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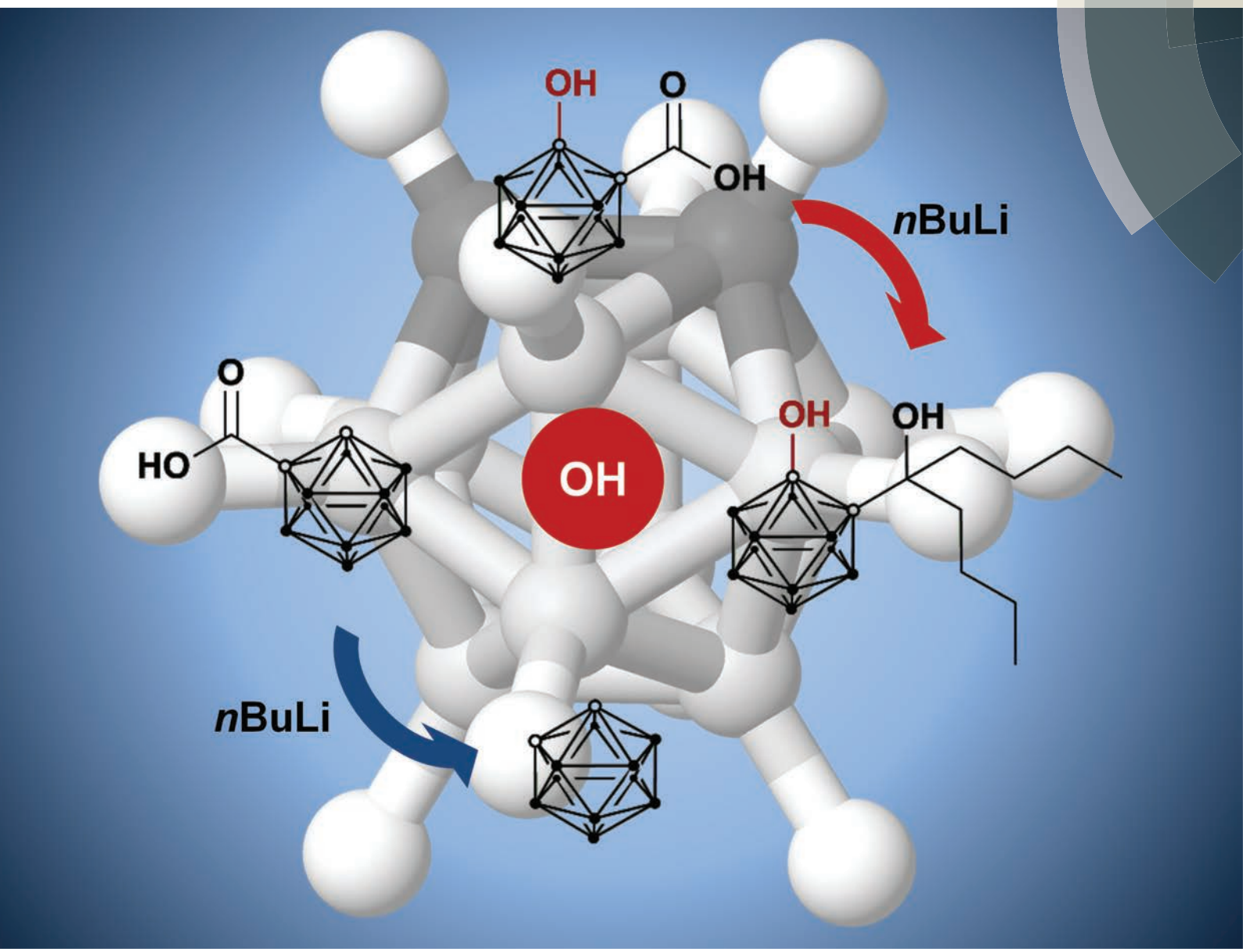

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Reduction of hydroxy-functionalised carbaboranyl carboxylic acids to tertiary alcohols by organolithium reagents†

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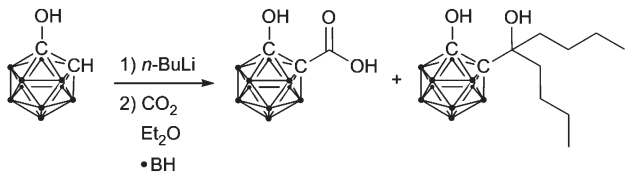
Reduction of hydroxy-functionalised carbaboranyl carboxylic acids by organolithium reagents yields the corresponding tertiary alcohols. This is in contrast to *exo*-polyhedral C–C bond cleavage of unsubstituted carbaboranyl carboxylic acids upon reaction with lithium organyls. The proposed dimeric contact ion pairs may also explain the formation of tertiary alcohols instead of the expected ketones.

Carbaboranyl alcohols are commonly synthesised by reaction of C-lithiated derivatives with epoxides, aldehydes or ketones to yield primary, secondary or tertiary alcohols, respectively, while attempts to reduce carbaboranyl ketones with Grignard or organolithium reagents to yield tertiary alcohols usually result in cleavage of the *exo*-polyhedral C–C bond of the cluster.[1] Especially the use of organolithium reagents leads to cleavage of the carbon–carbon bond, probably due to formation of an unstable tertiary alkoxide.[1e,f] It was suggested that the intermediate alcoholates are more stable when formed by Grignard reagents, as O–Mg bonds are less polar than O–Li bonds.[1g] Similar reactivity was reported for carbaboranyl esters.[1f] Thus, *exo*-polyhedral C–C bond cleavage should also be expected in the reaction of carbaboranyl carboxylic acids with organolithium reagents, as the electron-deficient cluster highly activates the terminal carboxyl group for facile reaction with the organolithium reagent resulting in cleavage of the carboxylic acid rather than reduction.

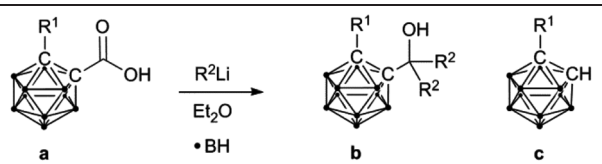
However, during the carboxylation of the lithiated 1-hydroxy-1,2-dicarba-*closo*-dodecaborane, formation of a side product was observed, which was identified as the corresponding tertiary alcohol of the targeted carbaboranyl carboxylic acid, 1-hydroxy-1,2-dicarba-*closo*-dodecaboranyl-2-carboxylic acid (salborin)[2] (Scheme 1). This observation suggests that the carboxylic acid was further reduced by an excess of the used organolithium reagent, although the latter would be expected to react preferentially with carbon dioxide. Reduction of carboxylic acids with organolithium reagents typically results in the formation of the corresponding ketones as main products;[3] attack of the organolithium reagent at a carboxylate leads to a geminal diol, which gives the corresponding ketone upon acidic work-up. A tertiary alcohol cannot be formed under these conditions, as elimination of an oxygen atom would be required. Only a second reduction step after work-up of the ketone yields the tertiary alcohol.[3] Thus, the unexpected formation of a carbaboranyl alcohol seems to involve a different mechanism.



Scheme 1

We therefore further investigated this unique reactivity of 1-hydroxy-1,2-dicarba-*closo*-dodecaboranyl-2-carboxylic acid (**1a**)[2] with specific alkyl lithium reagents, which provides a synthetic route towards selected tertiary carbaboranyl alcohols (Table 1).

Table 1 Reduction of carbaboranyl carboxylic acids by organolithium reagents



Reaction	R^1	R^2	Products
1	OH	C_4H_9	**b** + **c** (1 : 1)
2	H	C_4H_9	**c**
3	OCH_3	C_4H_9	**c**
4	OH	CH_3	**b** + **c** (1 : 1)

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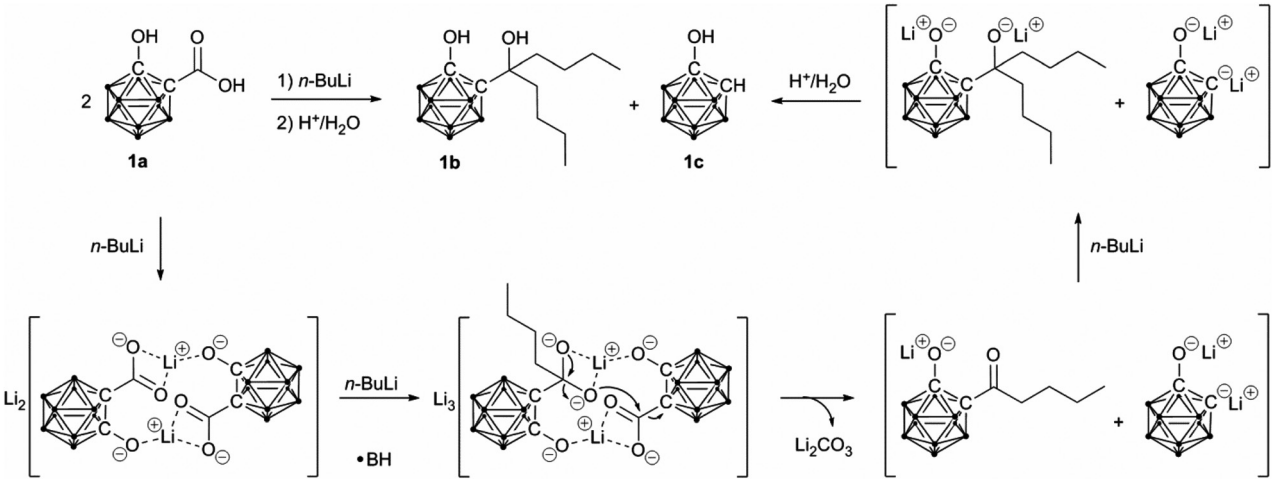

Scheme 2

Thus, the tertiary alcohol **1b** could be selectively prepared from pure salborin (**1a**) and *n*-BuLi and was fully characterised including X-crystallography.‡ However, even use of a large excess of *n*-butyllithium did not increase the yield of **1b** to more than 50%. Furthermore, formation of the tertiary alcohol **1b** was always accompanied by formation of 1-hydroxy-carbaborane **1c** resulting from cleavage of the *exo*-polyhedral C–C bond. Thus, full conversion of salborin (**1a**) always gives a 1 : 1 mixture of **1b** and **1c**.

The proposed mechanism involving the formation of dimeric contact ion pairs (Scheme 2) explains the formation of the tertiary alcohol **1b** together with 1-hydroxy-carbaborane **1c**.§ The formation of such dimers would allow transfer of an oxygen atom of the intermediate geminal diol to the carboxylate group of a second lithiated salborin molecule. The resulting cleavage of the *exo*-polyhedral C–C bond would lead to elimination of lithium carbonate as well as formation of the corresponding ketone as intermediate and dilithiated **1c**. The highly reactive ketone is then further reduced to the tertiary alcohol **1b** by *n*-butyllithium, and acidic work-up gives the observed 1 : 1 mixture of **1b** and **1c**. The formation of hydrogen-bonded dimers by carbaboranyl carboxylic acids is well known from crystal structures of different derivatives.[4] However, in solution and upon deprotonation, different interactions can be expected.

Salborin (**1a**) mainly differs from other carbaborane derivatives which were reported to undergo *exo*-polyhedral C–C bond cleavage upon reaction with organolithium reagents[1] in the substituent at the second carbon atom of the cluster, *i.e.*, a hydroxyl group. Indeed, when the reaction was carried out with 1,2-dicarba-*closo*-dodecaboranyl-1-carboxylic acid (**2a**),[5] only the unsubstituted cluster **2c** was obtained by decarboxylation (Table 1). Thus, the hydroxyl group seems to play an important role in the mechanism of reduction by preventing *exo*-polyhedral C–C bond cleavage in these compounds. According to the proposed mechanism, the hydroxyl group could be involved in stabilising the intermediate geminal diolate (Scheme 2). This assumption is further supported by the fact that the respective 1-methoxy-1,2-dicarba-*closo*-dodecaboranyl-2-carboxylic acid (**3a**) did not give the corresponding tertiary alcohol but only the decarboxylation product **3c** in the reaction with *n*-BuLi. Besides methylation of salborin (**1a**), also addition of tetramethylethylenediamine (tmeda), which is known to be an excellent Lewis base for the complexation of lithium cations, noticeably decreased the formation of the tertiary alcohol **1b** in the reaction of **1a** with *n*-BuLi.

Other organolithium reagents besides *n*-butyllithium were also employed in the reduction of salborin. While methyllithium gave the corresponding tertiary alcohol 2-(1-hydroxy-1,2-dicarba-*closo*-dodecaboranyl)-propan-2-ol (**4b**) (Table 1), the addition of *sec*- or *tert*-butyllithium as well as phenyllithium only resulted in decarboxylated 1-hydroxy-carbaborane **1c**, that is, the steric properties of the organolithium reagent also have a major influence on the reaction. Thus, sterically demanding reagents apparently promote *exo*-polyhedral C–C bond cleavage by preventing formation of the proposed dimeric contact ion pairs.

Conclusions

1-Hydroxy-1,2-dicarba-*closo*-dodecaboranyl-2-carboxylic acid (salborin, **1a**) reacted with *n*-butyllithium and methyllithium to give unexpectedly the corresponding tertiary alcohols **1b** and **4b** in 1 : 1 mixtures with 1-hydroxy-carbaborane **1c**, which could be separated by column chromatography or crystallisation. The proposed reaction mechanism involving the formation of dimeric contact ion pairs also underlines the importance of the hydroxyl group in the 1-position of the cluster in this process. Thus, carbaboranyl carboxylic acids without a hydroxyl group and the use of sterically demanding organolithium reagents led exclusively to *exo*-polyhedral C–C bond cleavage.

Acknowledgements

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Notes and references

‡ Crystallographic data for **1b** ($Mo_{K\alpha}$ radiation (λ = 0.71073 Å)): $C_{11}H_{30}B_{10}O_2$, M = 302.45, orthorhombic, space group *Pbca*, a = 11.6357(9), b = 9.7575(8), c = 31.537(4) Å, V = 3580.6(6) Å^3, Z = 8, T = 130(2) K, 25 019 reflections measured, 3663 unique (R_{int} = 0.1138). Final R indices (all data): R_1 = 0.1001, wR_2 = 0.1356. Through OH···O donor–acceptor bonds chains are formed along the b axis. The structure was solved by direct methods and all non-hydrogen atoms were refined anisotropically. CCDC 961910 contains the supplementary crystallographic data for this paper. These data can be obtained free of charge *via* www.ccdc.cam.ac.uk/conts/retrieving.html.

§ In order to obtain spectroscopic evidence for the suggested intermediates, time-resolved ^{1}H, ^{11}B{^{1}H} and ^{7}Li NMR spectra of the reduction reaction were recorded. For this purpose, solutions of the lithium salt of salborin in Et_2O and *n*-BuLi in *n*-hexane were frozen out in an NMR tube. The NMR tube was allowed to slowly warm up in the NMR spectrometer, which allowed data acquisition at the starting point of the reaction. Despite very short measurement times (below 60 seconds) no signals of intermediates could be detected. The recorded spectra either corresponded to those of the starting material or the reaction products. This indicates that the rate of the reaction is too high to allow the detection of intermediates on the NMR timescale.

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