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Carbenoid-mediated nucleophilic “hydrolysis” of 2-(dichloromethylidene)-1,1,3,3-tetramethylindane with DMSO participation, affording access to one-sidedly overcrowded ketone and bromoalkene descendants§

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§Sterically congested molecules, 27. For Part 26 see [1].

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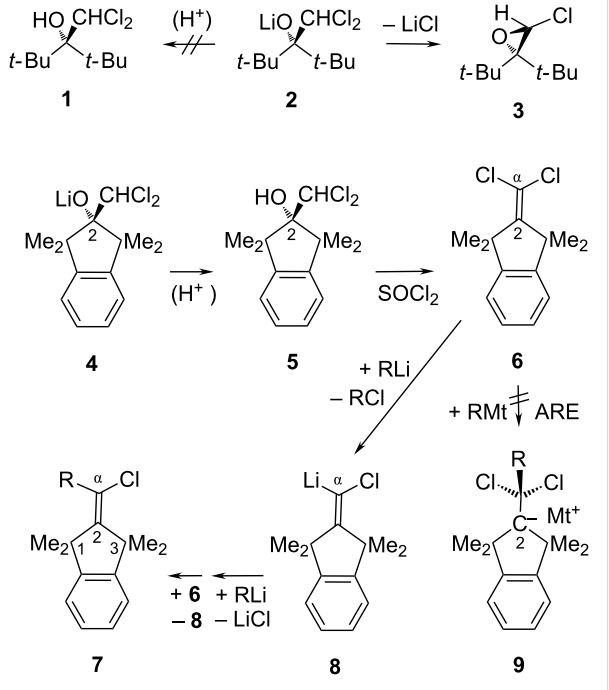
Abstract

2-(Dichloromethylidene)-1,1,3,3-tetramethylindane was “hydrolyzed” by solid KOH in DMSO as the solvent at ≥100 °C through an initial chlorine particle transfer to give a Cl,K-carbenoid. This short-lived intermediate disclosed its occurrence through a reversible proton transfer which competed with an oxygen transfer from DMSO that created dimethyl sulfide. The presumably resultant transitory ketene incorporated KOH to afford the potassium salt of 1,1,3,3-tetramethylindan-2-carboxylic acid (the product of a formal hydrolysis). The lithium salt of this key acid is able to acylate aryllithium compounds, furnishing one-sidedly overcrowded ketones along with the corresponding tertiary alcohols. The latter side-products (ca. 10%) were formed against a substantially increasing repulsive resistance, as testified through the diminished rotational mobility of their aryl groups. As a less troublesome further side-product, the dianion of the above key acid was recognized through carboxylation which afforded 1,1,3,3-tetramethylindan-2,2-dicarboxylic acid. Brominative deoxygenation of the ketones furnished two one-sidedly overcrowded bromoalkenes. Some presently relevant properties of the above Cl,K-carbenoid are provided in Supporting Information File 1.

Introduction

The 1,1,3,3-tetramethylindan-2-yl(idene) fragments shown in the hydrocarbon parts of formulae **4**–**8** (Scheme 1) are preferable to the corresponding acyclic di-*tert*-butylmethylidene moiety (*t*-Bu_2C in **1**–**3**) as the shielding substituent in static and dynamic model systems for several reasons. (i) With respect to repulsive strain, an attempted protonation of the alkoxide **2**

immediately after its generation [2] at −70 °C failed to provide **1**, because **2** cyclized too rapidly with formation of the chlorooxirane **3**. On the other hand, the somewhat alleviated internal repulsion in alkoxide **4** allowed it to be trapped by protonation below −10 °C before the cyclization could interfere [3], so that the resultant alcohol **5** could be isolated (crude yield 90% from 1,1,3,3-tetramethylindan-2-one) and dehydrated to give 2-(dichloromethylidene)-1,1,3,3-tetramethylindane (**6**) as the only product (97% yield). (ii) In X-ray diffraction analyses [4-9], the 1,1,3,3-tetramethylindan-2-ylidene parts turned out to be rather rigid, except for an occasional folding along the C-1/C-3 axis, and they did not exhibit the structural disorder problems and vexing angular flexibility which can arise with the *t*-Bu$_2$C groups exemplified in Scheme 1. (iii) Depending on the substituents at the exocyclic C-α atom in **7**, all four methyl groups in the 1,1,3,3-tetramethylindan-2-ylidene parts [10] and in their truncated analogue 1,1,3,3-tetramethylcyclopent-2-ylidene [11] may be nonequivalent and provide useful stereochemical and stereodynamic NMR information that would not be available from models containing the *t*-Bu$_2$C moiety with free rotation about the *t*-Bu–C bonds. (iv) Vinylic nucleophilic substitution (S_NV) of the chloride anion from **6** by even a very strong nucleophile R–Mt (Mt = alkali metal) to give **7** may appear problematic, because the first intermediate **9** expected with the usual ARE (addition–rotation–elimination) [12] mechanism would suffer from poor stabilization of the negative charge at C-2 which is flanked by two *tert*-alkyl groups.



Scheme 1: 1,1,3,3-Tetramethylindane derivatives are preferable.

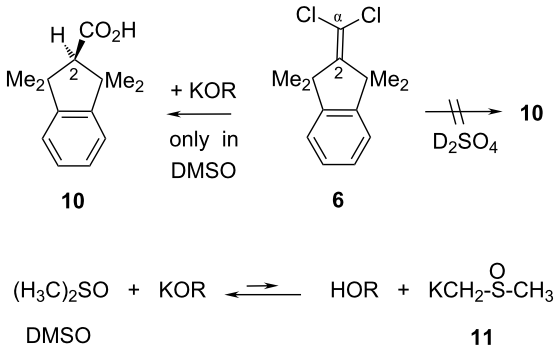
Instead, the substitution products **7** were obtained from **6** in THF via the cyclic Li,Cl-carbenoid **8** at room temperature (rt) by the carbenoid chain mechanism [3], as indicated in the bottom line of Scheme 1. These S_NV reactions proceed properly because **8** has a reduced (albeit not vanishing) inclination toward cycloalkyne formation through the Fritsch–Buttenberg–Wiechell (FBW) rearrangement [13], whereas S_NV reactions of acyclic Mt,Hal-carbenoids often have to compete with FBW processes forming acyclic alkynes.

The α,α-dibromo analogue of **6** (available [14] from **6** in two steps) was found to undergo corresponding but more intricate carbenoid chain reactions. Therefore, it was planned to prepare α-bromo analogues of **7** from related ketones which should be accessible via the carboxylic acid **10** to be expected from a hydrolysis of **6**.

Results and Discussion

"Hydrolysis" of the α,α-dichloroalkene 6

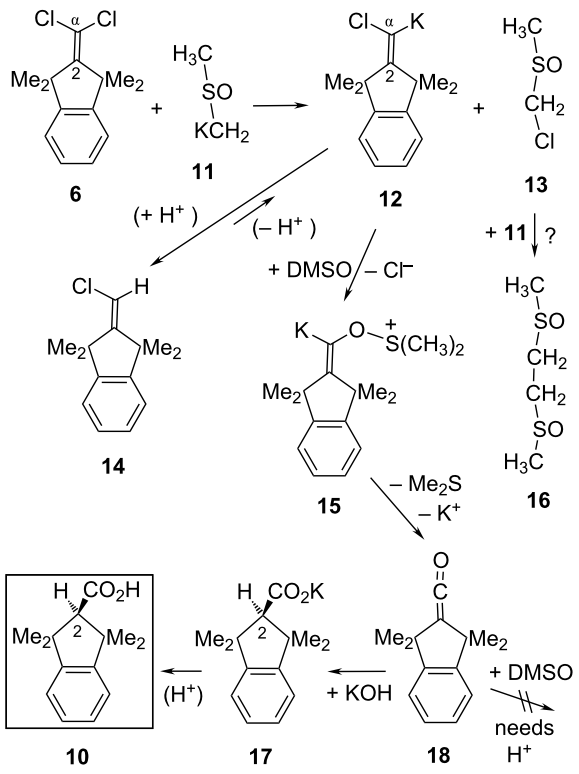
The carboxylic acid **10** (Scheme 2) would normally (and more expediently than before [15]) be accessible through a simple hydrolysis reaction [16,17] of **6** with concentrated (80–100%) sulfuric acid. Our in situ ^{1}H NMR spectra showed that **6** was insoluble in D_2SO_4 (97%) at rt and that two promising, equally intense methyl singlet signals, as expected for **10**, appeared after seven hours at 100 °C. However, the usual (Et_2O/water) work-up procedure did not afford any (acidic or nonacidic) organic product, which suggests that **6** or **10** were converted to water-soluble, unserviceable arenesulfonic acids that disappeared with the aqueous phases.



Scheme 2: "Hydrolysis" of **6**, and the KOR/dimsyl-K (**11**) system.

Without electron-withdrawing substituents in both **6** and the prospective ARE [12] intermediate **9**, several strongly caustic methods of hydrolysis with KOH failed to consume **6** in diethylene glycol [18] (11 hours at 135 °C), in triglyme (six hours, 150 °C), in HMPA [tris(dimethylamino)phosphinoxide, five hours at 150 °C], and in acetonitrile (23 hours, 70 °C).

Reisolation of pure **6** from hot formic acid (44 hours, 90 °C) or from dimethyl sulfoxide solution (DMSO, five hours at 156 °C without a base) showed that C–Cl bond heterolysis (vinylic S_N1 reaction) did not occur in these polar solvents. In DMSO with potassium *tert*-butoxide (KO*t*-Bu, four equiv, >22 hours at 140 °C) or better with solid KOH (at least 29 equiv, ≥ six hours at 100 °C or 60 min at 154 °C), however, **6** was slowly transformed into **10**. This may be reminiscent of a 10^9-fold increased kinetic basicity [19,20] of $KOCH_3$ in DMSO as a solvent. Due to the strongly enhanced thermodynamic basicity of solid KOH in DMSO [21-23], this system will provide and maintain a small concentration of the potassium salt **11** of DMSO ("dimsyl-K", Scheme 2). On the other hand, a more special involvement of DMSO as an oxidant in the present "hydrolysis" of **6** became evident when pure dimethyl sulfide (Me_2S, boiling point 37 °C) distilled from the reaction vessel into a cold trap during such a preparation of **10**. In situ ^{1}H NMR spectra revealed the obligatory formation of ca. one equivalent of Me_2S (δ_H = 2.06 ppm). Small portions of Me_2S stemmed from the slow destruction of DMSO by **11**, as confirmed in a faster run with **11** alone in DMSO during four hours at 150 °C, and presumably also from generation of the side-product potassium formate as formulated further below. Clearly, Me_2S could not have been formed from **6** in a simple hydrolytic ARE [12] process with an intermediate such as **9** as a precursor of **10**. Instead, we propose a carbenoid pathway in Scheme 3 and justify the specified steps in the sequel.



Scheme 3: Proposed carbenoid pathway from **6** to acid **10** and dimethyl sulfide (Me_2S) in DMSO as the solvent.

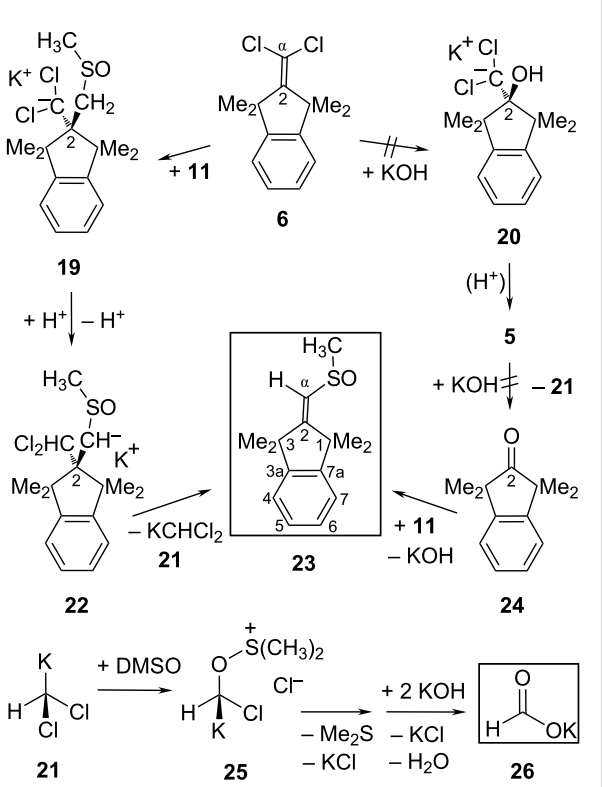
In a Cl/K interchange reaction that generates the Cl,K-carbenoid **12**, the transfer of a chlorine particle from **6** to KOH cannot be excluded at the outset in view of the early protocols [24-27] which described the application of dry NaOEt or KO*t*-Bu at ca. 190 °C for converting $aryl_2C{=}CCl_2$ into $aryl_2CH{-}CO_2H$ along with aryl–C≡C–aryl (the latter in a Fritsch–Buttenberg–Wiechell (FBW) rearrangement [13]). However, dimsyl-K (**11**) in DMSO without KOH consumed **6** immediately already at rt, albeit without formation of the acid **10**. This suggests KOH to be essential for creating product **10**; it also suggests that KOH might be a poor competitor of **11** in a nucleophilic attack on **6**, perhaps due partially to the low solubility (ca. 0.001 M [21]) of KOH in DMSO. Granting preference to the chlorine transfer from **6** to **11**, the byproduct **13** of **12** would hardly be traceable: even if **13** reacted with **11**, for example, the resultant water-soluble [28] bis(sulfoxide) **16** might get lost in the usual procedure of aqueous work-up. As an important confirmation of the Cl,K-carbenoid **12**, however, its conjugated CH-acid **14** [29] was observed during the early period of a running transformation and vanished slowly with regeneration of **12**. This interpretation was corroborated through independent generations of **12** from **14**: Using suspensions of KO*t*-Bu as the base in warm THF or cyclohexane for deprotonating **14**, the generated **12** was found [30] to undergo expansion (FBW) of its five-membered ring rather than the intended formation of the acid **10**. As two demonstrations that FBW ring expansion is not an inevitable fate of bona-fide **12**, we deprotonated **14** also with the freely soluble base $KN(SiMe_3)_2$ (in place of the hardly soluble KO*t*-Bu) in *t*-BuOMe or in THF as the solvents and observed [30] in situ merely the nonexpanded enamine (the expected S_NV product). Alternatively, we generated **12** from the dichloroalkene **6** with a THF solution of benzyl potassium, finding only the carbenoid chain (S_NV) product and its descendants but again no ring expansion [30]. Thus, **12** behaves like a normal unsaturated carbenoid whose S_NV reaction requires a more abundant, soluble nucleophile than solid KO*t*-Bu (or, by analogy, solid KOH). These observations pointed to a possible S_NV reaction of **12** with DMSO and/or dimsyl-K (**11**), as proposed in Scheme 3 and later on as follows.

In a rapid oxygen-transfer reaction that is known [31,32] for saturated carbenes or carbenoids, **12** will attack the solvent DMSO to generate the K,O-carbenoid **15** which decays in an E1cb-like expulsion of the observed Me_2S. The resultant, still unknown di-*tert*-alkyl ketene **18** appears to have only limited options in this milieu: Taking *t*-$Bu_2C{=}C{=}O$ [2] as a model of

the slightly less congested ketene **18**, a Pummerer-type acylation of DMSO by **18** should require the assistance of a carboxylic acid [33]; this is excluded in our strongly basic system. On the other hand, KOH consumed *t*-Bu_2C=C=O at rt readily [34]; thus, the certainly faster addition of KOH to **18** can give the observed (in situ ^{1}H NMR) potassium salt **17** of **10**. Of course, [2-D]**17** was detected and [2-D]**10** isolated [30] (with ca. 80% D, for example) from runs of **6** with KOH in [D_6]DMSO due to the H/D interchange reaction affording KOD; a separate experiment established that [2-D]**17** was not formed in a subsequent step from unlabeled **17** with **11** in [D_6]DMSO in the course of 11 hours at 120 °C. In the outlined mechanism, the formal "hydrolysis" of **6** to produce the acid **10** can be seen to consist of an initial reduction of **6** generating the carbenoid **12**, followed by the oxidation of **12** by DMSO that affords the precursors of **10**.

Although the isolated yield of acid **10** never exceeded 60%, our preparation is convenient because **10** was obtained as the only acid and in a suitably clean state, expecially when the acidified alkaline layers of aqueous work-up were extracted with pentane (in place of Et_2O) which can more efficiently be cleaned from the last traces of DMSO through washing with water. The procedure can also be made colleague-friendly by an early deodorizing of the Me_2S contamination through a short treatment of the aqueous solution of **17** with NaOCl (but not $KMnO_4$), to be terminated soon through the addition of $NaHSO_3$. Gratifyingly, all side-products did not contaminate the acid **10** because they assembled in the nonacidic fraction as described in the sequel.

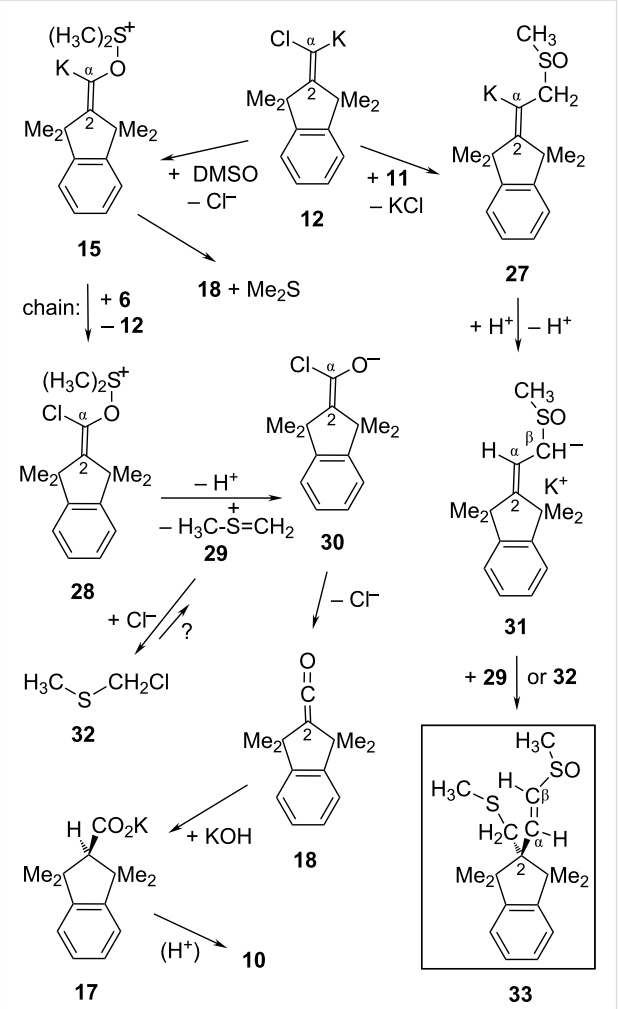
The structure of the main side-product **23** (Scheme 4) suggests that it might result from a base-catalyzed condensation of DMSO with 1,1,3,3-tetramethylindan-2-one (**24**) [35]; this assumption seemed confirmed through the isolation of **23** (57%) from **24** with KOH (28 equiv) in DMSO after 16 hours at 100 °C. However, the idea that **24** might have been generated from **6** via **20** (and the dichloro alcohol **5**) had to be dismissed: Although an authentic [3] sample of **5** was quickly consumed under the above conditions of hydrolyzing **6**, it furnished none of **24**, **23** or **10**. Nevertheless, **24** accumulated in the last period of transforming **6** into **10** (>15 hours at or above 100 °C); such a late appearance of **24** may be caused by a slowly emerging precursor (other than **5**). While **24** obviously did not hasten to form **23** with DMSO, an alternative route from **6** with **11** to **23** appears reasonable: the first intermediate **19** would isomerize to **22** and then dissociate into $KCHCl_2$ (**21**) and product **23**. As a Cl,K-carbenoid, **21** will fall a victim to the above-mentioned type of oxygen-transfer reaction [31,32] with DMSO, via **25** for example, to furnish Me_2S and potassium formate (**26**) which was actually detected (δ_H = 8.54 ppm) in situ.



Scheme 4: Proposed pathway to the main side-product **23** formed by nucleophilic addition of **11** to C-2 of **6**.

The carbenoid chain [3] option has not yet been addressed in the above proposals, because the results outlined in Scheme 3 and Scheme 4 were not compatible with that variant. However, a further side-product **33** was encountered whose structure may reasonably be explained using the carbenoid chain mechanism in the following manner. As a competitor of the Me_2S-producing decay of the K,O-carbenoid **15** to give **18** (Scheme 5), a chlorine particle transfer from **6** to **15** will close a carbenoid chain cycle and give rise to the chain carrier **12** together with the primary product **28**. In analogy with the base-induced O–S bond cleavage during the Pummerer acylation with *t*-Bu_2C=C=O [36], a base-induced decay of **28** can be expected to generate the 2-thioniapropene **29** along with the α-chloroenolate **30** that may produce the ketene **18** (or the unknown acyl choride) and finally (as in Scheme 3) the precursor **17** of acid **10**. This alternative route to acid **10** does not create Me_2S and may be a minor contribution, therefore. The expelled cation **29** may be consumed by the liberated chloride anion to give H_3C–S–CH_2Cl (**32**) or by dimsyl-K (**11**) or by formation of **33** along the following lines (Scheme 5).

In competition with the abundant DMSO to give **15**, dimsyl-K (**11**) may displace a chloride anion from the Cl,K-carbenoid **12** to generate the vinylpotassium derivative **27**. Proton transfer

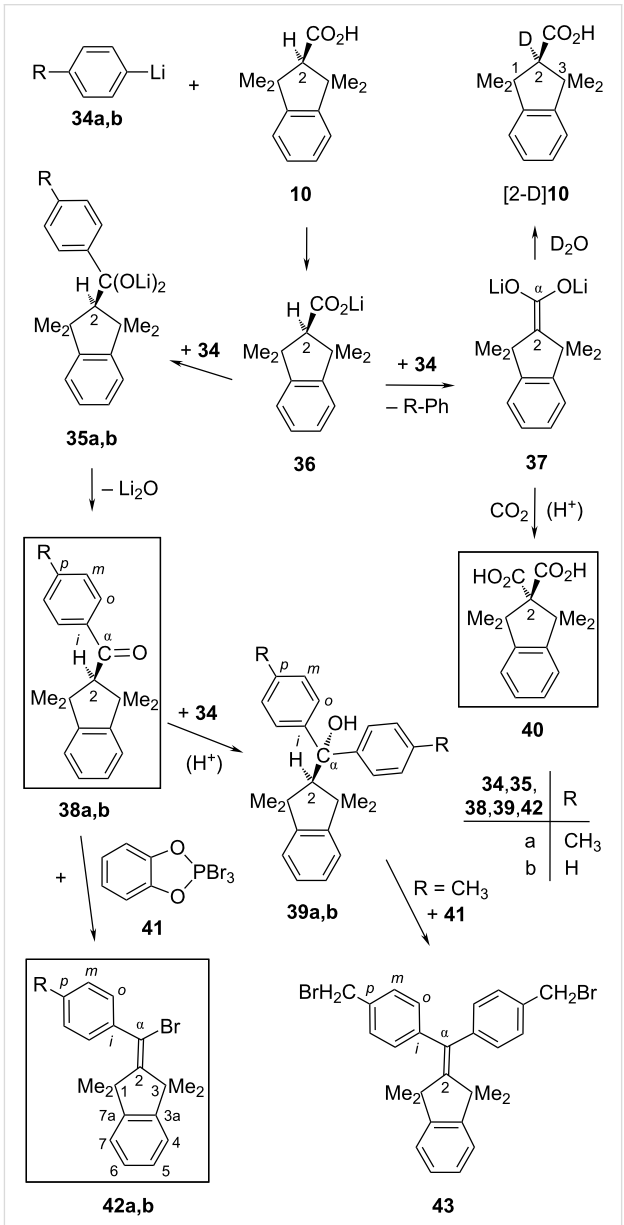


Scheme 5: Possible course of the carbenoid *chain* reaction of **12** with DMSO and the α,α-dichloroalkene **6**.

steps should isomerize **27** into the energetically more stable allyl anion derivative **31**. Either **29** or **32** may intercept **31** with formation of the side-product **33**, whose structure was recognized through its NMR data [30] as follows. The precursor **31** of **33** cannot have reacted at its C-β center, since this would have led to an isomer of **33** with only one proton-bearing olefinic ^{13}C center (C-α), whereas two olefinic CH centers (C-α and C-β) were detected in **33** while its C-2 atom was found to be aliphatic rather than olefinic. Although **33** is chiral, its only CH_2 signal exhibits merely weak line-broadening instead of the expected AB splitting pattern; this indicated the center of chirality (sulfur) to be rather distant from CH_2. The NOESY correlation of this quasi-singlet CH_2 signal with the SCH_3 resonance established the presence of a CH_2–S–CH_3 instead of a CH_2–S(O)–CH_3 fragment. The =CH–S(O)–CH_3 group and its proximity to the CH_2 protons were recognized through the NOESY correlations of the olefinic β-proton. This completes the mechanistic considerations for the unusual "hydrolysis" reaction of the unactivated α,α-dichloroalkene **6** and its side-products.

Toward one-sidedly overcrowded ketone and bromoalkene descendants

The α,α-(di-*tert*-alkyl)methyl aryl ketones **38** (Scheme 6) would normally be considered to be accessible through Friedel–Crafts acylation of arenes by the acid chloride of **10**. This possibility was repudiated, however, because the similar acyl chloride *t*-Bu_2CH–CO–Cl did not acylate benzene [37,38]. Instead, the technique [39] of acylating an aryllithium compound such as **34** by a lithium carboxylate such as **36** to form **35** proved effective



Scheme 6: Synthesis of the one-sidedly overcrowded descendants **38**, **39**, and **42**.

in Et_2O as the solvent, in spite of a dissuasive message [40] that was based on the failure with 2,6-dimethylbenzoic acid at ice temperature. Admittedly, our protocol requires prolonged stirring in Et_2O at or above rt due to steric shielding in **36**, which enabled at least two yield-reducing side-reactions to consume the aryllithium reagents **34a**,**b** to some extent, as delineated below. Therefore, acid **10** was treated with an excess of **34a**,**b** which were generated from aryl bromides, using either 2.5 equivalents thereof together with *tert*-butyllithium (*t*-BuLi, five equiv) or four equivalents of both aryl bromide and *n*-BuLi. The preformed sodium carboxylate of **10** in place of **36** was apparently too insoluble in Et_2O to react with **34**.

The primary products **35** tend to eliminate Li_2O slowly with formation of ketones **38** in the presence of aryllithium reagents **34** which will rapidly add to **38**, creating the tertiary alcohols **39**. The unwanted side-products **39** might also arise during simple aqueous work-up where hydrolytic ketone formation from primary products such as **35** was often [40,41] able to compete with the fast protolysis of residual aryllithium reagents. To avoid this suspected mischief, we applied nonaqueous quenching of residual **34**, using either carboxylation by solid CO_2 or the commended treatments with aniline [41] as the proton donor or with Me_3SiCl [40] prior to the aqueous work-up. However, none of these three precautionary measures improved the **38**/**39** ratios (ca. 9:1 after ca. 20 hours at rt) significantly, which means that the side-products **39** arose essentially before the work-up procedure. Actually, the unwelcome portions of **39** increased in parallel with extending reaction periods and made especially the isolation of pure ketone **38b** somewhat tedious. (An alternative route [30] can provide **38b** without side-products.) The overcrowded nature of **39a** and **39b** became evident [30] through NMR line broadening effects as caused by impeded rotations about the C-α/C-*ipso* single bonds.

As a second side-reaction, deprotonation of 2-H in **36** by **34** competed with the retarded acylation of **34**, so that the dianion **37** of acid **10** was generated and contributed to the recovery of **10** on aqueous work-up. The intermediacy of **37** was recognized through quenching either with D_2O to afford [2-D]**10** or with solid CO_2 and subsequent isolation of the highly symmetric diacid **40** (only seven ^{13}C NMR signals). The constitution of **40** followed from its ready decarboxylation in $CDCl_3$ solution at rt to regenerate acid **10** within four days.

Conversion of the ketone **38a** into bromoalkene **42a** through brominative deoxygenation [42,43] with tribromide **41** was slow in hot chloroform but almost complete within 17 hours at 80 °C in 1,2-dichloroethane as the solvent. The purification of **42a** by simple recrystallization was easy, unless the employed ketone **38a** was contaminated with its side-product **39a** whose *p*-methyl groups were brominated by reagent **41** with formation of **43** [30]. The pure ketone **38b** and reagent **41** furnished the known [44,45] bromoalkene **42b** as the only product [30,46].

Conclusion

The observed features of the "hydrolysis" reaction of the unactivated α,α-dichloroalkene **6** with solid KOH in DMSO are incompatible with the key intermediate **9** of the ARE [12] mechanism. Instead, a Cl,K-carbenoid **12** (indicated by the observation of its reversible protonation) is compatible and appropriate as the first intermediate in the route from **6** to acid **10**. This formal "hydrolysis" of **6** makes use of the impressively enhanced electrophilicity of "unsaturated" carbenoids [13] such as **12**, which property enables **12** to react with the moderately nucleophilic but abundant solvent DMSO that brings along the possibility of an oxygen transfer: The necessary cleavage of the O–S bond in the resultant K,O-carbenoid **15** may occur either directly (the Me_2S producing pathway in Scheme 3) or upon formation of the carbenoid *chain* product **28** (Scheme 5). Obviously, DMSO is a unique choice for oxidizing **12** in both the chain and the nonchain mechanistic options. The nonoxidizing nucleophiles $PhCH_2K$ and $KN(SiMe_3)_2$ can convert **12** to the expected nonacidic S_NV products, whereas **12** prefers to expand its five-membered ring if a suitable nucleophile is not available [30].

The easily isolated and purified acid **10** is able to transfer its bulky di-*tert*-alkylacetyl body onto a sufficiently reactive nucleophile. The first nucleophilic attack is already sterically impeded, as suggested by its ability to compete with the generation of dianion **37** of acid **10** (Scheme 6). Nevertheless, such one-sided shielding in the product ketone does not prevent the incorporation of a second nucleophile, affording a tertiary alcohol with a substantially impeded internal mobility. Final brominative deoxygenation of the ketones can yield bromoalkenes as the only products with moderately decreased speed.

Experimental

1,1,3,3-Tetramethylindan-2-carboxylic acid (10): The following procedure should be carried out in an efficient hood and/or with a cold trap that can collect and retain malodorant volatile products such as Me_2S. The dichloroalkene **6** (2.80 g, 11.0 mmol), dimethyl sulfoxide (45 mL), and a magnetic stirring bar were placed in a round-bottomed flask carrying either a wide-bore connection to a cooled trap or a T-shaped glass-tube with a bubbler and gas inlet. This suspension was stirred at 60 °C until **6** was completely dissolved. Freshly pulverized KOH (18.0 g, 321 mmol) was added and the brown mixture stirred at 100 °C under inert-gas cover for at least six hours,

then cooled to rt, poured into distilled water (250 mL), and shaken with Et_2O (3 × 50 mL). The malodorant aqueous layer containing the potassium salt **17** was treated batchwise with NaOCl solution in an amount that sufficed for showing a positive potassium iodide/starch test for 30 min, at which time this residual NaOCl was forthwith destroyed by solid $NaHSO_3$ that had to be added until the KI/starch test became negative. ($KMnO_4$ in place of NaOCl was found to decompose **17**.) The solution was thoroughly stirred with charcoal, then filtered, cooled in ice, and acidified with concd. hydrochloric acid. The precipitated acid **10** was extracted with Et_2O or (better) pentane (3 × 70 mL). These combined extracts were repeatedly washed with distilled water to remove traces of DMSO, dried over Na_2SO_4, and evaporated to leave the almost pure acid **10** as a white powder (1.31 g, 54%) with mp 188–190 °C (ref [15]: 189–190.5 °C); ^{1}H NMR ($CDCl_3$, 400 MHz) δ 1.41 (s, 6H, 1-/3-CH_3 syn to CO_2H), 1.52 (s, 6H, 1-/3-CH_3 anti to CO_2H), 2.91 (s, 1H, 2-H), 7.16 (AA´ part of an AA´BB´ system, 2H, 4-/7-H), 7.24 (BB´ part, 2H, 5-/6-H) ppm, assigned through the NOESY correlations 2-H ↔ anti-CH_3 ↔ syn-CH_3 ↔ 4-/7-H ↔ anti-CH_3; ^{1}H NMR ([D_6]acetone, 400 MHz) δ 1.35, 1.48, 2.85, 7.12, 7.18 ppm; ^{13}C NMR ($CDCl_3$, 100.6 MHz) δ 27.4 (1-/3-CH_3 syn to CO_2H), 30.2 (1-/3-CH_3 anti to CO_2H), 45.6 (C-1/-3), 64.8 (C-2), 122.3 (C-4/-7), 127.3 (C-5/-6), 149.4 (C-3a/7a), 179.1 (CO_2H) ppm, assigned through HSQC; ^{13}C NMR ([D_6]acetone, 100.6 MHz) δ 27.7, 30.5, 45.9, 65.2, 123.1, 128.0, 150.5, 173.4 ppm.

1,1,3,3-Tetramethyl-2-(methylsulfinylmethylidene)indane (23). The combined Et_2O extracts containing the nonacidic side-products, as obtained in the above preparation of **10** and separated from the alkaline aqueous layer, were washed with distilled water until neutral, dried over Na_2SO_4, and evaporated. The remaining brown solid (<977 mg) contained mainly the sulfoxides **23** and **33** (3:1) together with a little of 1,1,3,3-tetramethylindan-2-one (**24**). The pure sample of **23** (284 mg, 10%) was isolated through extraction into hot, low-boiling petroleum ether (60 mL), filtration, and concentration. Recrystallization afforded almost colorless needles with mp 134–135 °C; ^{1}H NMR ($CDCl_3$, 400 MHz) δ 1.41 and 1.45 (2 s, 2 × 3H, 2 × 3-CH_3), 1.51 and 1.73 (2 s, 2 × 3H, 2 × 1-CH_3), 2.67 (s, 3H, OS-CH_3), 6.25 (s, 1H, α-H), 7.17 (AA´ part of an AA´BB´ system, 2H, 4-/7-H), 7.27 (BB´ part, 2H, 5-/6-H) ppm, assigned through comparison with the phenylsulfinylmethylidene analogue [47]; ^{1}H NMR (DMSO, 200 MHz) δ 1.38 (2 × 3-CH_3), 1.46 and 1.63 (2 × 1-CH_3), 6.47 (α-H), 7.24 (quasi-s, 4-/5-/6-/7-H); ^{13}C NMR ($CDCl_3$, 100.6 MHz) δ 30.12 and 31.94 (2 × 3-CH_3), 31.54 and 32.95 (2 × 1-CH_3), 40.73 (OS–CH_3), 48.54 (C-3), 48.76 (C-1), 122.41 and 122.51 (C-4/-7), 127.70 and 127.82 (C-5/-6), 128.78 (C-α), 147.04 (C-3a), 148.23 (C-7a), 174.13 (C-2) ppm, assigned as above in accord with the deuterium-induced shifts $^2\Delta$ = –0.068 for C-2, $^3\Delta$ = −0.021 for C-3, and $^3\Delta$ = −0.045 ppm for C-1 as caused by the =C$^\alpha$D–S(O)–CD_3 group incorporated during a run in [D_6]DMSO; IR (KBr) ν: 2971, 2959, 2920, 2860, 1627 (w), 1484, 1363, 1032, 1022, 968, 748, 677, 505 cm^{-1}; anal. calcd for $C_{15}H_{20}OS$ (248.39): C, 72.53; H, 8.12; S, 12.91; found: C, 72.75; H, 8.25; S, 12.94.

2-(*p*-Methylbenzoyl)-1,1,3,3-tetramethylindane (38a): A round-bottomed Schlenk flask (50 mL) was charged with 4-bromotoluene (0.563 mL, 4.58 mmol), anhydrous Et_2O (10 mL), and a magnetic stirring bar. The contents were stirred and cooled at −78 °C under argon gas cover during the dropwise addition of *t*-BuLi (9.16 mmol) in pentane (6.10 mL), then stirred without cooling for 30 min. After the dropwise addition of acid **10** (400 mg, 1.83 mmol) in anhydrous Et_2O (10 mL) to this solution of *p*-methylphenyllithium (**34a**) and further stirring at rt for 18 hours, the mixture was poured onto solid CO_2, warmed up, and diluted with aqueous NaOH (1 M, 20 mL). The aqueous layer was shaken with Et_2O (3 × 20 mL) and the combined four Et_2O layers were washed with distilled water until neutral, dried over Na_2SO_4, and concentrated to leave the crude nonacidic material (455 mg) consisting mainly of **38a**, **39a**, and toluene (9:1:9). Repeated crystallizations from pentane afforded white needles of **38a** (isolated yield up to 35%); mp 95.5–96.5 °C (methanol); ^{1}H NMR ($CDCl_3$, 400 MHz) δ 1.34 and 1.39 (2 s, 2 × 6H, 2 × 1-/3-CH_3), 2.42 (s, 3H, *p*-CH_3), 4.10 (s, 1H, 2-H), 7.17 and 7.24 (AA´BB´ system, 2 × 2H, 4-/5-/6-/7-H), 7.28 (broadened d, ^3J = 8.3 Hz, 2H, 2 × *m*-H), 7.88 (dm, ^3J = 8.3 Hz, 2H, 2 × *o*-H) ppm; ^{1}H NMR (CCl_4, 80 MHz) δ 1.29, 1.35, 2.39, 3.99, 7.06 (s, 4H), 7.18 (d), 7.80 (d) ppm; ^{13}C NMR ($CDCl_3$, 100.6 MHz) δ 21.56 (*p*-CH_3), 28.02 and 30.98 (2 × 1-/3-CH_3), 47.17 (C-1/-3), 64.32 (C-2), 122.34 (C-4/-7), 127.12 (C-5/-6), 128.28 and 129.34 (2 × C-*m* and 2 × C-*o*), 138.36 (C-*ipso*), 143.50 (C-*p*), 149.99 (C-3a/7a), 201.25 (C=O) ppm; IR (KBr) ν: 2967, 2925, 2862, 1664 (s), 1606, 1480, 1368, 1228, 1209, 1186, 869, 759 cm^{-1}; anal. calcd for $C_{21}H_{24}O$ (292.42): C, 86.26; H, 8.27; found: C, 86.50; H, 8.41.

The above aqueous NaOH layer was acidified with concd. hydrochloric acid and was shaken with Et_2O (3 × 10 mL). These combined Et_2O extracts were washed with distilled water until neutral, dried over Na_2SO_4, and evaporated to leave a white powder containing acid **10**, *p*-methylbenzoic acid, *p*-cresol, and diacid **40** (ca. 4:2:2:1).

1,1,3,3-Tetramethylindan-2,2-dicarboxylic acid (40): The mixture of acids obtained above (see **38a**) was leached with pentane, which left the insoluble diacid **40** behind (65 mg, 14% yield). One recrystallization from hot toluene afforded clean **40** (30 mg) but led to the decarboxylation of a portion that

remained dissolved. The transparent needles of pure **40** had a mp of 195–197.5 °C (dec.), decomposed slowly on standing at rt in $CDCl_3$ solution, and were weakly soluble in CCl_4 only as long as they were a part of the original mixture with the other carboxylic acids. ^{1}H NMR ([D$_6$]acetone or $CDCl_3$, 400 MHz) δ 1.58 (s, 12H, 2 × 1-/3-CH_3), 7.21 (quasi-s, 4H, 4-/5-/6-/7-H) ppm; ^{13}C NMR ([D$_6$]acetone, 100.6 MHz) δ 28.83 (2 × 1-/3-CH_3), 48.98 (C-1/-3), 122.28 (C-4/-7), 125.79 (C-2), 127.59 (C-5/-6), 150.30 (C-3a/7a), 171.73 (2 × CO_2H) ppm, assigned through comparison with the acid **10**; IR (KBr) ν: 3400–2500 (very broad H–O), 1713 (s), 1291, 759 cm^{-1}; anal. calcd for $C_{15}H_{18}O_4$ (262.3): C, 68.69; H, 6.92; found: C, 69.23; H, 6.81.

40 was not formed from acid **10** with lithium *N*,*N*-diisopropylamide in THF as the solvent at rt: final quenching with solid CO_2 afforded only starting material **10**.

2-(α-Bromo-*p*-methylbenzylidene)-1,1,3,3-tetramethylindane (42a): A dry NMR tube (5 mm) was charged under argon cover gas with 2-bromo-1,3,2-benzodioxaphosphole [48] (0.12 mL, 0.95 mmol) and anhydrous, EtOH-free 1,2-dichloroethane (0.5 mL). The solution was cooled in ice, treated with elemental bromine (0.040 mL, 0.78 mmol), and kept at rt for 15 min. This yellow solution of 2,2,2-tribromo-2,2-dihydro-1,3,2-benzodioxaphosphole (**41**) [49] was recooled in ice for the addition of the pure, solid ketone **38a** (200 mg, 0.68 mmol), which caused an immediate color change to brown. The tightly stoppered tube was heated at 80 °C for at least 17 hours, then diluted with pentane (5 mL), and poured onto ice-cooled aqueous Na_2CO_3 solution (2 M, 5 mL), which was stirred for 15 min. The aqueous Na_2CO_3 layer was shaken with pentane (2 × 5 mL) and discarded. The combined pentane extracts were shaken with aqueous NaOH (2 M, 3 × 5 mL), washed with distilled water (10 mL), dried over $CaCl_2$, and evaporated to furnish the solid nonacidic fraction (256 mg) containing a little residual ketone **38a**. Recrystallization from ethanol (12 mL) yielded pure needles of **42a** (173 mg, 71%), mp 119.5–121 °C; ^{1}H NMR ($CDCl_3$, 400 MHz) δ 1.19 (s, 6H, 2 × 1-CH_3), 1.78 (s, 6H, 2 × 3-CH_3), 2.38 (s, 3H, *p*-CH_3), 7.03 (dm, ^3J = 7.5 Hz, 1H, 7-H), 7.16 and 7.22 (quasi-AB system, ^3J = 8 Hz, 2 × 2H, 2 × *o*-H and 2 × *m*-H of tolyl), 7.18–7.27 (m, 3H, 4-/5-/6-H) ppm, assigned through comparison with **42b** [45]; ^{1}H NMR (CCl_4, 80 MHz) δ 1.17, 1.76, 2.38, 7.14 ppm; ^{13}C NMR ($CDCl_3$, 100.6 MHz) δ 21.30 (*p*-CH_3), 28.05 (2 × 3-CH_3), 31.19 (2 ×1-CH_3), 50.55 (C-1/-3), 117.95 (C-α), 122.10 (C-4), 122.59 (C-7), 127.16 (C-5), 127.24 (C-6), 128.53 (2 × C-*m*), 129.61 (2 × C-*o*), 137.66 (C-*p*), 139.93 (C-*ipso*), 149.00 (C-3a), 149.86 (C-7a), 157.11 (C-2) ppm, assigned as above; IR (KBr) ν: 2987, 2959, 2924, 2865, 1505, 1487, 1456, 1363, 799, 757 cm^{-1}; anal. calcd for $C_{21}H_{23}Br$ (355.32): C, 70.99; H, 6.52; Br, 22.49; found: C, 70.88, H, 6.66; Br, 23.17.

Supporting Information

Supporting Information File 1

Alternative synthesis of ketone **38b**; preparation of [2-D]**10**, **33**, **39a**, **39b**, **42b**, and **43**; FBW ring expansion of carbenoid **12**; S_NV reactions of **12** with $PhCH_2K$ and with $KN(SiMe_3)_2$.
[http://www.beilstein-journals.org/bjoc/content/supplementary/1860-5397-10-28-S1.pdf]

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