all 6672		0.0819	
wR_2 for all 6672		0.1798	
goodness of fit		1.053	
Weighting scheme	$w = 1/[\sigma^2(Fo^2) + (0.0358\ P)^2 + 1.7052\ P]$ where $P = [\max(Fo^2, 0) + 2\ F_c^2\ ] / 3$		
$\rho_{max}/\rho_{min}/\rho_{err}$ (e Å^{-3})		0.22 / - 0.28 / 0.03	
Refinement program		SHELXTL v 5.03	
Drawing program		ORTEP-III	

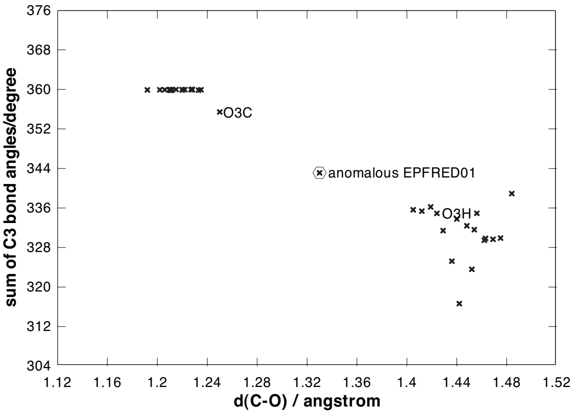


Figure 2. Scatterplot of the sum of bond angles about C3 versus C3-O bond distance

Table 3. Fractional monoclinic coordinates[a] and isotropic atomic displacement parameters[b] (Å^2) for the nonhydrogen atoms

Atom[c]	*x*	*y*	*z*	U_{iso}
C1	0.45627(14)	0.3573(4)	0.37281(7)	0.0441(5)
C2	0.4800(2)	0.1774(5)	0.40485(8)	0.0557(6)
C3	0.4002(2)	0.1422(4)	0.43860(7)	0.0514(6)
O3H	0.4083(2)	0.2979(6)	0.47287(9)	0.0552(6)
O3C	0.4063(4)	0.1903(12)	0.4796(2)	0.0552(6)
C4	0.2961(2)	0.1295(3)	0.41664(7)	0.0406(5)
C5	0.27035(13)	0.3170(3)	0.38477(6)	0.0339(4)
C6	0.17039(14)	0.2712(3)	0.35968(6)	0.0381(5)
C7	0.14812(13)	0.4143(3)	0.31967(7)	0.0381(4)
C8	0.23062(12)	0.3981(3)	0.28541(6)	0.0311(4)
C9	0.33224(13)	0.4716(3)	0.30724(6)	0.0318(4)
C10	0.35340(12)	0.3283(3)	0.34913(6)	0.0329(4)
C11	0.41295(13)	0.4369(3)	0.27211(6)	0.0363(4)
C12	0.38588(13)	0.5267(3)	0.22529(6)	0.0364(4)
C13	0.28770(13)	0.4400(3)	0.20398(6)	0.0315(4)
C14	0.20178(13)	0.4849(3)	0.23743(6)	0.0327(4)
C15	0.10583(14)	0.3742(4)	0.21911(7)	0.0442(5)
C16	0.0957(2)	0.3496(4)	0.16740(7)	0.0503(6)
C17	0.15432(14)	0.4985(4)	0.13743(7)	0.0428(5)
C18	0.26249(13)	0.5478(3)	0.15777(6)	0.0357(4)
C19	0.34283(15)	0.5053(4)	0.12303(7)	0.0436(5)
C20	0.3230(2)	0.5979(4)	0.07558(7)	0.0518(6)
C21	0.2181(2)	0.5290(5)	0.05750(8)	0.0637(7)
C22	0.1627(2)	0.3973(5)	0.09083(8)	0.0563(6)
C23	0.2184(2)	0.0802(4)	0.45168(8)	0.0548(6)
C24	0.2599(2)	0.5176(4)	0.41279(7)	0.0448(5)
C25	0.3377(2)	0.7036(3)	0.32075(7)	0.0436(5)
C26	0.3035(2)	0.2024(3)	0.19726(7)	0.0425(5)
C27	0.1786(2)	0.7197(3)	0.24086(7)	0.0435(5)
C28	0.0921(2)	0.7003(5)	0.13065(8)	0.0581(6)
C29	0.3327(2)	0.8349(5)	0.07717(9)	0.0708(8)
C30	0.4019(2)	0.5134(6)	0.04454(8)	0.0772(9)

a. The standard deviations of the least significant digits are given in parentheses.

b. Equivalent isotropic atomic displacement parameters for the atoms refined anisotropically. The values for O3H and O3C were refined isotropically and constrained to be equal. U_{eq} or $U_{iso} = \exp(-8\pi^2 U[\sin\theta/\lambda]^2)$

c. Occupancy was refined for O3H/H3H/H3HO and O3C with the constraint that the sum equal unity; the occupancy of O3H/H3H/H3HO is 0.680(5).

Figure 3. Ring A fragment with oxygen bound to *sp*^{2} and *sp*^{3} carbon at C3

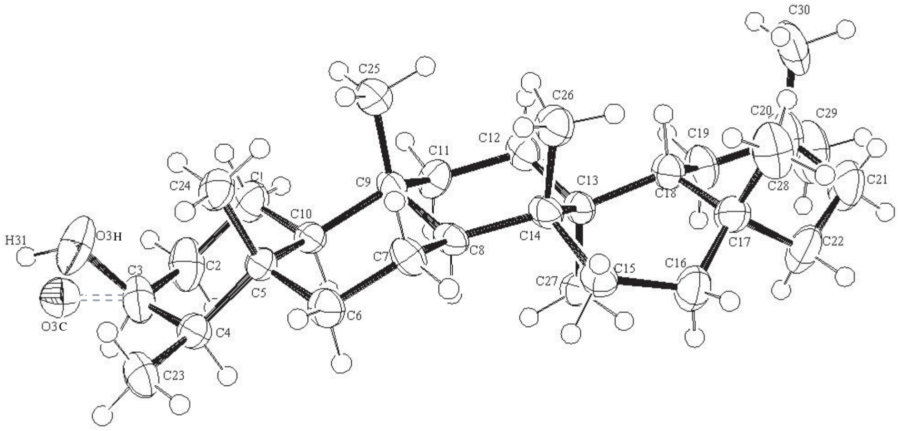


Figure 4. Perspective drawing of disordered epifriedelin-3-ol and friedelin-3-one. The minor occupancy disordered oxygen position, O3C, is indicated by a shaded atom and bond

Table 4. Crystal data for the different friedelin structure determinations

Compound	**Friedelin -3- one**	**Epifriedelin -3-ol**	**Friedelin -3- one**	**Anomalous**	**Disordered**	
CSD Refcode	ZZZQAI11	EPFRED	ZZZQAI02	EPFRED01	Freidelin-3-one / Epifriedelin-3-ol	
Formula	$C_{30}H_{50}O$	$C_{30}H_{52}O$	$C_{30}H_{50}O$	$C_{30}H5_{2O}$	$C_{30}H_{50}O$	$C_{30}H_{52}O$
Space group	$P2_12_12_1$	*C2*	$P2_12_12_1$	*C2*	*C2*	
Crystal system	Orthorhombic	Monoclinic	Orthorhombic	Monoclinic	Monoclinic	
a (Å)	6.371(1)	13.43(2)	6.362(2)	13.419(4)	13.4372(27)	
b (Å)	13.943(2)	6.35(1)	13.923(2)	6.422(2)	6.4300(13)	
c (Å)	28.456(6)	29.59(3)	28.419(5)	29.586(7)	29.5987(59)	
β (º)	90	92.5(2)	90	91.91(2)	91.97(3)	
Z	4	4	4	4	4	
Volume (Å^3)	2527.8(7)	2521.0(2)	2517.3(3)	2548.2(4)	2555.54(4)	
MW (Dalton)	426.70	427.71	426.70	427.71	428.75	426.73
D_{cal} (Mg m^{-3})	1.121	1.130	1.126	1.117	1.109	1.116
R-factor	0.133	0.17	0.047	0.068	0.0563	
Reference	Mo *et al.*, 1989	Laing *et al.*, 1977	Declercq *et al.*, 1991	Shi *et al.*, 1992	Present work	

Table 5. Selected Interatomic Bond Distances[a] (Å)

Endocyclic					
C1-C2	1.521(3)	C8-C14	1.561(3)	C15-C16	1.540(3)
C1-C10	1.538(2)	C8-C9 *	1.562(2)	C16-C17	1.540(3)
C2-C3	1.508(3)	C9-C11	1.545(2)	C17-C22	1.533(3)
C3-C4	1.523(3)	C9-C10	1.562(3)	C17-C18 *	1.585(3)
C4-C5	1.562(3)	C11-C12	1.533(3)	C18-C19	1.541(3)
C5-C6	1.539(3)	C12-C13	1.545(2)	C19-C20	1.540(3)
C5-C10 *	1.564(2)	C13-C18	1.559(3)	C20-C21	1.553(3)
C6-C7	1.521(3)	C13-C14 *	1.574(2)	C21-C22	1.515(4)
C7-C8	1.532(2)	C14-C15	1.553(3)		
Exocyclic					
C3-O3H[b]	1.426(4)	C9-C25	1.545(3)	C20-C30	1.527(3)
C3-O3C[b]	1.251(6)	C13-C26	1.555(3)	C20-C29	1.529(4)
C4-C23	1.531(3)	C14-C27	1.545(3)	O3H-O3C[b]	0.720
C5-C24	1.542(3)	C17-C28	1.551(3)		

[a] The standard deviations of the least significant digits are given in parentheses.

[b] O3H and O3C are the alternate positions for the disordered -C-OH and -C=O oxygen atom. O3H-O3C is the apparent separation of the disordered positions. Ring junction bonds are denoted by *.

Table 6. Selected Interatomic Bond Angles[a] (°)

C2-C1-C10	110.9(2)	C12-C13-C26	106.7(2)
C3-C2-C1	112.9(2)	C12-C13-C18	110.70(15)
O3C-C3-C2[b]	125.6(3)	C26-C13-C18	110.5(2)
O3H-C3-C2[b]	109.1(2)	C12-C13-C14	108.14(14)
O3C-C3-C4[b]	117.0(3)	C26-C13-C14	111.50(15)
O3H-C3-C4[b]	112.8(2)	C18-C13-C14	109.22(14)
C2-C3-C4	112.9(2)	C27-C14-C15	107.7(2)
C3-C4-C23	111.1(2)	C27-C14-C8	109.5(2)
C3-C4-C5	113.4(2)	C15-C14-C8	109.27(15)
C23-C4-C5	115.3(2)	C27-C14-C13	111.99(15)
C6-C5-C24	108.9(2)	C15-C14-C13	108.3(2)
C6-C5-C4	108.3(2)	C8-C14-C13	110.06(14)
C24-C5-C4	110.0(2)	C16-C15-C14	115.9(2)
C6-C5-C10	108.32(14)	C17-C16-C15	118.7(2)
C24-C5-C10	113.9(2)	C22-C17-C16	108.0(2)
C4-C5-C10	107.2(2)	C22-C17-C28	107.1(2)
C7-C6-C5	113.8(2)	C16-C17-C28	108.1(2)
C6-C7-C8	110.3(2)	C22-C17-C18	109.3(2)
C7-C8-C14	114.57(14)	C16-C17-C18	112.7(2)
C7-C8-C9	110.35(15)	C28-C17-C18	111.4(2)
C14-C8-C9	116.94(14)	C19-C18-C13	111.8(2)
C25-C9-C11	106.6(2)	C19-C18-C17	111.4(2)
C25-C9-C10	111.0(2)	C13-C18-C17	114.3(2)
C11-C9-C10	109.69(15)	C18-C19-C20	115.9(2)
C25-C9-C8	115.6(2)	C30-C20-C29	108.2(2)
C11-C9-C8	107.57(14)	C30-C20-C19	108.1(2)
C10-C9-C8	106.36(14)	C29-C20-C19	110.2(2)
C1-C10-C5	110.42(15)	C30-C20-C21	109.4(2)
C1-C10-C9	115.2(2)	C29-C20-C21	111.7(2)
C5-C10-C9	116.66(15)	C19-C20-C21	109.2(2)
C12-C11-C9	113.86(15)	C22-C21-C20	113.3(2)
C11-C12-C13	113.9(2)	C21-C22-C17	113.7(2)

[a] The standard deviations of the least significant digits are given in parentheses.

[b] O3H and O3C are the alternate positions for the disordered -C-OH and -C=O oxygen atom.

Table 7. Least-squares mean planes[a] and atomic deviations (Å) from the Planes

Plane 1. Carbonyl atoms (RMSD of fitted atoms = 0.075 Å)					
1.805(19) x + 6.337(3) y - 2.72(12) z = 0.89(5)					
defining atoms		**hydroxyl group atoms**		**bonded atoms**	
-0.041(1)	C2	-0.749(5)	O3H	-1.311(6)	C1
0.130(3)	C3	-1.367(21)	H3HO	-1.359(5)	C5
-0.037(1)	C4	1.046(4)	H3H	0.230(5)	C23
-0.052(1)	O3C				
Plane 2. Ring A Atoms (RMSD of fitted atoms = 0.234 Å)					
-0.198(13) x + 5.344(3) y + 16.432(24) z = 7.700(10)					
defining atoms		**equatorially bound atoms**		**axially bound atoms**	
0.245(2)	C1	-0.092(2)	H1A	1.213(2)	H1B
-0.195(2)	C2	0.207(2)	H2B	-1.158(2)	H2A
0.188(2)	C3	0.116(7)	O3C	0.581(4)	O3H
-0.221(2)	C4	0.107(4)	C23	-1.199(2)	H4
0.263(1)	C5	-0.374(3)	C6	1.797(3)	C24
-0.279(2)	C10	-0.197(3)	C9	-1.240(2)	H10
Plane 3. Ring B Atoms (RMSD of fitted atoms = 0.238 Å)					
-1.274(12) x + 6.013(2) y + 10.145(22) z = 5.277(8)					
defining atoms		**equatorially bound atoms**		**axially bound atoms**	
0.252(1)	C9	-0.416(3)	C11	1.777(3)	C25
-0.212(1)	C10	0.072(4)	C1	-1.189(1)	H10
0.188(1)	C5	-0.649(3)	C4	1.691(3)	C24
-0.215(2)	C6	0.145(2)	H6B	-1.182(2)	H6A
0.268(2)	C7	-0.027(2)	H7B	1.238(2)	H7A
-0.282(1)	C8	-0.210(3)	C14	-1.241(1)	H8
Plane 4. Ring C Atoms (RMSD of fitted atoms = 0.228 Å)					
-1.170(11) x + 6.373(1) y + 2.852(23) z = 3.297(7)					
defining atoms		**equatorially bound atoms**		**axially bound atoms**	
0.251(2)	C12	-0.058(2)	H12A	1.221(2)	H12B
-0.219(2)	C11	0.143(2)	H11A	-1.186(2)	H11B
0.196(1)	C9	-0.622(3)	C10	1.707(3)	C25
-0.215(1)	C8	0.082(3)	C7	-1.194(1)	H8
0.235(1)	C14	-0.411(4)	C15	-1.799(3)	C26
-0.247(1)	C13	0.337(3)	C18	1.768(3)	C27
Plane 5. Ring D Atoms (RMSD of fitted atoms = 0.278 Å)					
-4.359(13) x + 6.020(2) y + 4.173(29) z = 2.680(6)					
defining atoms		**equatorially bound atoms**		**axially bound atoms**	
0.131(2)	C18	-0.619(4)	C19	1.052(2)	H18
-0.434(1)	C13	-0.252(4)	C12	1.879(3)	C27
0.350(2)	C14	-0.098(4)	C8	-1.962(3)	C26
0.026(2)	C15	-0.733(2)	H15A	0.783(2)	H15B
-0.295(2)	C16	0.056(2)	H16B	-1.259(2)	H16A
0.222(2)	C17	-0.619(4)	C22	1.679(4)	C28
Plane 6. Ring E Atoms (RMSD of fitted atoms = 0.293 Å)					
-3.622(16) x + 6.187(2) y + 0.275(36) z = 2.318(7)					
defining atoms		**equatorially bound atoms**		**axially bound atoms**	
0.232(2)	C20	-0.585(5)	C30	1.664(4)	C29
-0.399(2)	C19	-0.287(2)	H19B	-1.352(2)	H19A
0.164(2)	C18	-0.581(4)	C13	-0.456(4)	C16
0.246(2)	C17	1.088(2)	H18	1.717(4)	C28
-0.424(2)	C22	-0.357(3)	H22B	-1.366(2)	H22A
0.181(2)	C21	-0.339(2)	H21A	1.082(2)	H21B

[a] Coordinates (x, y, z) are in crystal coordinates. Interplanar angles are as follows:carbonyl-A=39.79(18), A-B=14.49(9), B-C=14.52(5), C-D=14.15(6), D-E=8.22(9).

Table 8. Selected torsion angles (Å)

Junction	Atoms	Torsion angles
A-B	C6-C5-C10-C	-175.7(2)
A-B	C4-C5-C10-C9	167.0(2)
B-C	C7-C8-C9-C11	176.1(2)
B-C	C14-C8-C9-C10	-168.0(2)
C-D	C12-C13-C14-C15	-173.0(2)
C-D	C18-C13-C14-C8	-174.1(2)
	C26-C13-C14-C27	-174.5(2)
D-E	C16-C17-C18-C19	127.1(2)
D-E	C22-C17-C18-C13	-121.1(2)

can be obtained free of charge from The Cambridge Crystallographic Data Centre via www.ccdc.cam.ac.uk/data_request/ci*f*.

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