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Preparation of stable fulvene and difulvene aldehydes from benzaldehydes and an indene-derived enamine: formation of novel indene-fused benzodiazepines and attempted syntheses of di- and tricarbaporphyrinoid systems☆

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ABSTRACT

Although carbaporphyrins and related systems have been widely studied, far less work has been carried out on the synthesis of porphyrin analogues with more than one carbocyclic subunit. Fulvene aldehydes are potentially valuable intermediates for studies of this type. A versatile methodology has been developed where benzaldehydes are reacted with an indene-derived enamine in the presence of dibutylboron triflate to give fulvene monoaldehydes. This chemistry allows halo, alkyl, methoxy or cyanovinyl units to be introduced and the resulting fulvenes are stable compounds that are easily purified by column chromatography. Isophthalaldehydes afford difulvene dialdehydes that are equally stable and these can be reduced with $CeCl_3$-$NaBH_4$ to give the related dicarbinols. The difulvene dialdehydes failed to give macrocyclic products when reacted with *o*-phenylenediamine in the presence of $CeCl_3$ but instead gave unprecedented bis-indene-fused benzodiazepines. Fulvene monoaldehydes also reacted under these conditions to give benzodiazepine products in good yields. These results highlight the potential utility of fulvene aldehydes for synthetic applications both inside and outside of the area of porphyrin analogue chemistry.

1. Introduction

Porphyrins (**1**) have many biological functions, generally in the form of metalated species such as the hemes and chlorophylls, but they are in many respects unique natural products that exhibit strongly nonbenzenoid aromatic properties.[1] The porphyrin nucleus shows strong diatropic characteristics in proton NMR spectroscopy, where the external *meso*-protons are deshielded to approximately +10 ppm while the internal NH resonances are shifted upfield to ca., −4 ppm[2]. These properties can be attributed to the presence of [18]annulene substructures (shown in bold),[3,4] although a full description of porphyrinoid aromaticity needs to take into account contributions from all four of the pyrrole subunits.[5,6] Carbaporphyrins (**2**) have been synthesized where a pyrrole unit has been replaced by a cyclopentadienyl moiety, and these macrocycles show comparable diatropic properties to tetrapyrrolic porphyrins.[7–9] In addition, carbaporphyrins **2**, and the more commonly studied benzocarbaporphyrins **3**, have been shown to easily form silver(III) and gold(III) derivatives,[10–12] and readily undergo unusual regioselective oxidations.[13,14] In addition, ketal derivatives of carbaporphyrins have been shown to be promising agents in the treatment of leishmaniasis.[15] Although true carbaporphyrins possess a five-membered carbocyclic subunit, many related porphyrin analogues have been synthesized,[1,16,17] including tropiporphyrins (**4**),[18] oxybenziporphyrins (**5**),[19–22] carbachlorins,[23] azuliporphyrins (**6**)[24–27] and benziporphyrins (**7**).[19,20,28,29] These systems show a range of aromatic properties and have demonstrated a wealth of chemical properties,[4,16,17] including the ability to generate organometallic derivates under mild conditions.[10–12,30–32] In addition, *N*-confused porphyrins **8** have the same type of coordination core[33–37] and have attracted considerable interest since they were first discovered fifteen years ago.[38] For these reasons, the synthesis of further modified porphyrinoid systems has been a focus of our research group for a number of years.[39] Quatyrin (**9**), a tetracarbaporphyrin, is of great theoretical interest and although it has not yet been synthesized, it is considered to be the Holy Grail of porphyrin analogue chemistry.[39] The synthesis of **9** represents a considerable challenge, but porphyrin analogues with an intermediary number of carbocyclic rings should be more accessible. The first example of a dicarbaporphyrin (**10**) was first reported by our group in 1999,[39] and two types of doubly *N*-confused porphyrins were subsequently reported by Furuta and co-workers.[40,41] Dicarbaporphyrin **10** was easily prepared by reacting 3,4-diethylpyrrole and 1,3-indanedicarbaldehyde in the presence of HBr, followed by oxidation with

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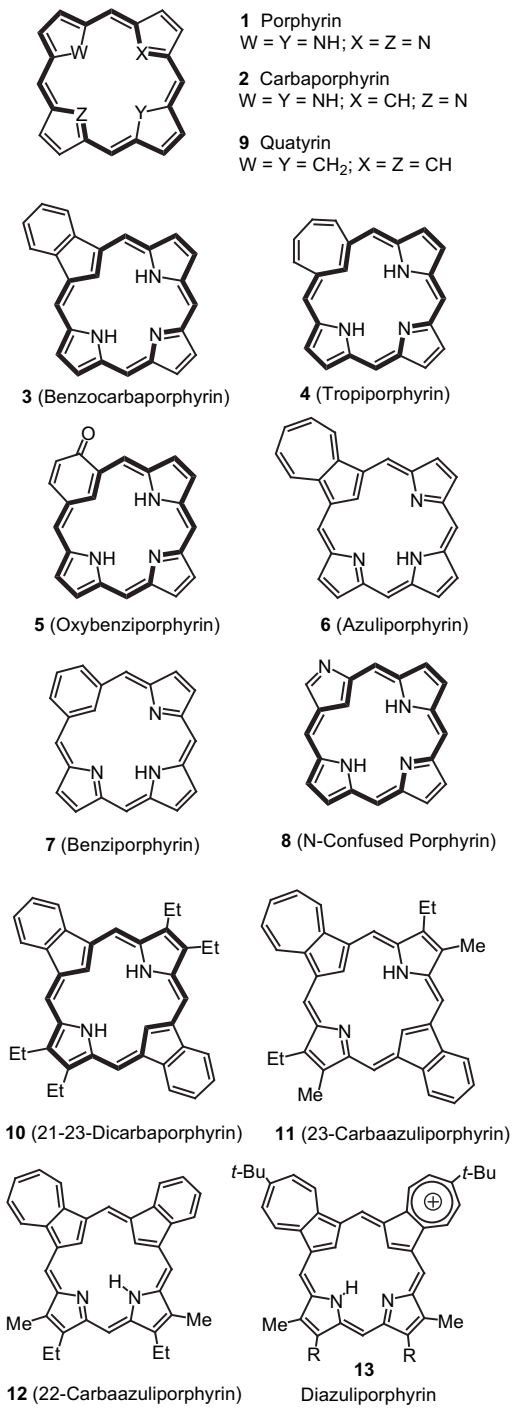
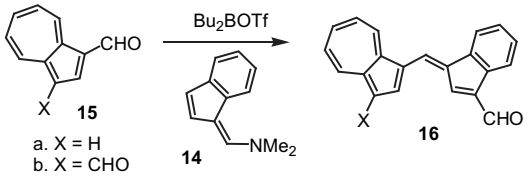
ferric chloride.[39] However, although this *opp*-dicarbaporphyrin showed a porphyrin-like UV–vis spectrum and gave highly diatropic proton NMR spectra, it was somewhat unstable and this has limited further investigations.[39] Porphyrinoid **11** with mixed azulene and indene subunits was prepared by a '3+1' methodology but this also proved to be rather unstable.[42,43] The synthesis of porphyrins and their analogues generally relies on the ability of pyrroles to undergo electrophilic substitution at their α-positions.[17,42] The formation of carbon–carbon bonds that link the individual subunits can be generated by using other electron-rich aromatic precursors such as azulene[42] and resorcinol,[44] but this approach has severe limitations with regard to the synthesis of di-, tri- or tetracarbaporphyrinoid systems.



Recently, we have reported the synthesis of *adj*-dicarbaporphyrinoids **12** and **13**[45,46] using a MacDonald '2+2' strategy.[47] This methodology requires access to intermediary dialdehydes with two carbocyclic units linked by a single carbon bridge. Macrocycles **12** and **13** with adjacent carbocyclic rings have proven to be robust systems with significant diatropic character and **13** also afforded an unusual palladium(II) organometallic complex.[45,46] As porphyrinoids **10** and **11** with alternating carbocyclic and pyrrolic subunits (*opp*-dicarbaporphyrinoids) are far less stable than **12** or **13**, *adj*-dicarbaporphyrinoids appear to provide a much better entry into highly modified carbaporphyrinoid systems. In order to fully exploit this area, convenient routes to structurally suitable dialdehyde precursors need to be developed.[45] In particular, fulvene dialdehydes are potentially well suited for applications in this area, but few examples of this type of structure have been described in the literature.[45] In this paper, we have investigated the synthesis of fulvenes derived from benzaldehydes and attempts have been made to use these structures in the synthesis of di- and tricarbaporphyrinoids. Although benziporphyrin analogues of this type were not obtained, a general route to fulvene aldehydes has been developed and these have been used to synthesize a unique series of benzodiazepines.[48]

2. Results and discussion

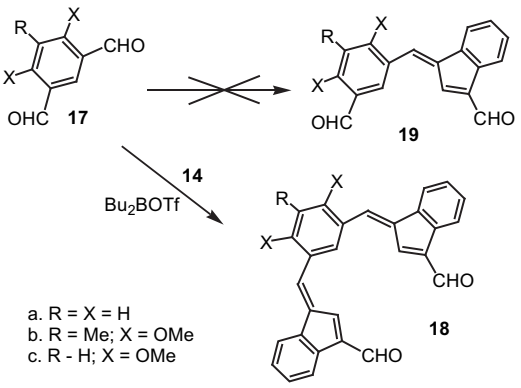
In a recent preliminary communication,[45] we reported a synthesis of fulvene aldehydes from an easily accessible indene enamine **14**.[49] Azulene carbaldehyde **15a**[50] reacted with **14** in the presence of dibutylboron triflate to give, following hydrolysis with aqueous sodium acetate, the corresponding fulvene aldehyde **16a** in 75% yield (Scheme 1).[45] This chemistry clearly has potential applications outside of the area of porphyrin analogue synthesis.[51,52]



Scheme 1.

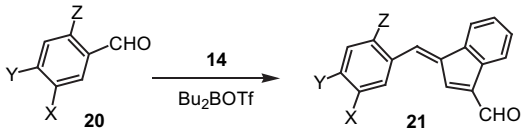
However, our interests stemmed from the fulvene moiety **16** representing the northern half of the dicarbaporphyrinoid system **12**.[45] Macrocycle formation necessitates the use of a dialdehyde **16b**. Attempts to formylate **16a** (e.g., Vilsmeier–Haack reaction) were unsuccessful but the required dialdehyde **16b** could be obtained when azulene dialdehyde **15b** was reacted with 1 equiv of the enamine. This intermediate was then successfully taken on for the synthesis of the new porphyrinoid system **12**.[45] Surprisingly, 1,3-benzenedicarbaldehydes **17a** and **17b** reacted with **14** in the presence of Bu_2BOTf to give the difulvenes **18** under these conditions (Scheme 2).[45] Difulvenes **18** were the only isolatable products under any of the reaction conditions investigated and even when only one equivalent of **14** was used, little or no fulvene dialdehyde **19** was observed. Obviously, better yields of the difulvenes could be obtained when 2 or more equivalents of **14** were used.[45] Difulvenes **18** are stable orange solids and are unique systems in their own right. Difulvene **18c** could also be generated from dimethoxyisophthalaldehyde **17c** but in this case we were unable to fully purify the product due to its very poor solubility characteristics.

As monofulvenes could not be formed directly from isophthalaldehydes, stepwise routes to fulvene dialdehydes were



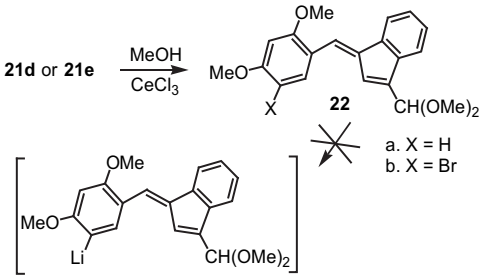
Scheme 2.

pursued. In addition, we were interested in investigating the application of the indene enamine chemistry as a general route for fulvene synthesis. With this in mind, the conversion of a series of benzaldehydes **20** to fulvenes **21** was investigated (Scheme 3). In the original study,[45] a series of Lewis acids were investigated as catalysts for this reaction but only $TiCl_3$ and Bu_2BOTf gave significant amounts of products, and the latter proved to be far superior. The reaction of azulene carbaldehyde **15a** with **14** proceeded efficiently at room temperature in dichloromethane. However, most of the benzaldehydes only reacted in refluxing 1,2-dichloroethane. Electron-withdrawing groups appear to increase the reactivity of the benzaldehydes, and 4-chlorobenzaldehyde (**20a**) reacted with **14** in dichloromethane at room temperature to give, following the hydrolysis step, the fulvene aldehyde **21a** in 50% yield. 4-Methoxybenzaldehyde and benzaldehyde gave good yields of fulvenes **21b** and **21c**, respectively, but only when the reaction was conducted in refluxing $C_2H_4Cl_2$ for 16 h. 2,4-Dimethoxybenzaldehyde (**20d**) and the related bromobenzaldehyde **20e** also reacted with **14** under these conditions but gave mediocre results. However, good yields of fulvenes **21d** and **21e** could be obtained when the reactions were carried out in the presence of a small amount of anhydrous sodium sulfate.[53] The fulvenes were all stable compounds; **21c** was isolated as an oil but the remaining fulvene aldehydes were isolated as yellow, orange or red colored solids. Fulvenes **21** were fully characterized and the proton NMR spectra showed the bridge methane proton and the isolated indene CH as two 1H singlets near 7.8 ppm (Fig. 1). As expected, the EIMS showed strong molecular ions, and the unsubstituted fulvene aldehyde **21c** gave [M^+–CHO] peak as the major fragment ion.



Scheme 3.

Dimethoxyfulvenes **21d** and **21e** were synthesized, in part, as potential precursors for the preparation of fulvene dialdehydes. As methoxy units generally aid and direct metalation reactions, it was anticipated that protected fulvenes could be treated with a suitable lithiating agent, and then reacted with DMF, to introduce the second formyl moiety (Scheme 4). Aldehydes **21d** and **21e** were converted into the corresponding dimethyl acetals **22** by reacting them with methanol in the presence of cerium chloride. However, all attempts to metalate these fulvenes failed. Most of these reactions focused on the bromo-derivative **22b**. However, reactions with *n*-butyllithium or *tert*-butyllithium at varying temperatures (−78 °C to refluxing ether), varying solvents (diethyl ether or THF), or in the presence of additives such as TMEDA, all failed to give any reaction and following work up the original fulvene aldehyde **21e** was isolated.



Scheme 4.

The conditions used to synthesize fulvenes **21** cannot tolerate the presence of acid sensitive groups such as acetals. Cyanovinyl groups are sometimes used as acid stable protective groups in pyrrole chemistry,[54] and the possible use of this moiety in generating fulvene dialdehydes was briefly considered (Scheme 5). Reaction of 4,6-dimethoxyisophthalaldehyde (**17c**) with ethyl cyanoacetate in the presence of piperidine and refluxing ethanol gave a mixture of **17c**, monoprotected cyanovinyl derivative **23** and a doubly protected by-product. The required monoaldehyde was purified by column chromatography and isolated in 44% yield. Further reaction with **14** and Bu_2BOTf in refluxing $C_2H_4Cl_2$ gave the related fulvene **24** in 61% yield. However, all attempts to remove the protective group were unsuccessful. Removal of this group essentially involves a retro-Knoevenagel reaction and is commonly accomplished with refluxing aqueous sodium hydroxide.[54] Fulvene **24** completely decomposed under those conditions but milder hydrolysis methods failed to cleave the cyanovinyl unit.

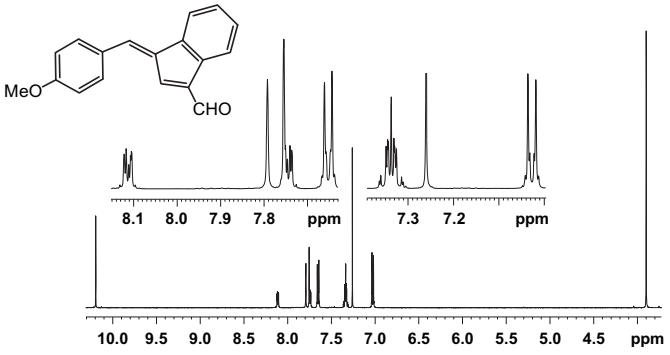
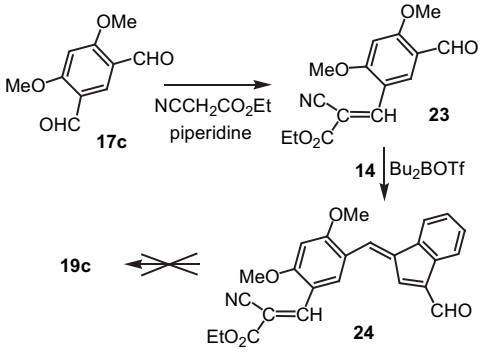
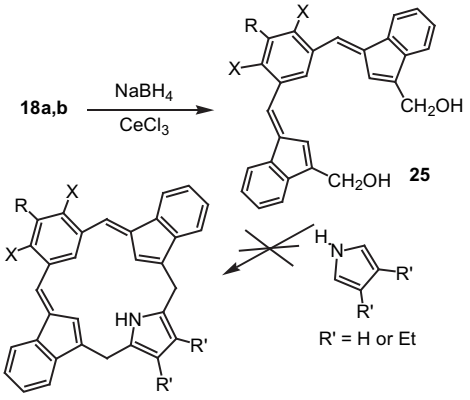


Figure 1. 500 MHz proton NMR spectrum of fulvene aldehyde **21b** in $CDCl_3$.



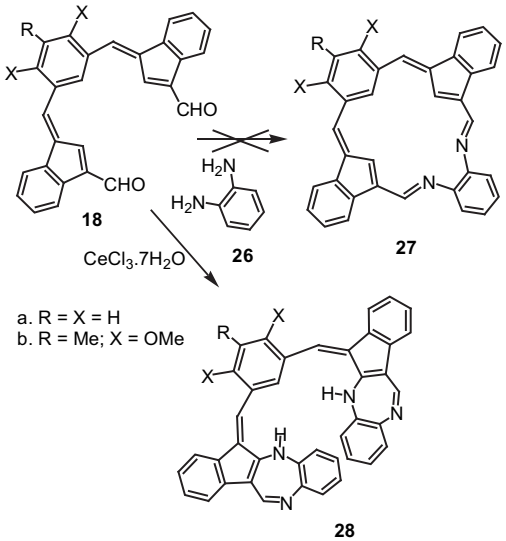
Scheme 5.

Although these studies did not afford fulvene dialdehydes **19**, difulvene dialdehydes **18** were easily obtainable and could conceivably be used to prepare tricarbaporphyrinoid systems. As the difulvenes are already fully conjugated, the dialdehydes are at too high an oxidation level for our purposes. Reduction of the dialdehydes with sodium borohydride gave complex mixtures of products, presumably due to competitive conjugate additions, but the Luche conditions ($CeCl_3$–$NaBH_4$) gave good results and the corresponding diols **25** could be isolated as stable yellow powders in 66–92% yield (Scheme 6). However, attempts to react these dicarbinols with pyrrole or 3,4-diethylpyrrole under acid catalyzed conditions (e.g., $BF_3 \cdot Et_2O$ in CH_2Cl_2) gave no isolatable macrocyclic products.



Scheme 6.

Tripyrrolic dialdehydes have been widely used to prepare Schiff base macrocycles (e.g., texaphyrins) that resemble expanded porphyrins and show useful biomedicinal applications and coordination chemistry.[55] Texaphyrins are prepared by reacting tripyrrane dialdehydes with *o*-phenylenediamine (**26**) and we speculated that similar macrocyclic products (**27**) might be obtained in reactions with diformyl difulvenes **18** (Scheme 7). Initial attempts to carry out this type of condensation under acid catalyzed conditions gave rise to no useful products. However, when difulvenes **18** were reacted with *o*-phenylenediamine in the presence of cerium trichloride heptahydrate, a major new product was generated. The spectroscopic data for these products were not consistent with the proposed tricarbatexaphyrin system **27**.



Scheme 7.

Reaction of **18a** with **26** gave the product as yellow needles and FAB mass spectrometry gave an $[M+H]^+$ ion at *m*/*z* 563. High resolution MS data gave the formula for the $[M+H]^+$ ion as $C_{40}H_{27}N_4^+$ (calcd: 563.2236; found: 563.2233), and therefore the product had the formula $C_{40}H_{26}N_4$; the product obtained from **18b** similarly gave a molecular formula of $C_{43}H_{32}N_4O_2$. These data demonstrated that two equivalents of **26** had reacted with difulvenes **18** to produce these products. This was confirmed by the proton NMR spectra for these products in d_6-DMSO (Fig. 2). The product derived from **18a** showed a 2H downfield resonance at 13.0 ppm that was consistent with two equivalent strongly hydrogen bonded NH units, two 2H singlets corresponding to two types of isolated methines, and a series of peaks corresponding to 20 aromatic protons. The proton NMR spectra showed that an element of symmetry must be present and this was confirmed by the carbon-13 NMR data. Put together, these results are consistent with the formation of dibenzodiazepines **28** (Scheme 7).

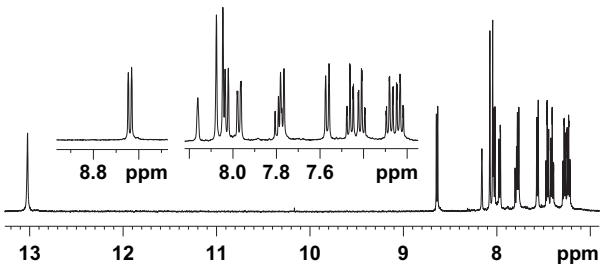
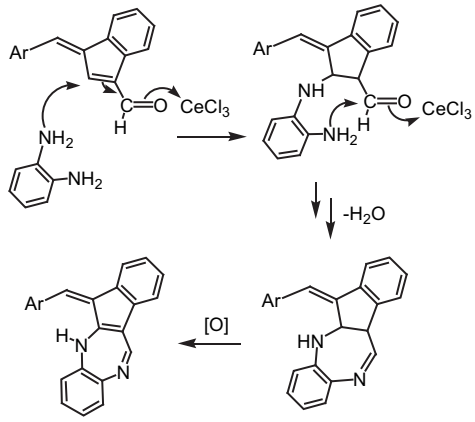
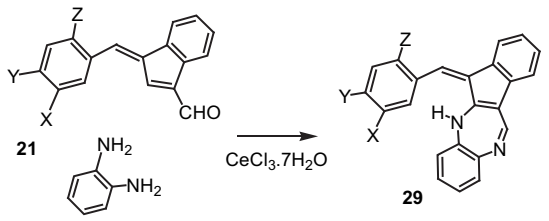


Figure 2. 500 MHz proton NMR spectrum of bis-benzodiazepine **28a** derived from difulvene **18a** in d_6-DMSO.

Although the formation of benzodiazepines had not been anticipated, in retrospect the formation of these heterocyclic adducts is not surprising. Conjugate addition of *o*-phenylenediamine onto the central indene carbon, followed by cyclization and elimination of water, would give a dihydrobenzodiazepine unit and air oxidation presumably gives the observed products (Scheme 8). This chemistry should be equally feasible for monofulvene aldehydes **21**. As the products obtained from difulvenes **18** represent a new class of benzodiazepines, it was of some interest to see whether further examples of this type could be generated from **21a**–**e** (Scheme 9). Reaction of **26** with fulvenes **21** in the presence of cerium trichloride in dichloromethane–methanol gave the benzodiazepines **29** in 44–67% yield. These highly unusual benzodiazepines were isolated as yellow or orange solids and gave high quality proton NMR data in d_6-DMSO (Fig. 3). Again, the NH resonance was observed at 13 ppm and two isolated singlets were present near 8 ppm. The EIMS gave strong molecular ions and the less substituted benzodiazepines **29a**–**c** showed little fragmentation.



Scheme 8.



Scheme 9.

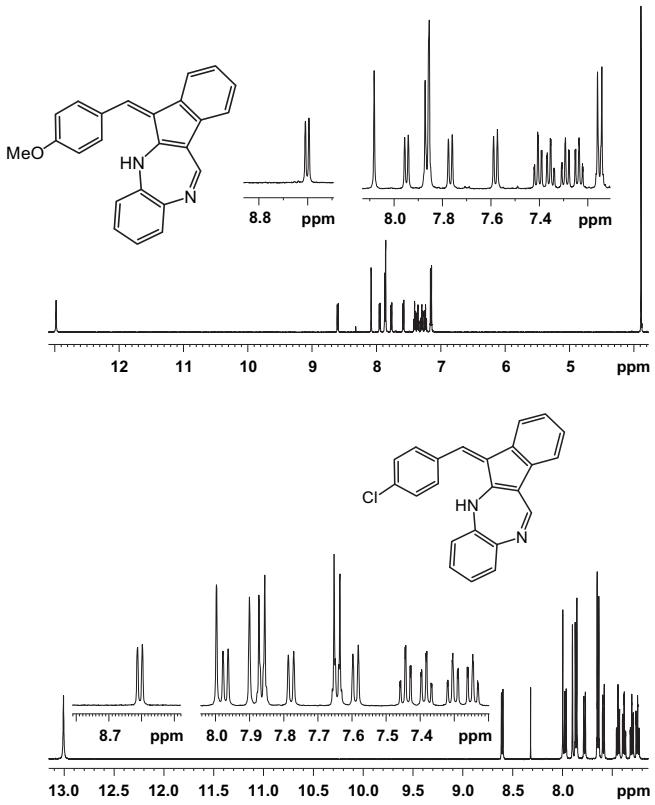


Figure 3. 500 MHz proton NMR spectra of benzodiazepines **29b** (upper spectrum) and **29a** (lower spectrum) in d_6-DMSO.

3. Conclusions

Reaction of benzaldehydes with an indene enamine in the presence of Bu_2BOTf gave a series of stable fulvene aldehydes, while isophthalaldehydes gave related difulvene dialdehydes. This methodology is quite general and it is anticipated that fulvene structures will allow access to new families of porphyrin analogues. Attempts to convert the initially formed fulvene monoaldehydes into dialdehydes have so far not been successful but these compounds are quite stable and can be transformed into acetals or carbinol derivatives. In addition, the methodology allows methoxy-, halo- or cyanovinyl groups to be introduced. Fulvene aldehydes also reacted with *o*-phenylenediamine to give a novel series of benzodiazepines. Further investigations into the chemistry of fulvene aldehydes will no doubt lead to other useful synthetic applications.

4. Experimental

4.1. General

Dibutylboron triflate in dichloromethane (1.0 M), isophthalaldehyde, 4-methoxybenzaldehyde, 4-chlorobenzaldehyde, benzaldehyde, 2,4-dimethoxybenzaldehyde, *o*-phenylenediamine, ethyl cyanoacetate, piperidine, cerium trichloride heptahydrate and sodium borohydride were purchased from Aldrich or Acros, and were used without further purification. 5-Bromo-2,4-dimethoxybenzaldehyde was prepared by a literature procedure.[56] Chromatography was performed using grade 3 neutral alumina or 70–230 mesh silica gel. Melting points were determined in open capillary tubes on a Mel-Temp apparatus and are uncorrected. Proton and carbon-13 NMR data were obtained on Varian Gemini 300 or 400 MHz FT NMR spectrometers; selected spectra, including those shown in Figures 1–3, were rerun on a Bruker 500 MHz Avance III NMR spectrometer. Mass spectral determinations were conducted at the Mass Spectral Laboratory, School of Chemical Sciences, University of Illinois at Urbana-Champaign, and elemental analyses were obtained from the School of Chemical Sciences Microanalysis Laboratory at the University of Illinois.

4.2. Synthetic procedures

*4.2.1. 1-(4-Chlorophenylmethylene)indene-3-carbaldehyde (**21a**).* A solution of 4-chlorobenzaldehyde (77 mg, 0.55 mmol) in dichloromethane (60 mL) was added to a 250 mL round-bottomed flask, and cooled with an ice bath to 5–8 °C. A 1 M solution of dibutylboron triflate in dichloromethane (600 μL) was then added, immediately followed by indene enamine **14** (100 mg, 0.58 mmol). The ice bath was removed and the solution was allowed to stir overnight at room temperature. The next day, the reaction was quenched with 50 mL of a saturated sodium acetate solution. The organic layer was separated and the aqueous phase was extracted with dichloromethane (3×). The combined organic layers were then washed with a saturated sodium bicarbonate solution and then with brine. The product was dried over sodium sulfate and the solvent removed under reduced pressure. The resulting residue was purified by flash chromatography on silica, eluting with 20% hexanes–dichloromethane. Recrystallization from chloroform–hexanes gave the fulvene aldehyde **21a** (73 mg, 0.27 mmol, 50%) as a brown solid, mp 98–100 °C; ^{1}H NMR (300 MHz, $CDCl_3$): δ 7.33–7.38 (2H, m), 7.47 (2H, d, J=8.4 Hz), 7.57 (2H, d, J=8.4 Hz), 7.64 (1H, s), 7.74 (1H, d, J=6.8 Hz), 7.76 (1H, s), 8.10 (1H, d, J=7.6 Hz), 10.19 (1H, s); ^{13}C NMR (75 MHz, $CDCl_3$): δ 119.5, 123.0, 126.8, 128.4, 129.4, 131.7, 134.4, 134.6, 136.1, 137.5, 138.7, 139.3, 143.5, 146.6, 188.8; EIMS (70 eV): m/z (rel int.) 269 (6.5), 268 (35), 267 (21), 266 (92, M^+), 265 (8.4), 231 (34), 204 (15), 203 (85), 202 (100), 201 (17); HRMS (EI), m/z calcd for $C_{17}H_{11}ClO$: 266.0498. Found: 266.0497. Anal. calcd for $C_{17}H_{11}ClO.0.6H_2O$: C, 73.57; H, 4.43. Found: C, 73.46; H, 4.60.

*4.2.2. 1-(4-Methoxyphenylmethylene)indene-3-carbaldehyde (**21b**).* Dibutylboron triflate (1.60 mL of a 1 M solution in dichloromethane) was added to a stirred solution of *p*-anisaldehyde (144 μL, 161 mg, 1.19 mmol) in dichloroethane (250 mL). The mixture was heated under reflux, and a solution of indene enamine (300 mg, 1.75 mmol) in 1,2-dichloroethane (250 mL) was added dropwise over 5–10 min. The mixture was allowed to stir under reflux overnight. The next day, the reaction was quenched by adding a saturated sodium bicarbonate solution (150 mL). The organic layer was separated, and the aqueous solution was extracted with dichloromethane (3×). The organic layers were combined, washed with brine, and dried over sodium sulfate. The solvent was removed on a rotary evaporator, and the residue purified by flash chromatography on silica gel eluting with 20% hexanes–dichloromethane. Recrystallization from chloroform–hexanes gave fulvene **21b** (165 mg, 0.63 mmol, 53%) as amber needles, mp 140–141 °C; ^{1}H NMR (400 MHz, $CDCl_3$): δ 3.90 (3H, s), 7.02 (2H, d, J=8.4 Hz), 7.30–7.38 (2H, m), 7.65 (2H, d, J=8.8 Hz), 7.70–7.76 (1H, m), 7.75 (1H, s), 7.79 (1H, s), 8.11 (1H, d, J=8.4 Hz), 10.19 (1H, s); ^{13}C NMR (100 MHz$CDCl_3$): δ 55.5, 114.8, 119.1, 122.7, 126.4, 127.7, 129.0, 132.6,

136.3, 136.6, 137.0, 138.0, 139.3, 142.5, 161.5, 188.8; EIMS (70 eV): *m*/*z* (rel int.) 263 (21), 262 (100, M^+), 261 (8.9), 247 (8.8), 233 (16), 219 (20), 202 (13), 189 (31); HRMS (EI), *m*/*z* calcd for $C_{18}H_{14}O_2$: 262.0994. Found: 262.0992. Anal. calcd for $C_{18}H_{14}O_2$: C, 82.42; H, 5.38. Found: C, 82.26; H, 5.38.

*4.2.3. 1-(Phenylmethylene)indene-3-carbaldehyde (**21c**).* Benzaldehyde (300 μL, 313 mg, 2.95 mmol), dibutylboron triflate (2.95 mL of a 1 M solution in dichloromethane) and indene enamine (504 mg, 2.95 mmol) were reacted under the conditions described in Section 4.2.2. The crude product was purified by column chromatography on silica eluting with 25% hexanes–dichloromethane and the resulting brown oil was washed repeatedly with hexanes to give the fulvene **21c** (658 mg, 2.84 mmol, 96%); ^{1}H NMR (300 MHz, $CDCl_3$): δ 7.35–7.41 (2H, m), 7.45–7.56 (3H, m), 7.62–7.67 (2H, m), 7.68 (1H, s), 7.74 (1H, d, *J*=8.7 Hz), 7.81 (1H, s), 8.12 (1H, d, *J*=8.4 Hz), 10.16 (1H, s); ^{13}C NMR (75 MHz, $CDCl_3$): δ 119.4, 122.7, 126.6, 128.1, 129.0, 129.7, 130.6, 136.08, 136.13, 137.3, 137.6, 138.7, 139.4, 143.0, 188.8; EIMS (70 eV): *m*/*z* (rel int.) 234 (2.5), 233 (20), 230 (100, M^+), 231 (20), 204 (21), 203 (78), 202 (63); HRMS (EI), *m*/*z* calcd for $C_{17}H_{12}O$: 232.0888. Found: 232.0885.

*4.2.4. 1-(2,4-Dimethoxyphenylmethylene)indene-3-carbaldehyde (**21d**).* 2,4-Dimethoxybenzaldehyde (286 mg, 1.17 mmol), indene enamine (415 mg, 2.43 mmol) and a 1 M solution of dibutylboron triflate in dichloromethane (2.40 mL) were reacted under the previous conditions in the presence of sodium sulfate (0.50 g). Purification by flash chromatography on silica, eluting with 10% hexanes–dichloromethane, and recrystallization from chloroform–hexanes gave the fulvene **21d** (223 mg, 0.76 mmol, 44%) as an orange solid, mp 127–128 °C; ^{1}H NMR (400 MHz, $CDCl_3$): δ 3.89 (3H, s), 3.92 (3H, s), 6.52 (1H, d, *J*=2.4 Hz), 6.63 (1H, dd, *J*=11.2 Hz, *J*=2.4 Hz), 7.30–7.40 (2H, m), 7.60 (1H, d, *J*=8.8 Hz), 7.69 (1H, s), 7.78–7.84 (1H, m), 8.11 (1H, d, *J*=8.8 Hz), 8.13 (1H, s), 10.17 (1H, s); ^{13}C NMR (100 MHz, $CDCl_3$): δ 55.6, 55.7, 98.6, 105.9, 118.7, 119.3, 122.5, 126.2, 127.4, 132.3, 133.2, 136.3, 137.1, 138.1, 140.0, 141.9, 160.3, 163.3, 188.8; HRMS (EI), *m*/*z* calcd for $C_{19}H_{16}O_3$: 292.1100. Found: 292.1102. Anal. calcd for $C_{19}H_{16}O_3$: C, 78.06; H, 5.58. Found: C, 77.76; H, 5.31.

*4.2.5. 1-(5-Bromo-2,4-dimethoxyphenylmethylene)indene-3-carbaldehyde (**21e**).* 5-Bromo-2,4-dimethoxybenzaldehyde (286 mg, 1.17 mmol), dibutylboron triflate (2.4 mL of a 1 M solution in dichloromethane) and indene enamine (400 mg, 2.34 mmol) were reacted under the same conditions as described in Section4.2.4 in the presence of sodium sulfate (0.50 g). The crude product was purified by flash chromatography on silica eluting with 10% hexanes–dichloromethane. Recrystallization from acetone and hexanes afforded the fulvene (216 mg, 0.58 mmol, 50%) as a red crystalline solid, mp 208–210 °C; ^{1}H NMR (400 MHz, $CDCl_3$): δ 3.96 (3H, s), 4.00 (3H, s), 6.54 (1H, s), 7.30–7.36 (2H, m), 7.64 (1H, s), 7.76 (1H, d, *J*=8.0 Hz), 7.81 (1H, s), 8.01 (1H, s), 8.11 (1H, d, *J*=8.0 Hz), 10.21 (1H, s); ^{13}C NMR (100 MHz, $CDCl_3$): δ 56.1, 56.5, 96.3, 103.2, 119.4, 122.7, 126.4, 127.7, 130.2, 135.4, 137.2, 137.8, 139.28, 139.35, 139.39, 142.5, 158.6, 159.5, 189.0; HRMS (EI), *m*/*z* calcd for $C_{19}H_{15}BrO_3$: 370.0205. Found: 370.0208. Anal. calcd for $C_{19}H_{15}BrO_3$: C, 61.47; H, 4.07. Found: C, 61.40; H, 4.09.

*4.2.6. 1-(5-Bromo-2,4-dimethoxyphenylmethylene)-3-dimethoxymethylindene (**22b**).* Fulvene **21e** (100 mg, 0.27 mmol), trimethyl orthoformate (2.5 mL), and dichloroethane (30 mL) were added to a round-bottomed flask equipped with a drying tube. Cerium trichloride heptahydrate (265 mg) and methanol (80 mL) were added, and the contents of the flask were allowed to stir at room temperature overnight. The reaction was quenched with a saturated sodium bicarbonate solution (40 mL), and the mixture extracted with dichloromethane and dried over sodium sulfate. After removing the solvent under reduced pressure, the product was purified by chromatography on grade three basic alumina eluting initially with 10% dichloromethane–hexanes; the polarity was gradually increased to 20% dichloromethane–hexanes and the first yellow band was collected. Recrystallization from dichloromethane–hexanes gave the protected fulvene (102 mg, 0.245 mmol, 91%) as yellow needles, mp 128–130 °C; ^{1}H NMR (500 MHz, $CDCl_3$): δ 3.39 (6H, s), 3.92 (3H, s), 3.96 (3H, s), 5.54 (1H, br d, *J*=1.0 Hz), 6.51 (1H, s), 7.00 (1H, br t, *J*=1.0 Hz), 7.21–7.28 (2H, m), 7.51–7.53 (1H, m), 7.65 (1H, s), 7.69–7.72 (1H, m), 7.80 (1H, s); ^{13}C NMR (100 MHz, d_6-DMSO): δ 52.9, 56.2, 56.6, 96.3, 100.4, 102.8, 119.4, 120.1, 120.7, 123.2, 124.6, 125.5, 127.5, 135.2, 137.7, 138.4, 139.9, 143.7, 157.4, 159.0; EIMS (70 eV): *m*/*z* (rel int.) 419 (11), 418 (48), 417 (11), 416 (48, M^+), 388 (29), 387 (99), 386 (30), 385 (100); HRMS (EI), *m*/*z* calcd for $C_{21}H_{21}BrO_4$: 416.0623. Found: 416.0624. Anal. calcd for $C_{21}H_{21}BrO_4$: C, 60.44; H, 5.07. Found: C, 59.91; H, 4.99.

*4.2.7. 1-(5-(2-Cyano-2-ethoxycarbonylvinyl)-2,4-dimethoxyphenylmethylene)indene-3-carbaldehyde (**24**).* 2,4-Dimethoxybenzene dialdehyde **17c** (199 mg, 1.02 mmol), two drops of piperidine, and absolute ethanol (10 mL) were added to a round-bottomed flask equipped for reflux. Ethyl cyanoacetate (0.091 g) was added dropwise through an addition funnel and was further rinsed in with an additional 10 mL of ethanol. The reaction mixture was allowed to stir under reflux for 3 h. The diprotected by-product was removed by suction filtration, and the filtrate was evaporated under reduced pressure. The residue was purified by column chromatography on silica, eluting initially with 60% dichloromethane–hexanes and then gradually increasing the polarity to 100% dichloromethane. Recrystallization from chloroform–hexanes gave **23** (130 mg, 0.45 mmol, 44%) as a yellow powder, mp 166–169 °C; ^{1}H NMR (300 MHz, $CDCl_3$): δ 1.38 (3H, t, *J*=7.2 Hz), 4.01 (3H, s), 4.03 (3H, s), 4.36 (2H, q, *J*=7.2 Hz), 6.46 (1H, s), 8.56 (1H, s), 8.78 (1H, s), 10.26 (1H, s); ^{13}C NMR (75 MHz, $CDCl_3$): δ 14.2, 56.1, 56.3, 62.4, 94.5, 101.9, 114.3, 115.6, 119.1, 131.8, 147.9, 162.9, 165.1, 166.6, 186.9. Dibutylboron triflate (800 μL of a 1 M solution in dichloromethane) was added to a solution of **23** (100 mg, 0.35 mmol) in dichloroethane (75 mL). The mixture was heated under reflux, and indene enamine (102 mg, 0.60 mmol) in 75 mL of dichloroethane was then added dropwise over a 5–10 min period. Once all the indene enamine was added the reaction was allowed to stir at reflux overnight. The next day the reaction was quenched with 65 mL of a saturated sodium acetate solution. The product was extracted, and the aqueous layer was washed with dichloromethane (3×). The organic layers were combined and washed with a saturated aqueous sodium bicarbonate solution and then with brine. The product was dried over sodium sulfate and the solvent removed under reduced pressure. The residue was purified via flash chromatography on silica and eluting with 10% hexanes–dichloromethane. Recrystallization from chloroform–hexanes gave the fulvene (88 mg, 0.21 mmol, 61%) as an orange solid, mp 204–206 °C; ^{1}H NMR (300 MHz, $CDCl_3$): δ 1.41 (3H, t, *J*=6.9 Hz), 3.98 (3H, s), 4.00 (3H, s), 4.38 (2H, q, *J*=6.9 Hz), 6.45 (1H, s), 7.26–7.38 (2H, m), 7.63 (1H, d, *J*=8.1 Hz), 7.94 (1H, s), 8.05 (1H, s), 8.09 (1H, d, *J*=8.4 Hz), 8.52 (1H, s), 8.64 (1H, s), 10.16 (1H, s); ^{13}C NMR (75 MHz, $CDCl_3$): δ 14.2, 56.2, 62.4, 94.6, 100.7, 114.6, 116.6, 118.9, 119.4, 122.9, 126.2, 126.5, 127.8, 128.7, 131.0, 132.0, 137.8, 140.3, 143.0, 148.4, 162.7, 163.0, 164.2, 190.0; EIMS (70 eV): *m*/*z* (rel int.) 417 (9.6), 416 (28), 415 (100, M^+), 387 (15); HRMS (EI), *m*/*z* calcd for $C_{25}H_{21}NO_5$: 415.1420. Found: 415.1417. Anal. calcd for $C_{25}H_{21}NO_5$: C, 72.28; H, 5.09; N, 3.37. Found: C, 71.96; H, 4.99; N, 3.26.

*4.2.8. Difulvene dicarbinol **25b**.* Dialdehyde **18b**[45] (92 mg, 0.20 mmol) and cerium trichloride heptahydrate (86 mg) were

placed in a round-bottomed flask equipped with a drying tube, and dichloromethane (20 mL), absolute ethanol (10 mL), and methanol (25 mL) were added to dissolve the reagents. Sodium borohydride (19 mg) was then added and the contents of the flask were allowed to stir at room temperature for 35 min. The reaction was quenched with water (25 mL) and the product precipitated out as a yellow solid. The precipitate was collected via suction filtration and washed with two 5 mL portions of hexanes. The product was recrystallized from chloroform to give the dicarbinol (61 mg, 0.13 mmol, 66%) as yellow needles, mp 233 °C, dec; ^{1}H NMR (500 MHz, d_6-DMSO): δ 2.25 (3H, s), 3.76 (6H, s), 4.61 (4H, d, J=5.6 Hz), 5.16 (2H, t, J=5.6 Hz), 6.85 (2H, br t, J=1.8 Hz), 7.24–7.30 (4H, m), 7.34–7.38 (2H, m), 7.62 (1H, s), 7.66 (2H, s), 7.85–7.88 (2H, m); ^{13}C NMR (75 MHz, d_6-DMSO): δ 9.1, 57.7, 61.0, 119.19, 119.25, 120.2, 122.1, 124.7, 125.2, 125.8, 127.1, 130.8, 137.6, 138.6, 140.3, 149.1, 158.5; EIMS (70 eV): m/z (rel int.) 466 (9.5), 465 (33), 464 (100, M^+), 446 (44), 415 (13); HRMS (EI), m/z calcd for $C_{31}H_{28}O_4$: 464.1988. Found: 464.1985. Anal. calcd for $C_{31}H_{28}O_4 \cdot {}^1/_4H_2O$: C, 79.38; H, 6.12. Found: C, 79.46; H, 6.04.

*4.2.9. Difulvene dicarbinol **47a**.* Difulvene dialdehyde **18a**[45] (79 mg, 0.20 mmol) was reacted with cerium trichloride heptahydrate (98 mg) and sodium borohydride (20 mg) under the foregoing conditions. After quenching the reaction, the product was extracted with dichloromethane and dried over sodium sulfate. The solvent was removed under reduced pressure and the residue recrystallized from chloroform to give the dicarbinol (73 mg, 0.19 mmol, 92%) as yellow needles, mp 183–184 °C; ^{1}H NMR (400 MHz, $CDCl_3$): δ 2.33 (2H, br s), 4.86 (4H, br s), 7.16 (2H, s), 7.20–7.35 (7H, m), 7.48–7.56 (4H, m), 7.73–7.78 (2H, m), 8.01 (1H, s); ^{1}H NMR (500 MHz, d_6-DMSO): δ 4.62 (4H, d, J=5.5 Hz), 5.18 (2H, t, J=5.5 Hz), 7.00 (2H, br t, J=1.8 Hz), 7.23–7.29 (4H, m), 7.34–7.38 (2H, m), 7.60 (1H, t, J=7.7 Hz), 7.67–7.70 (4H, m), 7.84–7.87 (2H, m), 7.92 (1H, br t, J=1.5 Hz); ^{13}C NMR (75 MHz, d_6-DMSO): δ 57.7, 119.2, 119.3, 120.1, 125.2, 126.8, 127.1, 129.1, 129.1, 129.4, 131.0, 137.0, 137.9, 138.7, 140.1, 149.5; EIMS (70 eV): m/z (rel int.) 391 (31), 390 (100, M^+), 372 (28); HRMS (EI), m/z calcd for $C_{28}H_{22}O_2$: 390.1620. Found: 390.1624. Anal. calcd for $C_{28}H_{22}O_2.{}^1/_5H_2O$: C, 85.34; H, 5.73. Found: C, 85.31; H, 5.51.

*4.2.10. Bis-1,4-benzodiazepine **28b**.* Difulvene **18b**[45] (48 mg, 0.10 mmol), cerium trichloride heptahydrate (75 mg), and *o*-phenylenediamine (23 mg, 0.21 mmol) in dichloromethane (20 mL) and methanol (55 mL) were stirred under reflux overnight. The mixture was washed with water, and the aqueous layer back extracted with dichloromethane. The combined organic solutions were dried over sodium sulfate and evaporated under reduced pressure. The residue was purified by column chromatography on grade three basic alumina, eluting initially with 60% dichloromethane–hexanes and then 75% dichloromethane–hexanes. Recrystallization from chloroform–hexanes gave the bis-diazepine product (37 mg, 0.058 mmol, 58%) as an orange solid, mp 197 °C, dec; ^{1}H NMR (500 MHz, d_6-DMSO): δ 2.34 (3H, s), 3.82 (6H, s), 7.11–7.17 (4H, m), 7.34–7.7.37 (2H, m), 7.38–7.41 (2H, m), 7.42–7.46 (2H, m), 7.65–7.69 (2H, m), 7.76 (2H, s), 7.87 (1H, s), 7.99 (2H, s), 8.05 (2H, d, J=7.5 Hz), 8.60 (2H, d, J=7.5 Hz), 12.82 (2H, s); ^{13}C NMR (100 MHz, d_6-DMSO): δ 9.2, 61.1, 110.8, 119.0, 119.3, 121.3, 122.9, 124.5, 125.1, 125.5, 125.7, 125.96, 126.06, 127.4, 131.0, 133.9, 134.6, 137.4, 138.9, 139.0, 143.8, 147.6, 159.1; HRMS (FAB), m/z calcd for $C_{43}H_{32}N_4O_2^+H$: 637.2603. Found: 637.2602. Anal. calcd for $C_{43}H_{32}N_4O_2.H_2O.{}^1/_2CHCl_3$: C, 73.12; H, 4.87; N, 7.84. Found: C, 72.64; H, 5.02; N, 8.22.

*4.2.11. Bis-1,4-benzodiazepine **28a**.* Difulvene **18a**[45] (97 mg, 0.25 mmol), cerium trichloride heptahydrate (194 mg), and *o*-phenylenediamine (76 mg, 0.70 mmol) were reacted under the previous conditions. Purification by column chromatography on grade three basic alumina eluting with 60% dichloromethane–hexanes, and recrystallization from chloroform–hexanes, gave the bis-diazepine product (77 mg, 0.14 mmol, 55%) as a yellow solid, mp 214 °C, dec; ^{1}H NMR (500 MHz, d_6-DMSO): δ 7.21–7.25 (2H, m), 7.26–7.30 (2H, m), 7.39–7.43 (2H, m), 7.44–7.48 (2H, m), 7.56 (2H, d, J=7.7 Hz), 7.77 (2H, d, J=7.7 Hz), 7.79 (1H, t, J=7.7 Hz), 7.97 (2H, dd, J=1.4, 7.7 Hz), 8.03 (2H, d, J=7.3 Hz), 8.04 (2H, s), 8.07 (2H, s), 8.16 (1H, br t), 8.64 (2H, d, J=7.4 Hz), 13.02 (2H, s); ^{13}C NMR (125 MHz, d_6-DMSO): δ 111.3, 119.6, 119.9, 122.0, 123.3, 123.6, 124.8, 126.3, 127.9, 130.0, 130.7, 131.0, 132.9, 134.4, 135.5, 137.4, 138.1, 139.0, 139.1, 144.3, 148.2; HRMS (FAB), m/z calcd for $C_{40}H_{26}N_4$+H: 563.2236. Found: 563.2233. Anal. calcd for $C_{40}H_{26}N_4.CHCl_3$: C, 72.20; H, 3.99; N, 8.21. Found: C, 72.32; H, 4.25; N, 7.99.

*4.2.12. 12-(4-Chlorophenylmethylene)benzo[b]indeno[1,2-f]-1,4-diazepine (**29a**).* A mixture of fulvene aldehyde **21a** (102 mg, 0.38 mmol), cerium trichloride heptahydrate (141 mg) and *o*-phenylenediamine (39 mg, 0.36 mmol) in dichloromethane (20 mL) and methanol (60 mL) was stirred under reflux overnight. The mixture was washed with water, the aqueous layer was back extracted with dichloromethane and the combined organic solutions dried over sodium sulfate. After removing the solvent on a rotary evaporator, the residue was purified by column chromatography on grade three basic alumina eluting with 60% dichloromethane–hexanes. Recrystallization from chloroform–hexanes gave the diazepine (59 mg, 0.17 mmol, 44%) as yellow needles, mp 235–238 °C; ^{1}H NMR (500 MHz, d_6-DMSO): δ 7.21–7.24 (1H, m), 7.26–7.30 (1H, m), 7.34–7.38 (1H, m), 7.40–7.44 (1H, m), 7.57 (1H, d, J=7.8 Hz), 7.61–7.64 (2H, m), 7.76 (1H, d, J=7.9 Hz), 7.83–7.86 (2H, m), 7.88 (1H, s), 7.95 (1H, d, J=7.5 Hz), 7.98 (1H, s), 8.58 (1H, d, J=7.4 Hz), 12.99 (1H, s); ^{13}C NMR (75 MHz, d_6-DMSO): δ 110.8, 119.1, 119.4, 121.5, 122.8, 123.1, 124.1, 125.7, 127.4, 128.8, 129.4, 131.7, 133.5, 134.0, 135.1, 137.7, 138.4, 138.6, 143.9, 147.7; EIMS (70 eV): m/z (rel int.) 358 (2.7), 357 (9.7), 356 (40), 355 (41), 354 (100, M^+), 353 (41), 320 (4.8), 319 (20), 318 (14), 317 (15), 316 (5.1), 238 (8.1), 236 (23); HRMS (EI), m/z calcd for $C_{23}H_{15}N_2Cl$: 354.0924. Found: 354.0926. Anal. calcd for $C_{23}H_{15}ClN_2 \cdot {}^1/_2CHCl_3$: C, 68.09; H, 3.77; N, 6.76. Found: C, 68.35; H, 3.85; N, 6.76.

*4.2.13. 12-(4-Methoxyphenylmethylene)benzo[b]indeno[1,2-f]-1,4-diazepine (**29b**).* Fulvene **21b** (102 mg, 0.39 mmol), cerium trichloride heptahydrate (153 mg), and *o*-phenylenediamine (48 mg, 0.44 mmol) were reacted under the previously described conditions. The product was purified by column chromatography on grade three basic alumina eluting with 60% dichloromethane–hexanes, and recrystallized from chloroform–hexanes to give the diazepine (71 mg, 0.20 mmol, 52%) as yellow needles, mp 244–245 °C; ^{1}H NMR (500 MHz, d_6-DMSO): δ 3.86 (3H, s), 7.13 (2H, d, J=8.7 Hz), 7.20–7.24 (1H, m), 7.25–7.29 (1H, m), 7.31–7.35 (1H, m), 7.36–7.40 (1H, m), 7.56 (1H, d, J=7.8 Hz), 7.75 (1H, d, J=7.8 Hz), 7.82–7.86 (3H, m), 7.93 (1H, d, J=7.3 Hz), 8.06 (1H, s), 8.58 (1H, d, J=7.5 Hz), 12.96 (1H, s); ^{13}C NMR (75 MHz, d_6-DMSO): δ 55.2, 110.7, 114.5, 118.9, 119.0, 121.4, 122.6, 122.9, 124.4, 125.3, 126.7, 128.8, 131.0, 132.0, 133.8, 134.0, 135.6, 138.1, 138.2, 144.0, 148.1, 160.1; EIMS (70 eV): m/z (rel int.) 353 (4.5), 352 (15), 351 (20), 350 (66, M^+), 349 (11), 335 (14); HRMS (EI), m/z calcd for $C_{24}H_{18}N_2O$: 350.1419. Found: 350.1416. Anal. calcd for $C_{24}H_{18}N_2O \cdot {}^1/_3H_2O$: C, 80.88; H, 5.28; N, 7.86. Found: C, 80.88; H, 5.20; N, 7.84.

*4.2.14. 12-(Phenylmethylene)benzo[b]indeno[1,2-f]-1,4-diazepine (**29a**).* Fulvene **21a** (88 mg, 0.38 mmol), cerium trichloride heptahydrate (150 mg), and *o*-phenylenediamine (61 mg, 0.56 mmol) were reacted under the foregoing conditions. The product was purified by column chromatography on grade 3 basic alumina, eluting with 60% dichloromethane–hexanes, and recrystallized from chloroform–hexanes to give the diazepine (70 mg, 0.22 mmol, 58%) as a yellow solid, mp 126 °C, dec; ^{1}H NMR (300 MHz,

d_6-DMSO): δ 7.20–7.34 (2H, m), 7.35–7.55 (3H, m), 7.55–7.62 (3H, m), 7.78 (1H, d, *J*=7.8 Hz), 7.84 (2H, d, *J*=7.5 Hz), 7.90 (1H, s), 7.96 (1H, d, *J*=7.2 Hz), 8.05 (1H, s), 8.62 (1H, d, *J*=7.2 Hz), 13.01 (1H, br s); ^{13}C NMR (75 MHz, d_6-DMSO): δ 110.8, 119.1, 119.3, 121.5, 122.7, 123.1, 124.4, 125.6, 127.2, 128.76, 128.85, 130.2, 131.0, 134.0, 134.8, 136.2, 137.83, 137.88, 138.6, 144.0, 147.8; EIMS (70 eV): *m*/*z* (rel int.) 322 (8.6), 321 (25), 320 (100, M^+), 319 (57), 292 (3.1), 277 (3.8), 232 (31); HRMS (EI), *m*/*z* calcd for $C_{23}H_{16}N_2$: 320.1314. Found: 320.1310. Anal. calcd for $C_{40}H_{26}N_4 \cdot {}^1/_2CHCl_3$: C, 74.26; H, 4.38; N, 7.37. Found: C, 74.22; H, 4.45; N, 7.19.

*4.2.15. 12-(2,4-Dimethoxyphenylmethylene)benzo[b]indeno[1,2-f]-1,4-diazepine (**29d**).* Fulvene **21d** (202 mg, 0.69 mmol), cerium trichloride heptahydrate (281 mg), and *o*-phenylenediamine (79 mg, 0.73 mmol) were reacted under the previous conditions. The product was purified by column chromatography on grade three basic alumina, eluting with 60% dichloromethane–hexanes, and recrystallized from chloroform–hexanes to give the diazepine (150 mg, 0.39 mmol, 57%) as a yellow solid, mp 246–247 °C; ^{1}H NMR (400 MHz, d_6-DMSO): δ 3.89 (3H, s), 3.93 (3H, s), 6.74 (1H, s), 6.76 (1H, d, *J*=8.4 Hz), 7.20–7.30 (2H, m), 7.30–7.42 (2H, m), 7.55 (1H, d, *J*=8 Hz), 7.76–7.82 (2H, m), 7.88 (1H, d, *J*=7.6 Hz), 7.92 (1H, s), 7.93 (1H, s), 8.60 (1H, d, *J*=7.6 Hz), 12.93 (1H, s); ^{13}C NMR (75 MHz, d_6-DMSO): δ 55.3, 55.7, 98.3, 106.2, 110.7, 117.8, 118.8, 119.0, 121.3, 122.5, 122.9, 124.9, 125.3, 126.0, 126.6, 132.1, 133.3, 134.0, 135.6, 137.7, 138.4, 144.0, 148.1, 159.5, 162.0; EIMS (70 eV): *m*/*z* (rel int.) 382 (7.9), 381 (28), 380 (100, M^+), 379 (10), 365 (12); HRMS (EI), *m*/*z* calcd for $C_{25}H_{20}N_2O_2$: 380.1525. Found: 380.1520. Anal. calcd for $C_{25}H_{20}N_2O_2$: C, 78.93; H, 5.30; N, 7.36. Found: C, 78.43; H, 5.30; N, 7.15.

*4.2.16. 12-(5-Bromo-2,4-dimethoxyphenylmethylene)benzo[b]indeno[1,2-f]-1,4-diazepine (**29e**).* Fulvene **35d** (51 mg, 0.14 mmol), cerium trichloride heptahydrate (53 mg), and *o*-phenylenediamine (18 mg, 0.17 mmol) were reacted under the previous conditions. The product was purified by column chromatography on grade three basic alumina, eluting with 60% dichloromethane–hexanes, and recrystallized from chloroform–hexanes to give the diazepine (43 mg, 0.094 mmol, 67%) as an orange solid, mp 285–286 °C; ^{1}H NMR (400 MHz, d_6-DMSO): δ 4.00 (3H, s), 4.01 (3H, s), 6.91 (1H, s), 7.20–7.30 (2H, m), 7.30–7.42 (2H, m), 7.59 (1H, d, *J*=8.0 Hz), 7.77 (1H, d, *J*=8.0 Hz), 7.82–7.90 (3H, m), 7.90 (1H, s), 8.63 (1H, d, *J*=7.6 Hz), 13.04 (1H, s); ^{13}C NMR (100 MHz, d_6-DMSO): δ 56.2, 56.5, 97.5, 101.7, 110.8, 118.7, 118.9, 119.0, 121.4, 122.7, 123.0, 124.1, 124.4, 125.5, 126.9, 133.7, 134.0, 134.1, 136.5, 137.6, 138.5, 143.9, 147.9, 157.4, 158.9; HRMS (EI), *m*/*z* calcd for $C_{25}H_{19}BrN_2O_2$: 458.0630. Found: 458.0628. Anal. calcd for $C_{25}H_{19}BrN_2O_2.H_2O$: C, 62.90; H, 4.43; N, 5.87. Found: C, 63.11; H, 4.19; N, 5.86.

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Supplementary data

Supplementary data associated with this article can be found in the online version, at doi:10.1016/j.tet.2009.10.013.

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