1,10-epoxy-1β,5α,6β,7α,8β(H)-germacra-4(5),11(13)-dien-8,12-olide. The boat-boat conformation has been established for the ten-membered ring with a configuration of the ${}^{1}D_{14}$, ${}^{15}D_{5}$ type, and this is the first time that this has been detected in natural trans-trans-germacranolides.

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CRYSTAL AND MOLECULAR STRUCTURE OF SALVICIN – A DITERPENOID ACID OF THE CLERODANE SERIES

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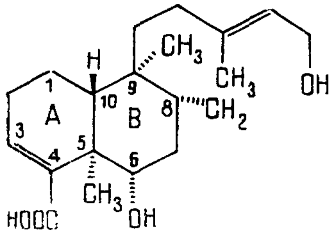
The spatial structure of the diterpenoid salvicin has been determined by x-ray structural analysis. The trans-linkage of rings A/B proposed previously has been confirmed. This indicates that rings A and B in related diterpenoids – salvin and salvinin – also have the trans-linkage.

Salvicin $C_{20}H_{32}O_4$ has been isolated previously from the epigeal part of Pulicaria salviifolia (family Compositae). A comparative analysis of the PMR spectra of salvicin and compounds close to it in structure [1, 2] enabled the most probable orientation of the substituents to be determined and a possible type of linkage of the rings to be suggested. However, the question of the linkage of the rings is an extremely complex one and solution on the basis of the results of PMR spectroscopy alone cannot be considered definitive, with the exception of cases of a direct correlation with known compounds [3, 4]. In the majority of cases [5-7], reliable information on the nature of the linkage of the rings can be obtained by x-ray structural analysis. We have therefore performed an x-ray structural inves-



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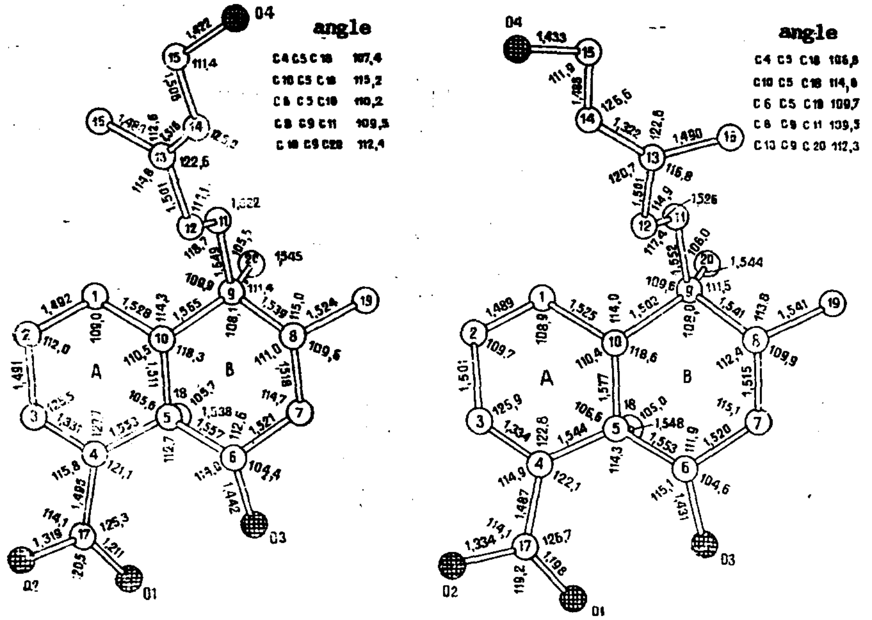

Fig. 1. Structures of the Ia and Ib molecules. The errors in the determination of the bond lengths and valence angles do not exceed 0.005 Å and 0.3°.

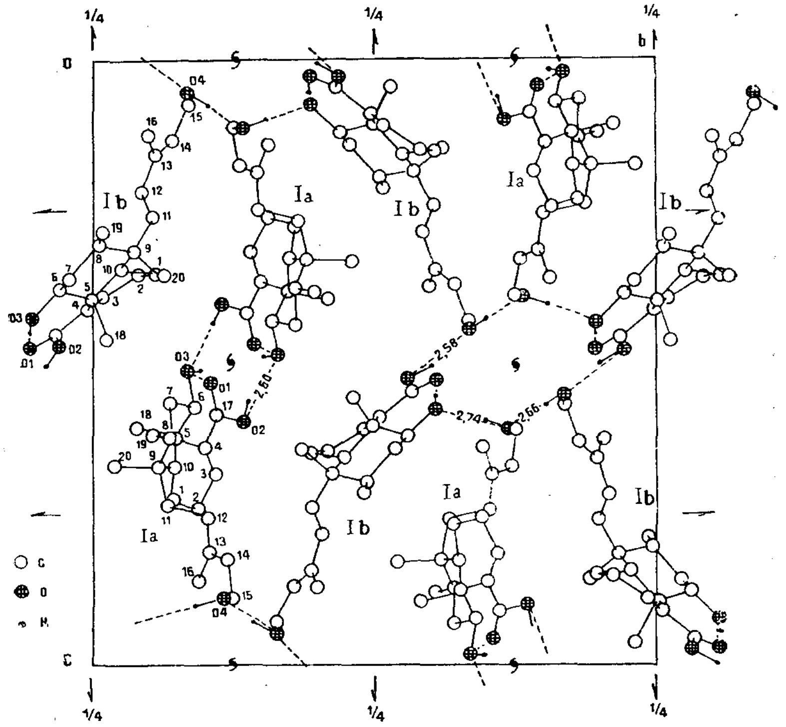

Fig. 2. Packing of the molecules from the structure of (I).

tigation of salvicin with the aim of determining its spatial structure unambiguously and elucidating the nature of the linkage of rings A and B in it and also in two related diterpenoids of the clerodane series — salvin and salvinin.

The results obtained confirmed the structure for salvicin (I) proposed previously [8] (see scheme on previous page).

In the crystal structure of (I) there are two independent molecules (Ia and Ib), the structures of which as projections on the mean square planes of the bicyclic systems are shown in Fig. 1, which also gives the bond lengths and valence angles. It can be seen from

TABLE 1. Main Torsional Angles (φ, deg) in the Ia and Ib Molecules

Angle	φ, deg		Angle	φ, deg	
	Ia	Ib		Ia	Ib
C10—C1—C2—C3	43,3	49,8	C10—C5—C6—C7	51,3	53,7
C1—C2—C3—C4	—10,8	—15,7	C5—C6—C7—C8	—57,9	—58,4
C2—C3—C4—C5	—0,2	—1,9	C6—C7—C8—C9	57,0	54,5
C3—C4—C5—C6	—130,5	—130,5	C7—C8—C9—C10	—51,65	—48,0
C4—C5—C10—C1	53,2	49,3	C8—C9—C10—C5	53,9	52,5
C5—C10—C1—C2	—67,8	—70,4	C9—C10—C5—C6	—52,8	—54,9
C2—C1—C10—C9	155,8	153,2	C7—C8—C9—C11	—171,2	—167,2
C3—C4—C5—C10	—20,8	—14,9	C8—C9—C10—C1	—173,3	—174,9
C3—C4—C17—O1	—166,1	167,8	C11—C9—C10—C1	—53,8	—55,7
C3—C4—C17—O2	12,4	—12,3	C11—C9—C10—C5	173,4	171,7
C5—C4—C17—O1	7,3	—16,9	C8—C9—C11—C12	66,2	68,6
C5—C4—C17—O2	—174,2	162,9	C9—C11—C12—C13	169,2	—164,9
C4—C5—C6—C7	166,2	170,2	C11—C12—C13—C14	113,8	—115,4
C4—C5—C10—C9	172,4	—176,5	C12—C13—C14—C15	177,6	—178,3
C6—C5—C10—C1	172,8	171,0	C13—C14—C15—O4	142,9	151,8

Fig. 1 that both molecules have the trans-linkage of rings A and B that is characteristic for clerodane diterpenoids [5, 6]. This fact enables us to consider that rings A and B in other diterpenoid lactones close in structure – salvin and salvinin – are also trans-linked, as suggested previously [2]. The methyl groups at C5, C8, and C9 and the OH group at C6 in the 6-membered rings A and B have the α-orientation. The conformation of the rings can be judged from the exocyclic torsional angles (Table 1). The six-membered ring A has the half-chair conformation that is characteristic for cyclohexene rings (the C3=C4 bond is double), while the saturated ring B has the chair conformation. As can be seen from Table 1, the majority of the corresponding torsional angles determining the conformations of the ring and the orientations of the substituents in molecules Ia and Ib differ by an average of 5-6°, which is apparently connected with packing effect. The Ia and Ib molecules differ substantially by the rotation of the carboxy group about the C4—C17 bond and also by that of the 3-hydroxy-1-methylprop-1-enyl group $-\underset{CH_3}{\underset{|}{C}}=CHCH_2OH$ about the C12—C13 bond (compare the corresponding torsional angles in Table 1). These differences are due to the participation of the terminal hydroxy groups O2H and O4H in intermolecular hydrogen bonds (Fig. 2).

An analysis of the geometries of the Ia and Ib molecule shows that the bond lengths agree well, on the whole, with the standard values [9]. The valence angles indicate substantial steric stresses in the molecules. They are shown in an increase in the size of the angles at the C11, C12, and C10 atoms which are due to the repulsion of the $-CH_2-\underset{CH_3}{\underset{|}{C}}=CH-CH_2-OH$ group from rings A and B, on the one hand, and the mutual repulsion of the syn-axial methyl substituents at C5 and C9, on the other hand.

In each of the two independent molecules in the structure of (I) there are three "active" H atoms. All six H atoms take part in hydrogen bonds. The H(O3) atoms in the Ia and Ib molecules form O3—H···O1 intramolecular H bonds (2.561, 0.68, 1.90 Å, 163°, and 2.553, 0.94, 1.61 Å, 173°, for Ia and Ib, respectively.* Because of an O2—H···O3 intermolecular H bond (2.600, 0.91, 1.73 Å, 159°), in which only the molecules of type Ia participate, these molecules form helical chains around screw axes of the 2_1 family (x, 1/4, 1/2). Each Ia molecule also participates in helical chains around screw axes of the 2_1 family (x, 3/4, 1/2), the pitch of this helix being formed by six H bonds (of which three are symmetrically independent), uniting two Ia molecules and four Ib molecules ($O4-H\cdots O3_{Ib}$ 2.736, 0.91, 1.85, 164°; $O4_{Ib}-H\cdots O4_{Ia}$ 2.655, 1.04, 1.62 Å, 173°; $O2_{Ib}-H\cdots O4_{Ib}$ 2.583, 1.03, 1.58 Å, 165°). Thus, the molecules in the (I) crystal are linked into an infinite three-dimensional system by means of H bonds.

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*Here and below, for each H bond are given the O···O, O—H, and H···O distances and the valence angle at the H atom. The errors in the determination of the O···O and the O—H distances and the OHO angles amount to 0.004-0.005 Å, 0.04-0.05 Å, and 3-5°, respectively.

TABLE 2. Coordinates (× 10^4) of the Nonhydrogen Atoms and Their Equivalent Isotemperature Factors in the Structure of Salvicin

Atom	Molecule Ia				Molecule Ib			
	x/a	y/b	z/c	B_{eq}*, Å^2	x/a	y/b	z/c	B_{eq}*, Å^2
O1	—2453(2)	2060(1)	5216(1)	4,37(5)	4561(3)	—1122(1)	4907(1)	7,35(7)
O2	—3462(2)	2713(1)	5928(1)	4,79(5)	2452(3)	—629(1)	4886(1)	7,16(7)
O3	158(2)	1717(1)	4988(1)	4,25(5)	7051(3)	—1087(1)	4402(1)	5,30(5)
O4	7182(3)	2352(1)	8977(1)	5,88(6)	3635(3)	1713(1)	384(1)	5,29(6)
C1	—220(4)	1367(2)	7309(1)	4,17(7)	4820(4)	1103(2)	3630(2)	4,99(8)
C2	—1265(4)	1932(2)	7427(2)	5,45(9)	3323(4)	832(2)	3591(2)	6,03(9)
C3	—1949(4)	2179(2)	6849(1)	4,26(7)	3176(4)	219(2)	4006(2)	5,61(9)
C4	—1537(3)	2013(2)	6267(1)	3,09(6)	4260(4)	— 139(2)	4250(2)	4,02(7)
C5	—244(3)	1527(2)	6133(1)	2,92(6)	5859(3)	24(2)	4117(1)	3,39(6)
C6	753(3)	1796(2)	5604(2)	3,18(6)	6774(4)	—603(2)	3918(1)	3,78(7)
C7	2188(3)	1421(2)	5577(1)	3,84(7)	8259(4)	—394(2)	3687(2)	4,64(8)
C8	3063(3)	1451(2)	6173(1)	3,58(6)	8261(3)	92(2)	3139(2)	4,15(7)
C9	2196(3)	1167(1)	6726(1)	3,12(6)	7366(3)	740(2)	3264(1)	3,46(6)
C10	700(3)	1536(1)	6740(1)	2,94(6)	5879(3)	516(2)	3536(1)	3,26(6)
C11	3021(3)	1308(2)	7340(1)	3,75(7)	7128(4)	1131(2)	2644(1)	3,88(7)
C12	3211(4)	2044(2)	7552(2)	4,52(7)	6149(4)	799(2)	2160(2)	5,02(8)
C13	3776(4)	2116(2)	8203(2)	4,16(7)	6255(4)	1097(2)	1517(1)	4,04(7)
C14	5053(4)	2375(2)	8327(2)	4,90(8)	5139(4)	1412(2)	1263(2)	5,21(9)
C15	5676(4)	2488(2)	8966(2)	6,7(1)	5073(4)	1714(2)	628(2)	6,4(1)
C16	2763(5)	1889(3)	8699(2)	8,4(1)	7649(5)	1003(2)	1184(2)	6,4(1)
C17	—2496(3)	2258(2)	5753(1)	3,45(6)	3819(4)	—674(2)	4703(2)	4,72(8)
C18	—871(4)	827(2)	5955(2)	4,12(7)	6489(4)	337(2)	4720(2)	4,93(8)
C19	4524(4)	1115(2)	6069(2)	5,75(9)	9823(4)	239(2)	2934(2)	7,0(1)
C20	2048(4)	383(2)	6688(2)	4,60(8)	8173(4)	1240(2)	3698(2)	4,99(8)

$^*B_{eq} = {}^4/_3\,(a^2B_{11}+b^2B_{22}+c^2B_{33}+abB_{12}\cos\gamma+acB_{13}\cos\beta+bcB_{23}\cos\alpha)$.

EXPERIMENTAL

Single crystals of salvicin were grown from solution in a mixture of ethyl acetate and hexane at room temperature. The space group and the parameters of the elementary cell were determined by the photographic method, and were then refined on a CAD-4 diffractometer using Mo K_α radiation: a = 9.276(4), b = 19.594(6), c = 21.484(8) Å; space group $P2_12_12_1$; z = 8; d_{calc} = 1.14 g/cm³. The calculations made use of 2614 reflections with intensities $I \geq 3\sigma$. The structure was interpreted by the direct method and was refined by the method of least squares first in the isotropic and then in the anisotropic approximation. All the H atoms were localized in a difference synthesis and were included in the refinement in the isotropic approximation. All the calculations were performed on a PDP-11/23 PLUS computer by means of a SDP-PLUS program [10]. The final divergence factors were R_1 = 0.034 and R_2 = 0.040. The coordinates of the atoms are given in Table 2.

CONCLUSIONS

The spatial structure of salvicin — a diterpenoid acid of the clerodane series having the trans linkage of rings A and B — has been reliably established by x-ray structural analysis. This result indicates that rings A and B in the related diterpenoids salvin and salvinin also have the trans-linkage.

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