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Studies on the Stability of Cycloprop-2-ene Carboxylate Dianions and Reactions with Electrophiles

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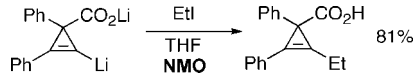

Dianions are generated from alkyllithium reagents and cycloprop-2-ene carboxylic acids, and these dianions can be functionalized by electrophiles at the vinylic position. In a previous report, we described that such dianions could be generated and reacted with electrophiles in Et_2O or THF. Upon further study, it was found that there were reproducibility issues for those reactions that were carried out in Et_2O. Working under the assumption that an impurity may have promoted these reactions, a detailed study was undertaken to determine the effect of variables on the generation, stability, and reactivity of cycloprop-2-ene carboxylate dianions. It has been found that certain additives can have a substantial effect on the chemistry of cycloprop-2-ene carboxylate dianions. In particular, it was determined that amine *N*-oxide additives have a beneficial effect both on the stability of cycloprop-2-ene carboxylate dianions and on the rates that such dianions undergo alkylation. Conditions for reacting dianions with a broad range of electrophiles are described.

Introduction

Chiral cyclopropenes have emerged as important intermediates for the stereocontrolled synthesis of functionalized cyclopropane derivatives.[1] Accordingly, much attention has been focused recently on the preparation of cyclopropenes in enantiomerically enriched form, and recently developed methods for enantioselective cyclopropenation,[2] resolution,[3] kinetic resolution,[4] and desymmetrization[5] provide broad access to enantiomerically enriched cyclopropenes. These methods provide access to chiral cyclopropenes from terminal alkynes, but there are relatively few methods that provide access to chiral cyclopropenes with two alkene substituents. This discrepancy prompted Eckert-Maksic,[6a−c] Lam,[6d] Gevorgyan,[7] and us[8] to investigate protocols for converting "terminal" cyclopropenes into "internal" cyclopropenes.[9] Gevorgyan and co-workers have described an elegant, Pd-catalyzed method for accessing chiral, internal cyclopropenes by the direct arylation of alkyl cycloprop-2-ene carboxylates.[7a] In more recent work, Gevorgyan and co-workers have also described a variant of the Morita−Baylis−Hillman reaction that converted methyl 2-butyl-1-(*p*-nitrophenyl)-3-trimethylsilylcycloprop-2-ene carboxylate into an internal cyclopropene using benzaldehyde as the electrophile.[7b] It is well

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(9) In analogy to the common nomenclature of alkynes, we refer to cyclopropenes with a single alkene substituent as "terminal" cyclopropenes and to those with two alkene substituents as "internal" cyclopropenes.

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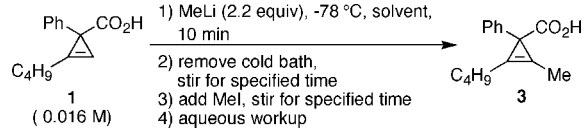
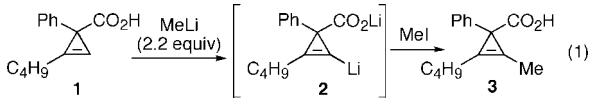
TABLE 1. Effects of Various Parameters on Dianion Alkylation.



entry	alkyllithium	solvent	before MeI addition	after MeI addition	yield of **3**[c] (%)
1	MeLi (1.6 M in Et_2O)	Et_2O	9 min[a]	20 min	7
2	MeLi ("homemade" from Li with low Na content 1.1 M in Et_2O)	Et_2O	9 min[a]	20 min	0
3	MeLi ("homemade" from Li with high Na content 1.1 M in Et_2O)	Et_2O	9 min[a]	20 min	5
4	*s*-BuLi (1.4 M in cyclohexane)	Et_2O	30 min[a]	20 min	6
5	MeLi (1.6 M in Et_2O)	Et_2O (0.16 M in **1**)[d]	4 min[a]	20 min	46
6	MeLi (1.6 M in Et_2O)	THF	9 min[a]	30 min	88[e]
7	*s*-BuLi (1.4 M in cyclohexane)	THF	10 min (0 °C)[b]	20 min	86
8	*s*-BuLi (1.4 M in cyclohexane)	THF	30 min (18 °C)[b]	20 min	68
9	*s*-BuLi (1.4 M in cyclohexane)	THF	60 min rt (21 °C)[b]	20 min	10
10	*s*-BuLi (1.4 M in cyclohexane)	THF	120 min rt (21 °C)[b]	20 min	0
11	MeLi (1.6 M in Et_2O)	Et_2O (0.16 M in **1**)[d] H_2O (0.7 equiv)	4 min	30 min	64
12	MeLi (1.6 M in Et_2O)	Et_2O (0.16 M in **1**)[d] MeOH (3.5 equiv)	4 min	30 min	56

[a] Unless noted otherwise, reactions were all carried out on the same scale (0.016 mmol of **1** in 10 mL of solvent). In representative reactions, internal temperatures were typically measured to be 0−5 °C after 9 min. After 30 min, the internal temperature had reached rt. [b] Internal temperature of the reaction at the time when MeI was added. [c] Yields and conversions were measured by ^{1}H NMR. [d] Reactions carried out at 0.16 M (1 mL solvent) had reached 0−5 °C after 4 min. [e] The yield measured by ^{1}H NMR was slightly lower than the isolated yield in later experiments (see Table 4).

established that cyclopropenes are acidic at the vinylic position and can be functionalized through deprotonation/electrophilic capture.[10] Eckert-Maksic and co-workers demonstrated that alkyl cycloprop-2-ene carboxylates can be generated and captured by silyl and germanyl electrophiles that were available for in situ reactivity.[6a−c] However, that protocol was limited to electrophiles that could be introduced prior to the introduction of base: the anions underwent ring-opening fragmentation when the electrophile was introduced subsequent to the addition of base. Lam has recently described a Cu-catalyzed method for silylation of cyclopropenes using TMSOTf,[6d] and a KF-mediated method for the stannylation of cyclopropenes by $Bu_3SnC_2F_5$.[6e] The cyclopropenes produced by the latter method can be further elaborated via Stille couplings.[6e] Our group described a procedure for anion formation/capture that utilized the dianions of cycloprop-2-ene carboxylic acids. For example, 1-phenyl-2-butyl-3-methylcycloprop-2-ene carboxylic acid (**3**) is produced by alkylation of dianion (**2**), which is derived from 1-phenyl-2-butylcycloprop-2-ene carboxylic acid (**1**) (eq 1).



(1)

Dianions such as **2** were found to be relatively stable toward ring-opening fragmentation, and hence could be reacted with a relatively wide range of electrophiles that included alkyl halides and aldehydes. The dianions could also be coupled to aryl iodides upon transmetalation with $ZnCl_2$ under Pd-catalyzed conditions. In general, dianions were formed from cycloprop-2-ene carboxylic acids by using MeLi at −78 °C in Et_2O or THF. For most reactions, the dianions were allowed to warm to room temperature prior to the addition of the electrophile. Although the majority of the experiments in our prior work involved racemic cyclopropenes, it was demonstrated that the dianion of nonracemic 1,2-diphenylcycloprop-2-ene carboxylic acid undergoes alkylation by MeI with excellent transfer of stereochemistry.[8] Overall, the reactions were operationally straightforward and did not require special precautions.

Recently, we became aware that the protocols that employed Et_2O as solvent could not be consistently repeated (see Table 1 of the 2004 publication:[8] all three entries in row 1, and the first entry in row 2). As all of the protocols in the earlier work had been reproduced prior to publication, it seemed possible that an adventitious and essential impurity may have been present in the earlier experiments. Accordingly, a study was undertaken to determine the effects of different additives on the stability and reactivity of the dianions. It was determined that amine *N*-oxides dramatically enhance both the reactivity and the stability of dianions from cycloprop-2-ene carboxylic acids. Conditions are described for reacting dianions with a variety of electrophiles, and the scope and limitations of the method are described.

Results and Discussion

We reported previously that **3** could be prepared by adding ethereal MeLi (2.2 equiv) to a 0.016 M solution of **1** in Et_2O at −78 °C, permitting the resulting solution to warm to room temperature, and subsequently adding MeI or MeOTs and allowing the mixture to stir for 30 min.[8] The product **3** was obtained in good yield (81%) upon acidic workup and chromatography. However, our more recent experiments have produced **3** in only low yield (Table 1, entries 1−3). The MeLi that was used in the published procedure was prepared from MeI/Li wire in Et_2O.[8] However, low yields (0−7%) were obtained regardless of the source or type of MeLi: attempts were made using commercially available MeLi from various vendors, and MeLi prepared from several grades of Li wire. A low yield of **3** was also obtained in an experiment that was carried out with *s*-BuLi instead of MeLi (Table 1, entry 4). However, it

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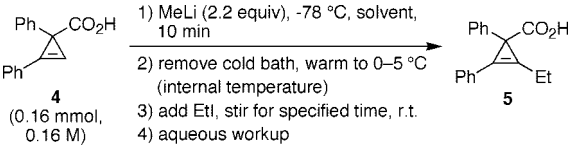
TABLE 2. Discovery that *N*-Oxides Promote Dianion Alkylation



entry	solvent	time elapsed after EtI addition	yield of **5**[a](%)
1	Et_2O[b]	9 min	10[c]
2	Et_2O, 12-C-4 (6%)[b]	9 min	9[c]
3	THF	30 min	32[c]
4	THF	2.5 h	45[d]
5	THF	30 min, 35 °C	34[d]
6	THF/TMEDA (2 equiv)	30 min	34[c]
7	THF/TMEDA (2 equiv)	1.5 h	34[d]
8	THF/TMANO (2 equiv)	30 min	53[c]
9	THF/NMO (2 equiv)	30 min	81[e]
10	THF/HMPA (2 equiv)	30 min	72[e]

[a] Yield estimated by analysis of the crude ^{1}H NMR spectrum. [b] The reaction was carried out at 0.016 M. [c] By TLC analysis, only **5** and **4** were detected. [d] Only traces of remaining **4** were detected by TLC analysis. Uncharacterized decomposition products were observed in the NMR spectrum of the crude mixture. [e] Isolated yield; compound **4** was not detected by TLC analysis.

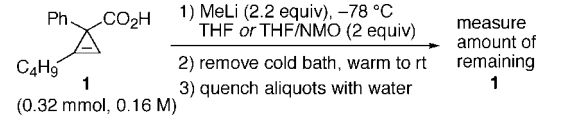
was possible to obtain **3** in moderate yield (46%) when the reaction was carried out at higher concentration (0.16 M) in Et_2O (Table 1, entry 5). A high yield (88%) of **3** was obtained when THF was used as the solvent instead of Et_2O (Table 1, entry 6).

The results displayed in entries 7−10 in Table 1 demonstrate that the dianion of **1** is not stable for long periods at room temperature. In these experiments, the dianion of **1** was generated with *s*-BuLi at −78 °C and permitted to stir while warming to room temperature for variable amounts of time before quenching with MeI. In a reaction where MeI was added 10 min after the cold bath was removed (internal temperature of 0 °C), **3** was produced in 86% yield (Table 1, entry 7). However, in a reaction where MeI was added 30 min after the cold bath was removed (internal temperature of 18 °C), the yield was only 68% (Table 1, entry 8). In experiments where the time prior to MeI addition was increased to 1 and 2 h, the yields of **3** were measured as 10% and 0%, respectively (Table 1, entries 9 and 10). Collectively, the results in Table 1 suggest that the dianion of **1** is only moderately stable at room temperature, and that the rate of dianion decomposition is comparable to the rate of alkylation by MeI when Et_2O is the solvent.

We had also reported previously that cyclopropene **5** could be synthesized from EtI and the dianion of **4**, which was prepared from MeLi in Et_2O with a catalytic amount of 12-crown-4. However, in more recent experiments we obtained **5** in low yield (9−10%) in Et_2O—with or without 12-crown-4 (Table 2, entries 1 and 2). Using THF as the solvent (0.16 M) resulted in only a modest improvement (32%, Table 2, entry 3). Increasing the temperature to 35 °C did not increase the yield (34%, Table 2, entry 5), and prolonged reaction times resulted in only a minor improvement (45%, Table 2, entry 4).

Studies were carried out to determine the effect of additives on the fate of the dianion alkylation. We focused initially on additives that may have reasonably been present as impurities in our earlier experiments. Adding water provided only a modest benefit for the reaction of **1** with MeI in Et_2O (64%, Table 1, entry 11). It was also speculated that methanol may have been

TABLE 3. The Effect of NMO on the Stability of the Dianion of 1



in THF		in THF/NMO	
time/internal temp[a]	amount of **1** remaining (%)	time/internal temp[a]	amount of **1** remaining (%)
15 min/21 °C	32	15 min/18 °C	74
30 min/23 °C	27	30 min/24 °C	58
45 min/24 °C	20	45 min/24 °C	44
60 min/24 °C	12	60 min/24 °C	38

[a] Time was measured from the point at which the dry ice bath was removed.

introduced to the system via reaction of oxygen with MeLi.[11] However, the addition of methanol also resulted in only a modest improvement in the yield of **3** in Et_2O (56%, Table 1, entry 12). The effect of adding LiI was also analyzed for reaction of EtI with the dianion of **1** in THF, but there was no benefit.[12]

The effect of amines or amine *N*-oxides on alkylation reactions was also considered. While the addition of TMEDA did not provide any benefit for the formation of **5** (Table 2, entries 6 and 7), the inclusion of amine *N*-oxides had a significant effect. The yield of **5** increased to 51% when trimethylamine *N*-oxide was included (Table 2, entry 8), and to 81% when *N*-methylmorpholine *N*-oxide (NMO) was included (Table 2, entry 9). NMO has been used as a less-toxic alternative to HMPA for promoting vinyl alumination reactions.[13a] Quinuclidine *N*-oxide has also been used as a general alternative to HMPA for a range of reactions, including dianion reaction.[13b,c] Indeed, the use of HMPA as a cosolvent also has a beneficial effect on the yield of **5** (72%, Table 2, entry 10). DMSO and 1,3-dimethylimidazolidinone are also commonly employed as HMPA alternatives, but these cosolvents were ineffective for the synthesis of **5**.

A conclusion from the experiments outlined in Table 2 is that dianion alkylation is accelerated by the inclusion of NMO. The experiments outlined below determined that NMO also has a beneficial effect on the stability of dianions. Thus, the dianion of **1** was generated at −78 °C with MeLi in THF (0.16 M) in the presence of an internal standard (mesitylene). The cold bath was removed and the dianion was permitted to warm to an internal temperature of 23 °C: at timed intervals aliquots were taken, quenched, and analyzed by ^{1}H NMR (Table 3). Only 27% of **1** remained after the cold bath had been removed for 30 min, and only 12% of **1** remained after 60 min. However, 58% and 38% of **1** remained after 30 and 60 min, respectively, in a similar experiment in which NMO was included.

From these experiments, it is concluded that the stability and reactivity of cycloprop-2-ene carboxylate dianions can be influenced by additives. Efforts are ongoing in our laboratories to determine other additives that promote dianion stability and reactivity toward electrophiles.

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(12) A 0.016 M solution of **1** was deprotonated by using 2.2 equiv of MeLi (1.47 M in Et_2O) and after warming to 0−5 °C EtI (2.6 equiv) and LiI (5 equiv) were added. The reaction was then allowed to stir for 30 min while warming to room temperature. Aqueous workup and analysis of the crude ^{1}H NMR spectrum indicated a 30% yield of **9** with the balance being unreacted starting material.

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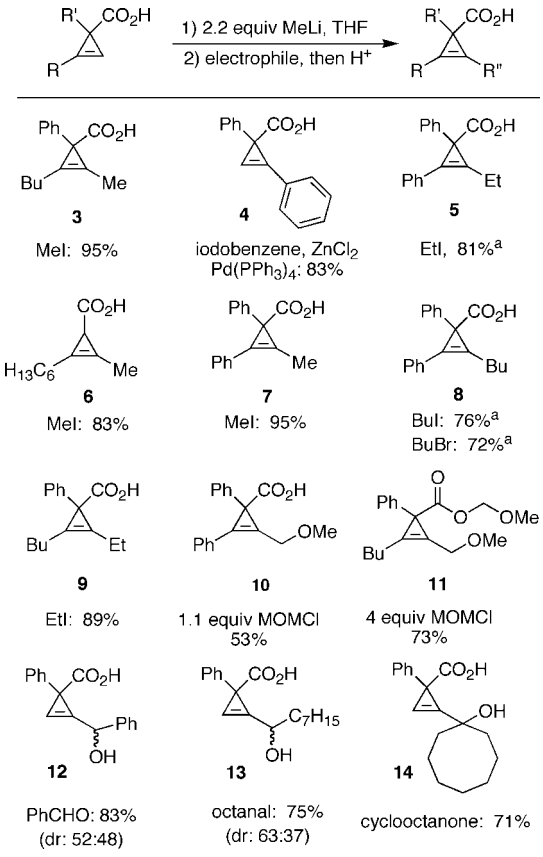
TABLE 4. Reactions of Dianions with Electrophiles



[a] NMO (2 equiv) was added prior to the addition of MeLi.

With a clearer understanding of the factors that govern the reactivity and stability of dianions, the scope of reactivity toward various electrophiles was determined (Table 4). In experiments where the starting cyclopropene was chiral, racemic material was utilized. While MeLi was used in general to effect deprotonation, the nature of the alkyllithium was not important. In THF the reactions of dianions proceed in high yield with a variety of alkyllithium bases: commercial MeLi, "homemade" MeLi from Li with low Na content, "homemade" MeLi from Li with high Na content, *s*-BuLi, and *n*-BuLi.[14,15] It was not necessary to use NMO in the reactions of dianions with highly reactive electrophiles such as aldehydes (which gave **12** and **13**), ketones (which gave **14**), MeI (which gave **3**, **6**, and **7**), and MOMCl. It was possible to achieve selective *C*-alkylation to give **10** with 1.1 equiv of MOMCl, albeit in modest yield (53%).[16] However, both the vinylic and carboxylate anions could be alkylated to give **11** in 73% yield when excess MOMCl (4.0 equiv) was utilized.

NMO was also not required for the reaction to form **4** via a cross-coupling reaction. Transmetalation was accomplished by adding anhydrous $ZnCl_2$[17] to the dianion of 1-phenylcycloprop-2-ene carboxylic acid at −78 °C and stirring for 10 min; subsequent cross-coupling with iodobenzene under Pd-catalyzed conditions (−78 °C → rt) gave **4** in 83% yield. We note that the dianion of 1-phenyl-cycloprop-2-ene carboxylic acid decomposes at temperatures above −40 °C, and it should be combined with electrophiles at low temperature for effective reactivity. In our prior report,[8] the dianion of 1-phenylcycloprop-2-ene carboxylic acid was warmed to 0−5 °C before electrophiles were added. It is plausible that an impurity in the earlier study may have stabilized the dianion at higher temperatures.[18]

Reactions of the dianion of **4** with primary alkyl halides did require NMO to achieve high conversion of starting material. As described previously, **5** was obtained in high yield only when NMO was included. The dianion of **4** also reacted to completion with butyl iodide to give **8** in 76% yield when NMO was included in the reaction. The analogous reaction of the dianion of **4** with butyl bromide only went to ∼50% conversion (by TLC analysis) after 45 min: **8** was obtained in 48% isolated yield. Running the reaction for 2 h and increasing the amount of butyl bromide to 5.5 equiv resulted in a 72% isolated yield, with the remainder being unreacted starting material (TLC analysis). Further increasing the reaction time did not improve the yield.

Several electrophiles were tried unsuccessfully. The dianion of **4** did not react with styrene oxide, 1,2-epoxydecane, or 2-cyclohexen-1-one. These reactions resulted only in returned starting material. Attempts to facilitate these reactions by adding CuI were unsuccessful, and resulted in decomposition. The reaction of the dianion of **1** with *N*-methoxy-*N*-methylbenzamide gave the product of *O*-acylation without *C*-acylation. Attempts to add a secondary halide, 2-iodopropane, to either the dianion of **1** or **4** gave products in <30% yield, and the products could not be isolated in pure form. Ethyl α-bromoacetate and *N*-ethylmaleimide were also unsuccessful and resulted only in unreacted starting material. The addition of propionyl chloride to the dianion of **1** resulted in decomposition. The reactions of the dianion of **4** with benzyl bromide or benzyl iodide did not proceed to completion (<50% conversion). Although the product was detected by ^{1}H NMR analysis of the crude reaction mixtures, the product decomposed during flash chromatography and could not be isolated in pure form.

Conclusions

A systematic study on the generation, stability, and reactivity of cycloprop-2-ene carboxylate dianions is described. The nature of the organolithium base used to deprotonate cycloprop-2-ene carboxylic acids is not a significant variable, but the solvent plays a major role in the efficiency of reactions toward electrophiles. Additionally, *N*-oxide additives have a dramatic influence on the stability and reactivity of the dianions.

Experimental Section

Representative Procedures: 1-Phenyl-2-butyl-3-methylcycloprop-2-ene Carboxylic Acid (3). To a dried 10-mL round-bottomed

(14) The dianion of **1** was generated with commercial MeLi, "homemade" MeLi from Li with low Na content, "homemade" MeLi from Li with high Na content, and commercial *s*-BuLi. In all cases, reaction with MeI gave **3** in 90−97% yield.

(15) The dianion of **4** was generated by using *n*-BuLi in the presence of NMO. Reaction with BuI produced compound **8** in 72% yield.

(16) Increasing the amount of MOMCl to 1.5 equiv only led to larger amounts of the dialkylated product. NMO did not help to improve this selectivity.

(17) The quality of the $ZnCl_2$ was found to be very important for the transmetalation/$Pd(PPh_3)_4$ coupling reaction of aryl halides. Initial attempts to use a commercial 1.0 M solution in Et_2O resulted in recovered starting material and only trace amounts of product. Anhydrous beads of $ZnCl_2$ (10 mesh) were found to give optimal results in the coupling reaction.

(18) Decomposition of the dianion of 1-phenylcycloprop-2-ene carboxylic acid (generated with MeLi at−78 °C in THF) occurs rapidly when the solution is warmed by an ice bath: within 2 min the solution turns black. In our prior report, a yellow solution was obtained when the solution was warmed to 0−5 °C.

flask was added (±)-1-phenyl-2-butylcycloprop-2-ene carboxylic acid (35 mg, 0.16 mmol). Freshly distilled THF (1 mL) was added via syringe, and the solution was cooled in a bath of dry ice/acetone. The solution was allowed to stir and MeLi (0.22 mL of a 1.6 M solution in Et_2O, 0.35 mmol) was added via syringe. After the mixture had stirred at −78 °C for 10 min, the dry ice/acetone bath was removed and the mixture was gradually allowed to warm until an internal temperature of 0−5 °C was reached (3 min on this scale). To the red solution was added MeI (60 mg, 26 μL, 0.42 mmol) via syringe. After being stirred at room temperature for 30 min, the reaction was quenched with water, and aq 3 M HCl was added to render the solution acidic (pH 1−2). The organic phase was separated and the aqueous phase was extracted three times with CH_2Cl_2. The combined organics were dried (Na_2SO_4), filtered, and concentrated. The residue was chromatographed on silica gel (5−15% ethyl acetate in hexanes) to provide 36 mg (97%) of the title compound as a white solid (mp 59−62 °C). A similar experiment starting with 100 mg of (±)-1-phenyl-2-butylcycloprop-2-ene carboxylic acid gave 99 mg (93%) of the title compound. The spectroscopic properties were identical with those described previously.[8]

1,2-Diphenyl-3-butylcycloprop-2-ene Carboxylic Acid (8). To a dried 25- mL round-bottomed flask was added (±)-1,2-diphenylcycloprop-2-ene carboxylic acid (114 mg, 0.483 mmol) and *N*-methylmorpholine *N*-oxide (113 mg, 0.966 mmol). Freshly distilled THF (3 mL) was added via syringe, and the solution was cooled in a bath of dry ice/acetone. The solution was allowed to stir and MeLi (0.67 mL of a 1.6 M solution in Et_2O, 1.1 mmol) was added via syringe. After the mixture had stirred at −78 °C for 10 min, the dry ice/acetone bath was removed and the mixture was gradually allowed to warm until the internal reaction temperature had reached 0−5 °C (5 min on this scale). To the blue solution was added BuI (232 mg, 144 μL, 1.26 mmol) via syringe. After being stirred at room temperature for 45 min, the reaction was quenched with water, and aq 3 M HCl was added to render the solution acidic (pH 1−2). The organic phase was separated and the aqueous phase was extracted five times with CH_2Cl_2. The combined organics were dried (Na_2SO_4), filtered, and concentrated. The residue was chromatographed on silica gel (10−15% ethyl acetate in hexanes) to provide 113 mg (80%) of the title compound as a white solid (mp 143−145.5 °C). An identical experiment gave 102 mg (72%) of the title compound. A similar experiment starting with 38 mg of (±)-1,2-diphenylcycloprop-2-ene carboxylic acid and reacting with BuBr (120 mg, 95 μL, 0.89 mmol) for 2 h gave 35 mg (73%) of the title compound. A repetition of the experiment with BuBr gave the title compound in 70% yield. ^{1}H NMR (DMSO-d_6, 400 MHz) δ 12.07 (br s, 1H), 7.46−7.53 (m, 4H), 7.37−7.42 (m, 1H), 7.30−7.33 (m, 2H), 7.22−7.26 (m, 2H), 7.13−7.17 (m, 1H), 2.69−2.84 (m, 2H), 1.63−1.71 (m, 2H), 1.33−1.42 (m, 2H), 0.88 (t, J = 7.5 Hz, 3H); ^{13}C NMR (DMSO-d_6, 100 MHz) δ 175.6 (C), 141.9 (C), 129.1 (CH), 128.8 (CH), 128.1 (CH), 127.8 (CH, 2 carbons), 126.3 (C), 125.8 (CH), 115.1 (C), 108.3 (C), 34.5 (C), 29.1 (CH_2), 24.0 (CH_2), 21.8 (CH_2), 13.6 (CH_3); IR (neat, cm^{-1}) 2933, 1684, 1495, 1236, 965; HRMS-CI(NH_3) m/z [M + H] calcd for $C_{20}H_{21}O_2$ 293.1542, found 293.1533.

1-Phenyl-2-(1-hydroxycyclooctyl)cycloprop-2-ene Carboxylic Acid (14). To a dried 25-mL round-bottomed flask was added 1-phenylcycloprop-2-ene carboxylic acid (52 mg, 0.33 mmol). Freshly distilled THF (2 mL) was added via syringe, and the solution was cooled in a bath of dry ice/acetone. The solution was allowed to stir and MeLi (0.45 mL of a 1.6 M solution in Et_2O, 0.72 mmol) was added via syringe. After the mixture had stirred at −78 °C for 10 min, the dry ice/acetone bath was replaced by a −40 °C bath, and the mixture was allowed to stir for 30 s. To the red solution was added cyclooctanone (107 mg, 111 μL, 0.845 mmol) via syringe. The cold bath was removed and stirring was continued for 5 min. The reaction was quenched with water, and aq 3 M HCl was added to render the solution acidic (pH 1−2). The organic phase was separated and the aqueous phase was extracted three times with ethyl acetate. The combined organics were dried (Na_2SO_4), filtered, and concentrated. The residue was chromatographed on silica gel (5−20% ethyl acetate in hexanes) to provide 68 mg (73%) of the title compound as a waxy solid, mp 97−102 °C. An identical experiment gave 63 mg (68%) of the title compound. Minor impurities were detected at 2.18, 1.24, and 0.85 ppm. ^{1}H NMR (DMSO-d_6, 400 MHz) δ 11.89 (br s, 1H), 7.31−7.34 (m, 2H), 7.20−7.24 (m, 3H), 7.10−7.14 (m, 1H), 4.99 (br s, 1H), 1.74−1.82 (m, 2H), 1.64−1.70 (m, 2H), 1.44−1.55 (m, 6H), 1.31−1.41 (m, 4H); ^{13}C NMR (DMSO-d_6, 100 MHz) δ 176.2 (C), 142.5 (C), 128.6 (CH, 2 carbons), 127.3 (CH, 2 carbons), 125.5 (CH), 125.2 (C), 97.6 (CH), 72.6 (C), 35.0 (CH_2), 34.8 (CH_2), 33.9 (C), 27.8 (CH_2), 27.5 (CH_2), 24.1 (CH_2), 21.3 (CH_2), 21.0 (CH_2); IR($CHCl_3$, cm^{-1}) 3028, 2928, 2856, 1686, 1474, 1232, 1028; HRMS-CI(NH_3) m/z [M + H], calcd for $C_{18}H_{23}O_3$ 287.1647, found 287.1657.

1,2-Diphenylcycloprop-2-ene Carboxylic Acid (4). To a dried 25-mL round-bottomed flask was added 1-phenylcycloprop-2-ene carboxylic acid (77 mg, 0.48 mmol). Freshly distilled THF (3 mL) was added via syringe, and the solution was cooled in a bath of dry ice/acetone. The solution was allowed to stir and MeLi (0.66 mL of a 1.6 M solution in Et_2O, 1.1 mmol) was added via syringe. After the mixture had stirred at −78 °C for 10 min, the dry ice/acetone bath was replaced by a −40 °C bath, and the mixture was allowed to stir for 2 min at this temperature. The mixture was again cooled to −78 °C, and to the red solution was added $ZnCl_2$ (79 mg, 0.58 mmol). After the mixture was stirred at −78 °C for 5 min, $Pd(PPh_3)_4$ (28 mg, 0.024 mmol) and iodobenzene (225 mg, 124 μL, 1.10 mmol) were added. The dry ice/acetone bath was again removed and the reaction was stirred overnight at room temperature for 16 h. The reaction was then quenched with water, and aq 3 M HCl was added to render the solution acidic (pH 1−2). The organic phase was separated and the aqueous phase was extracted three times with ethyl acetate. The combined organics were dried (Na_2SO_4), filtered, and concentrated. The residue was chromatographed on silica gel (5−30% ethyl acetate in hexanes) to provide 92 mg (81%) of the title compound as a white solid, mp 138−140 °C (lit.[3] mp 136−138 °C). An identical experiment gave 85 mg (75%) of the title compound. The spectroscopic properties were identical with those described previously.[3]

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Supporting Information Available: Full experimental and characterization details for all compounds, as well as copies of ^{1}H NMR and ^{13}C NMR spectra for new compounds. This material is available free of charge via the Internet at http://pubs.acs.org.

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