New Syntheses of the C,D-Ring Pyrromethenones of Phytochrome and Phycocyanin

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Pyrromethenone **7**, the C,D-ring segment of phytochrome (**Pr**, **4**), has been prepared in an efficient fashion employing three new strategies. Each of these has potential advantages for the synthesis of labeled material. Our first approach is related to the Gossauer synthesis, with the difference that strong alkali is avoided in the condensation of the C- and D-ring components **8** and **17**. The key silyloxypyrrole **17** was readily prepared on multigram scales beginning with inexpensive butyrolactone (**10**). A second synthesis began with 2-acetylbutyrolactone (**41**). The key steps involved conversion of **41** to the *Z*-enoltriflate **42**, followed by Pd(0)-catalyzed coupling with trimethylsilylacetylene, *p*-chlorophenylselenide ring opening, and finally, amidation to afford the ring-D synthon **45** having the proper geometry and oxidation state for conversion to **7**. Sonogashira coupling of **45** with the iodopyrrole **22**, followed by oxidative elimination, and F^--induced 5-*exo*-*dig* cyclization of the resultant pyrroloalkyne **47**, then completed the synthesis. In similar fashion, we have also prepared pyrromethenone **6**, the C,D-ring segment of phycocyanin (**2**).

Introduction

In green plants, two important phenomena are driven by light. One of these is photosynthesis, the fundamental source of nearly all biochemical energy, which utilizes chlorophyll (**1**) as the primary chromophore (Figure 1). Chlorin **1** absorbs light between 400 and 500 nm and 600−700 nm and initiates an electron-transfer sequence that leads ultimately to oxidation of H_2O to O_2 and reduction of $NADP^+$ to NADPH.[1] Enzyme-mediated dark reactions then convert CO_2 to glucose. In addition, most plants utilize auxiliary chromophores to supplement **1** (so-called "light-harvesting" pigments). These include conjugated polyenes, ranging in color from yellow to purple (carotenoids), and linear tetrapyrrole derivatives such as phycocyanin (**2**) and phycoerythrin (**3**). These last two compounds are protein-bound chromophores found in blue-green, eucaryotic, and cryptomonad algae.[2]

Photomorphogenesis is also dependent upon light and is the process by which growth regulatory information is transmitted to a plant's genetic apparatus.[3] Information of this type is vital to the timing of seasonal events, such as flowering and fruiting, chloroplast movement, stem growth, and chlorophyll (**1**) production (red light is known to "turn on" the genes for RUBISCO). The photoreceptor in this case is the blue-green tetrapyrrole phytochrome (**4**) (Figure 2),[3] a protein-bound chromophore that is present in plants in much smaller quantities than chlorophyll (4 kg of etiolated oat seedlings provide 50−60 mg of protein complex).[3h] In comparison to photosynthesis, where some aspects of the mechanism are known in considerable detail, relatively little is known about photomorphogenesis at the molecular level.[4] In

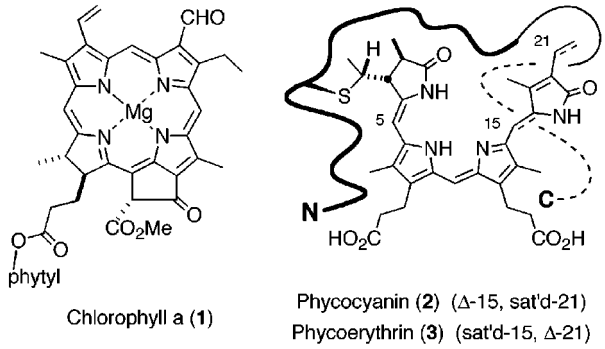

Figure 1. Chromophores of photosynthesis.

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(1) Lehninger, A. L. *Principles of Biochemistry*; Worth Publishers: New York, 1982; pp 645−79.

(2) (a) Schoenleber, R. W.; Kim, Y.; Rapoport, H. *J. Am. Chem. Soc.* **1984**, *106*, 2645 and references therein. (b) Glazer, A. N. In *The Biochemistry of Plants*; Hatch, M. D., Boardman, N. K., Eds.; Academic Press: New York, 1981; Vol. 8. For a review on biliproteins, see: (c) *Tetrahedron* **1983**, *39*, 1839; *Symposia-In-Print*, Bonnett, R., Ed. (d) Scheer, H. *Angew. Chem.* **1981**, *93*, 230; *Angew. Chem., Int. Ed. Engl.* **1981**, *20*, 241.

(3) (a) *Phytochrome and Photoregulation in Plants*; Furuya, M., Ed.; Academic Press: New York, 1987. For reviews on phytochrome-mediated responses in plants, see: (b) Statter, R. L.; Galston, A. W. In *Chemistry and Biochemistry of Plant Pigments*; Goodwin, T. W., Ed.; Academic Press: New York, 1976; Vol. 1, p 680. (c) Rüdiger, W.; Thümmler, F. *Angew. Chem., Int. Ed. Engl.* **1991**, *30*, 1216. (d) Rüdiger, W. *Photochem. Photobiol.* **1992**, *56*, 803. For reviews on phytochrome biochemistry and chromophore chemistry, see: (e) Terry, M. J.; Wahleithner, J. A.; Lagarias, J. C. *Arch. Biochem. Biophys.* **1993**, *306*, 1. (f) Pratt, L. H.;*Photochem. Photobiol.* **1978**, *27*, 81. (g) Kendrick, R. E.; Spruit, C. J. P. *Ibid.* **1977**, *26*, 201. Isolation and structure of phytochrome: (h) Lagarias, J. C.; Rapoport, H. *J. Am. Chem. Soc.* **1980**, *102*, 4821. (i) Hunt, R. E.; Pratt, L. H. *Plant Physiol.* **1979**, *64*, 332. (j) Jung, J.; Song, P.-S. *Photochem. Photobiol.* **1979**, *29*, 419.

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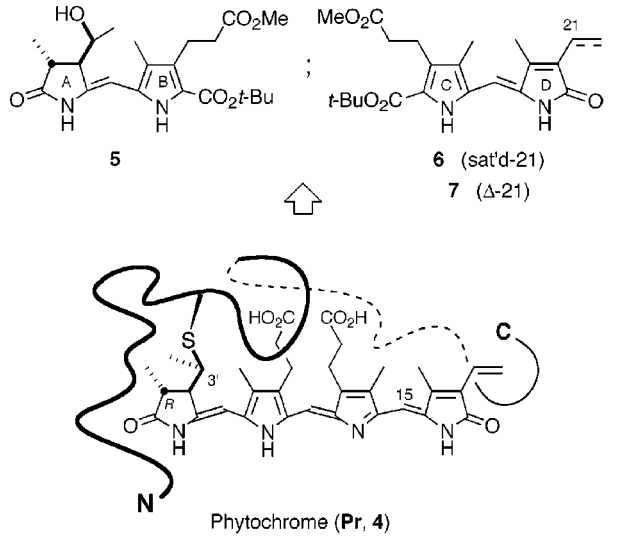


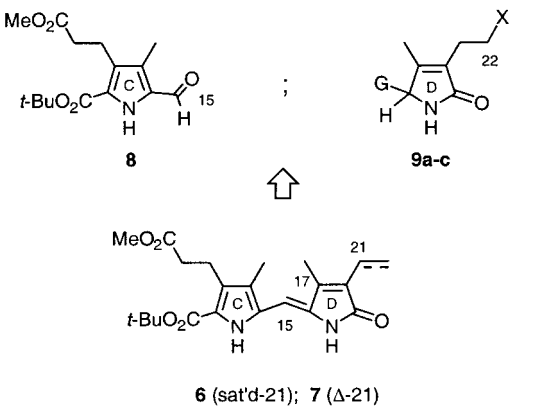
Figure 2. Chromophore of photomorphogenesis.

part this is due to the difficulty of isolating **4** and derivatives from natural sources,[3h,i] which has spurred synthetic activity in this area.[5] Recently, we reported a stereo- and enantiospecific synthesis of pyrromethenone **5**, a potential A,B-ring precursor to tetrapyrroles **2**−**4** (Figure 2).[5f] In this paper, we describe new syntheses of pyrromethenones **6** and **7**, which constitute the C,D-ring precursors of **2** and **4**, respectively.[5h,i]

Results and Discussion

The C + D → CD Route to Pyrromethenones. Nearly all reported syntheses of **6** and **7** employ some variant of the Gossauer strategy,[5m] typified by the KOH promoted condensation of formylpyrrole **8** with unsaturated lactams of type **9** (C + D → CD; Scheme 1). This approach is appealing due to its highly convergent nature, and in principle, it offers a wide range of flexibility. For example, condensation of **8** with **9a** (X, G = H) affords dihydropyrromethenone **6** in good yield following re-esterification.[5o] In some instances, however, the strongly alkaline conditions of this reaction are incompatible with sensitive functionality. This is particularly an issue with lactams **9** having X as a leaving group (**9b**,**c**), which are logical precursors to Δ-21 derivatives related to **7**. In such cases activation is typically delayed until after condensation, which can complicate the synthetic route.[5c,m] Inomata et al. recently described a modification of this approach,[5c] in which the lactam **9** was substituted with a strongly electron withdrawing group at the α-position (**9c**, G = *p*-toluenesulfonyl, X = STol). In this case condensation of **8** with **9c** was effected using the weaker base DBU, which alleviated the problem of propionate ester hydrolysis (see above). Subsequent oxidation of the STol group to the corresponding sulfoxide then provided the necessary activation for elimination. This methodology has a number of advantages over the original strategy, although the synthesis of **9c** is lengthy (nine steps from acrolein) and requires several expensive and/or toxic reagents.[3c] As described below, we have developed a variant of the C + D → CD approach to pyrromethenones that is amenable to multigram synthesis, and can be carried out under very mild conditions.

Scheme 1



Our strategy built upon the ready availability of the silyloxypyrrole **17**, which was synthesized in efficient fashion beginning with butyrolactone (**10**) (Scheme 2). Lactone **10** proved to be a convenient (and inexpensive) precursor to the carboxylic acid **11**, which was obtained in 75−85% yield upon S_N2-ring opening with *p*-chlorophenylselenide anion.[5i,p] Acid **11** was then converted in two steps, and excellent overall yield, to the amide derivative **14**, by initial activation with $(COCl)_2$ followed by in situ amination with aminoacetone dimethylacetal (**13**) (10−20 g scales). The remaining steps necessary in order to prepare **17** required considerable experimentation but were eventually reduced to a very clean process. Thus, reaction of **14** with $(Boc)_2O$ gave an essentially quantitative yield of the carbamate ester **15**, which underwent smooth intramolecular aldol condensation upon treatment with *t*-BuOK in THF at −10 °C.[5q] The resultant lactam **16** then afforded an 80−90% yield of

(4) (a) Andel, F., III; Murphy, J. T.; Haas, J. A.; McDowell, M. T.; van der Hoef, I.; Lugtenburg, J.; Lagarias, J. C.; Mathies, R. A. *Biochemistry* **2000**, *39*, 2667 and references therein. (b) Bischoff, M.; Hermann, G.; Rentsch, S.; Strehlow, D.; Winter, S.; Chosrowjan, H. *J. Phys. Chem. B* **2000**, *104*, 1810. (c) Mizutani, Y.; Tokutomi, S.; Kitagawa, T. *Biochemistry* **1994**, *33*, 153. (d) Micura, R.; Grubmayr, K. *Bioorg. Med. Chem. Lett.* **1994**, *4*, 2517. (e) Hildebrandt, P.; Hoffmann, A.; Lindemann, P.; Heibel, G.; Braslavsky, S. E.; Schaffner, K.; Schrader, B. *Biochemistry* **1992**, *31*, 7957. (f) Fodor, S. P. A.; Lagarias, J. C.; Mathies, R. A. *Biochemistry* **1990**, *29*, 11141. (g) Farrens, D. L.; Holt, R. E.; Rospendowski, B. N.; Song, P.-S.; Cotton, T. M. *J. Am. Chem. Soc.* **1989**, *111*, 9162. (h) Thümmler, F.; Rüdiger, W. *Tetrahedron* **1983**, *39*, 1943. (i) Rüdiger, W.; Thümmler, F.; Cmiel, E.; Schneider, S. *Proc. Natl. Acad. Sci. U.S.A.* **1983**, *80*, 6244. See also ref 3h.

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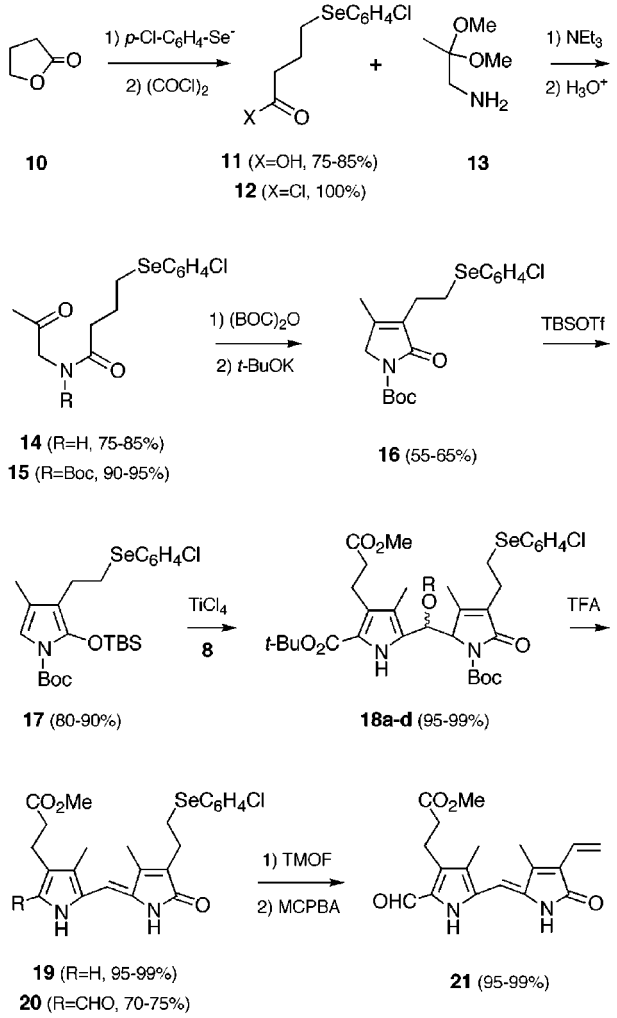
Scheme 2



the silyloxypyrrole **17** when reacted with *tert*-butyldimethylsilyl triflate (TBSOTf).[5r]

Our choice of pyrrole **17** as the D-ring component was influenced by a report of Montforts et al.,[5s] who described the aldol-like condensation of 2-methoxypyrroles with pyrroloaldehydes upon treatment with 48% HBr. Although these conditions proved to be too harsh for our purposes, there was precedent that the silyloxypyrrole **17** might react with aldehydes under much milder conditions.[5r,t] This in fact turned out to be the case. Lewis acid-catalyzed condensation of **17** with the pyrroloaldehyde **8** occurred rapidly at −78 °C and afforded a virtually quantitative yield of the silyl ethers **18a**,**b** (R = TBS) and alcohols **18c**,**d** (R = H). The composition of this diastereomeric mixture varied with the reaction conditions, and initially each isomer was isolated and independently characterized (cf. Experimental Section). However, in practice, it proved to be much more convenient to simply treat the mixture directly with TFA, which effected concomitant dehydration and decarboxylation to give a 95−99% yield of the dihydropyrromethenone **19** (R = H). Finally, this last material was cleanly converted to the desired C,D-ring precursor **21** by initial formylation with TMOF (70−75%, not optimized), followed by peracid induced selenoxide elimination (95−99%). The material thus obtained was identical in all respects to an authentic sample of **21**.[5i,m,14]

The Alkyne Amide Route to Pyrromethenones. Although versatile, the C + D → CD strategy has one important limitation. It is not suitable for the synthesis of saturated derivatives at C_{17}, which might be useful for studying the mode of action of phytochrome (**4**) (cf. **25**, Figure 3).[4] Therefore, we have developed a complementary strategy to synthesize pyrromethenones of type **6** and **7**, and dihydropyrromethenones of type **25**, that is equally convergent and can accommodate a wide range of functionality. The key steps in this approach involve the Pd(0)-catalyzed coupling of iodopyrrole **22** with terminal alkynes **23** (X = H, leaving group) and subsequent 5-*exo*-*dig* cyclization of the resultant pyrroloalkyne amides **24**.[5f]

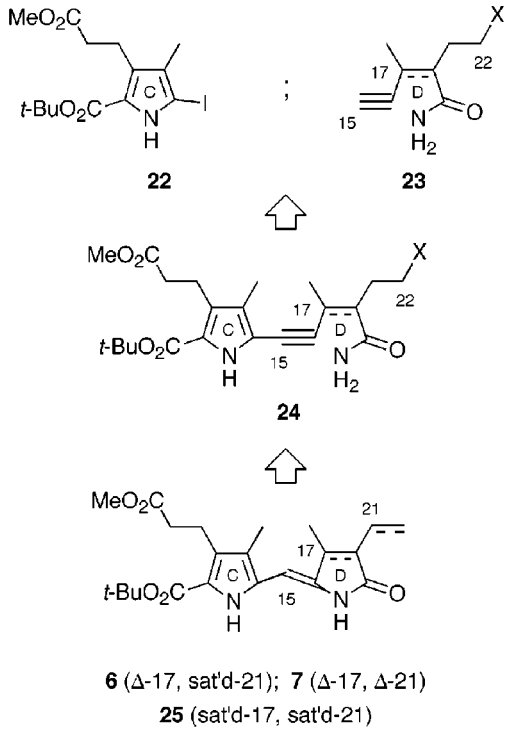


Figure 3. The alkyne amide route to pyrromethenones.

As previously reported,[5f,i] the requisite C-ring component **22** was conveniently synthesized using the Barton-Zard methodology,[6a] which has the advantage of permitting maximum flexibility in the choice of ester group R. We then made use of a Nicholas−Schreiber reaction for preparing the alkyne amide **30**,[7] our projected D-ring precursor to **6** (Scheme 3). In related studies we exploited this methodology for the synthesis of homochiral amides related to **30**, which required the use of chiral oxazolidinones.[5f,g] However, in the present case we employed the achiral oxazolidinone **27**, since control of absolute stereochemistry at C_{17}−C_{18} was unnecessary. Thus, dibutylborontriflate/*i*-Pr_2NEt-catalyzed condensation of **27** with the cobalt complex **26** gave a 97% yield of the racemic Nicholas adduct **28**, which by NMR analysis had exclusively syn-stereochemistry at C_{17}−C_{18} (determined after

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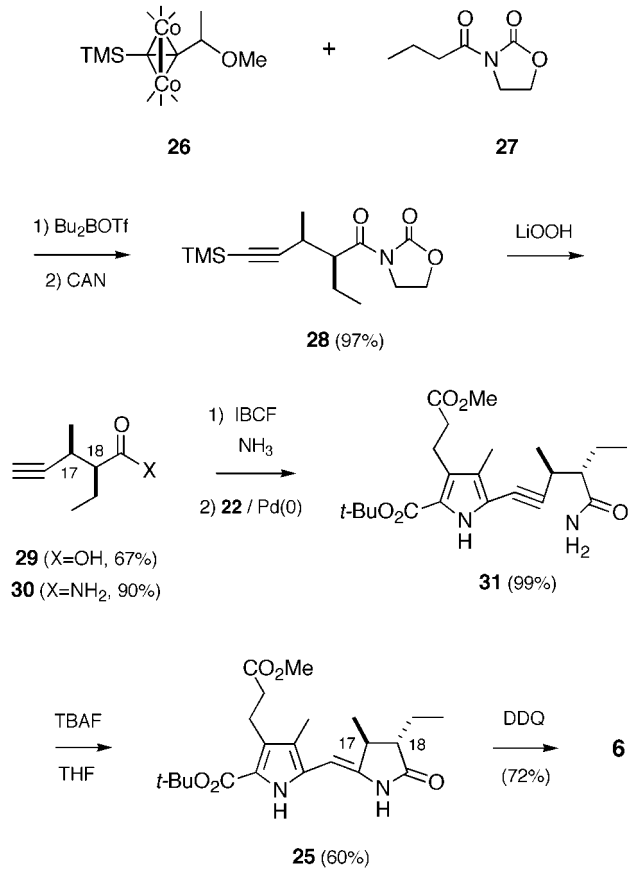
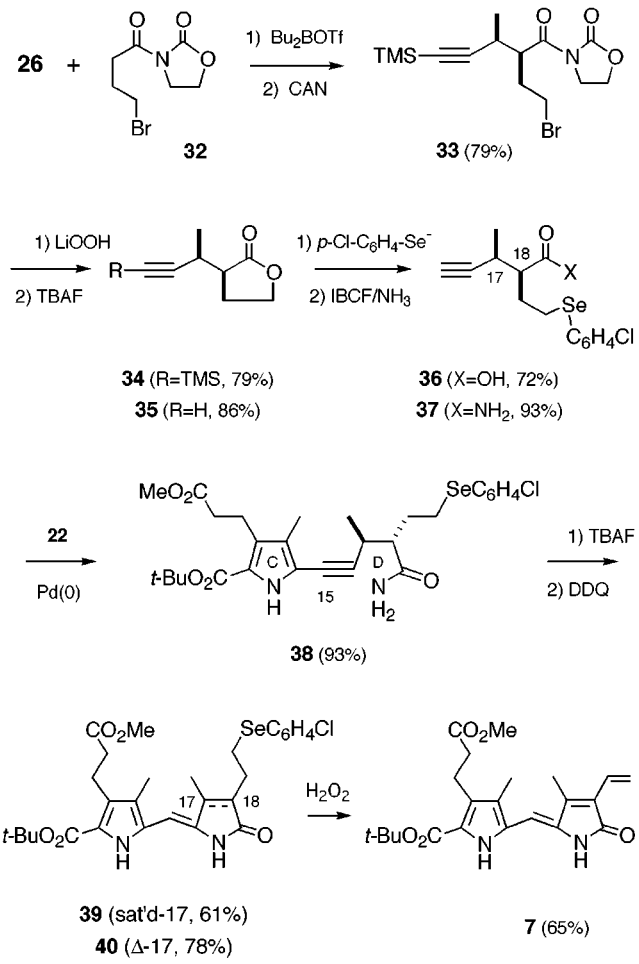
Scheme 3



Scheme 4



decomplexation). Adduct **28** then afforded a 60% overall yield of the target amide **30** by a straightforward sequence involving imide hydrolysis with concomitant TMS removal (67%)[8] and amidation of the resultant carboxylic acid **29** via the mixed isobutyl carbonate derivative (90%).[9] Interestingly, simple alkyl esters corresponding to **27** gave much lower yields of Nicholas adducts and exhibited little selectivity between syn and anti stereochemistry. Syn vs anti stereocontrol is important since only the syn isomers undergo facile 5-*exo*-*dig* cyclization.[5f] In any event, alkyne amide **30** was cleanly converted to the dihydropyrromethenone **25** by initial Pd(0)-catalyzed coupling with the iodopyrrole **22** (**30** → **31**, 99%),[10] followed by F^--induced cyclization (*Z*-isomer only, 60% overall yield from **22**).[5f] Finally, oxidation of **25** with DDQ gave a 72% yield of the pyrromethenone **6**, which had identical physical and spectral properties as reported in the literature.[5k,o]

We explored two approaches for the synthesis of Δ-21 pyrromethenone **7**, the C,D-ring precursor to phytochrome (**4**) (cf. Figure 2). Our initial experiments were carried out with the imide derivative **32** (Scheme 4), itself derived by acylation of 2-oxazolidinone with 4-bromobutyryl chloride. Imide **32** underwent clean condensation with the cobalt complex **26**,[5f,7] affording an ∼80% overall yield of adduct **33** following Co-decomplexation (syn isomer exclusively). Adduct **33** contains all of the features necessary for eventual conversion to alkyne amides of general structure **23** (cf. Figure 3, X = leaving group). Interestingly, however, all attempts at the selective hydrolysis of the imide group in **33** led directly to the formation of the alkyne lactone **34**, which was complete in <5 min at 0 °C (68% overall yield of **35** after TMS cleavage). Although not anticipated, this transformation was readily put to advantage. Thus, alkyne lactone **35** was now cleanly converted to the ring-opened alkyne amide **37** by initial S_N2 displacement with sodium *p*-chlorophenylselenide (72%),[11] followed by amidation of the resultant carboxylic acid **36** with isobutylchloroformate and NH_3 (93%).[9] Amide **37** then gave a 57% overall yield of dihydropyrromethenone **39** upon Pd(0)-mediated coupling with iodopyrrole **22** (93%), followed by 5-*exo*-*dig* cyclization of the resultant pyrroloalkyne **38** (61%, *Z*-isomer only).[5f] Finally, as described above for **6** (Scheme 3), oxidation of **39** with DDQ afforded a 78% yield of pyrromethenone **40** as a stable, crystalline solid, which had identical spectral and physical properties as those reported in the literature.[5m,14] Selenide **40** has previously been converted to **7** by oxidative elimination with H_2O_2 (65%).[5m]

(8) Evans, D. A.; Britton, T. C.; Ellman, J. A. *Tetrahedron Lett.* **1987**, *28*, 6141.

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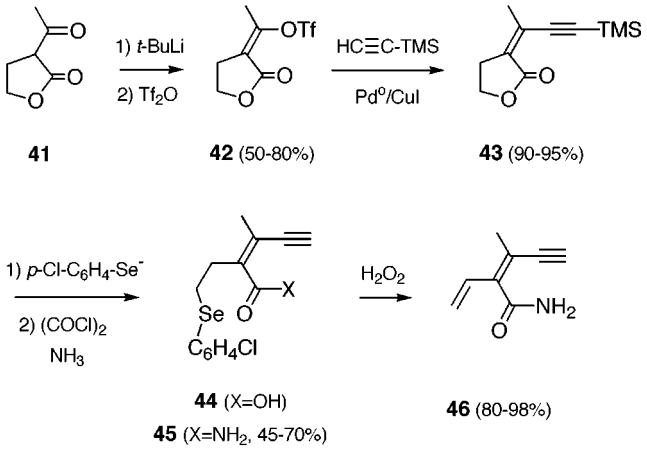
Scheme 5



We also developed a modification of the alkyne amide strategy, which for pyrromethenone **7** is more direct, and avoids the use of cobalt alkynes. As noted above, the Nicholas-Schreiber methodology is extremely useful for preparing *syn*-alkyne amides of type **30** and **37** in enantiomerically pure form.[5f,g] This was crucial for the preparation of chiral A,B-ring precursors such as **5** (Figure 2).[5f] For the synthesis of **7**, however, this strategy incorporates an unnecessary level of complexity, since the final pyrromethenone is devoid of stereochemical features. The stereocenters which are introduced at C_{17} and C_{18} in **33** are ultimately destroyed by oxidation.

Our third synthesis of **7** employs the unsaturated alkyne amide **46**, which has the proper oxidation state for final cyclization (Scheme 5). In this case, however, it was necessary to rigorously control the double bond geometry at C_{17} (phytochrome numbering). After investigating a number of routes, we were eventually able to prepare **46** in five steps from inexpensive starting materials. The key step in this synthesis was a stereoselective enolization of 2-acetylbutyrolactone (**41**), which at −78 °C afforded nearly exclusively the *Z*-lithioenolate. This last material, upon quenching with triflic anhydride (Tf_2O), then gave a 60−80% yield of *Z*-enoltriflate **42** as the only detectable isomer (yields represent a range from many experiments). Selectivity in this case presumably is due to Li^+ coordination with the enolate anion derived from **41**, in close analogy to the work of Brückner, Suffert et al. with 2-formylbutyrolactone.[12] Sonogashira coupling of **42** with trimethylsilylacetylene then gave a 90−95% yield of the alkyne lactone **43**,[10] which correctly sets the double bond geometry as *Z*. Next, alkyne lactone **43** was directly converted to the alkyne amide **45** by initial S_N2 ring opening with sodium *p*-chlorophenylselenide,[11] followed by in situ amidation of the resultant carboxylic acid **44** with $(COCl)_2/NH_3$ (45−70% overall yield).[9] Amide **45** is a stable crystalline solid which we have routinely prepared on multigram scales. Finally, oxidation of **45** with H_2O_2 led to smooth selenoxide elimination, producing the alkene derivative **46** as an unstable, easily polymerized solid (80−90%).

Scheme 6

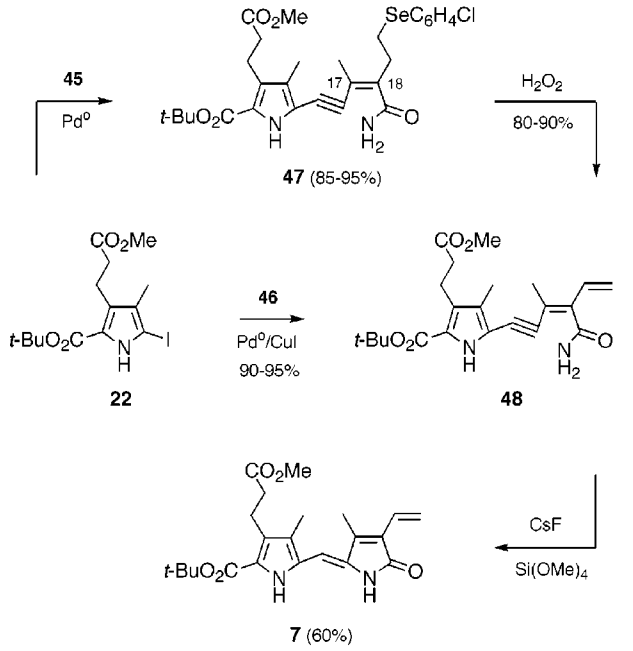


Table 1. Cyclization of Pyrroloalkyne 48

entry	reagent	conditions	time (h)	yield of **7** (%)
1	Pd(II)	MeCN/rt	48	0
2	Mont. clay	$CHCl_3/\Delta$	13	0
3	CsF/silica gel	THF/Δ	48	0
4	TBAF	THF/Δ	96	40
5	TBAF/Al_2O_3	THF/Δ	24	25
6	F^-/polymer	THF/Δ	13	0
7	CsF/$Si(OMe)_4$	THF/Δ		

Both **45** and **46** proved to be excellent substrates for Pd(0)-mediated coupling with the iodopyrrole **22** (Scheme 6). On relatively small scales (<1 g), Sonogashira coupling of **22** with the unsaturated alkyne amide **46** gave a 90−95% yield of the pyrroloalkyne **48**. This pathway has the advantage of being highly convergent. However, the success of this reaction depends on employing only freshly prepared **46**, since this material polymerizes rapidly even when stored at 0 °C. For larger scale reactions (>1 g), it was generally more convenient to delay oxidative elimination until a later step of the synthesis. Following this route, Pd(0)-catalyzed coupling of alkyne amide **45** with **22** gave an 85−90% yield of the stable alkyne pyrrole **47**, which upon treatment with H_2O_2 was cleanly converted to the identical unsaturated derivative **48**.

Finally, we investigated numerous conditions to effect the requisite 5-*exo*-*dig* cyclization leading from **48** to the pyrromethenone **7** (Table 1). As in our previous studies, no cyclization was observed using Pd(II) as a catalyst,[5f] using Montmorillonite K-10 clay,[13a] or using CsF absorbed on silica gel (entries 1−3). Some measure of success was achieved employing a large excess of TBAF (>6 equiv),[5f] which afforded ∼40% of **7** after 96 h at reflux in THF (entry 4). Under these conditions, however, substantial decomposition also occurred. No improvement was observed with various modified TBAF reagents, including TBAF/Al_2O_3 (entry 5, 25%), and Amberlyst A-26 quaternary ammonium fluoride resin (entry 6, 0%). By far the best results were obtained with the reagent system CsF/$Si(OMe)_4$ (entry 7), which was initially introduced by Corriu and Perz as a catalyst for Michael

(13) (a) Jackson, A. H.; Pandey, R. K.; Rao, K. R. N.; Roberts, E. *Tetrahedron Lett.* **1985**, *26*, 793. (b) Corriu, R. J. P.; Perz, R. *Tetrahedron Lett.* **1985**, *26*, 1311. See also (b) Ahn, K. H.; Lee, S. J. *Tetrahedron Lett.* **1994**, *35*, 1875.

(14) We are grateful to Professor Albert Gossauer, of the Université de Fribourg Suisse, for providing us with NMR and IR spectra for **7**. We also thank Professor Franz-Peter Montforts, of the Universität Bremen, for bringing to our attention ref 5s.

additions.[13b] In the present case, cyclization of **48** with 5 equiv of CsF/20 equiv of $Si(OMe)_4$ gave a 60% yield of **7** after only 6 h heating in THF, in contrast to the 96 h period required with TBAF (entry 4).[14] The only byproduct was a small amount of the corresponding dimethylester obtained by transesterification. As previously suggested,[13b] the active catalyst in this reaction might involve a pentacoordinated silicon species formed by nucleophilic attack by F^- on $Si(OMe)_4$.

Conclusion

The synthesis of **7** outlined in Scheme 6 is about half the length of our earlier approach (Scheme 4), and it should be readily adaptable to the preparation of specifically labeled substrates. The utility of the alkyne amide strategy for the synthesis of **6** and **7** derives partly from the ready availability of the key intermediates **22**, **30**, and **45**. In addition, the transformations involved are sufficiently mild for the introduction of labile functionality of the type found in naturally occurring tetrapyrroles. We believe that in certain cases this route will have advantages over the traditional C + D → CD strategy, especially when such an approach requires strongly alkaline conditions.

The versatility of the C + D → CD strategy has been significantly enhanced by employing silyloxypyrroles of type **17** as the nucleophilic D-ring component. Not only are such pyrroles relatively simple to prepare, but this modification permits the key bond forming step to be accomplished under very mild conditions.

Experimental Section

All reactions were carried out in oven-dried glassware under an inert atmosphere of nitrogen or argon. Air- and moisture-sensitive compounds were introduced via syringe or cannula and weighed in a drybox. Reactions involving light sensitive compounds were carried out wrapped in foil. Melting points are uncorrected and were measured on a Fisher-Jones melting point apparatus. Proton magnetic resonance spectra (^{1}H NMR) were recorded at either 300 or 400 MHz as indicated.

1-[4-(4-Chlorophenylselanyl)]butyric Acid (11). A solution of 10.80 g (28.34 mmol, 1.0 equiv) of bis(4-chlorophenyl)-diselenide in 150 mL of absolute EtOH was cooled to 0 °C and treated portionwise with 2.18 g (57.54 mmol, 2.03 equiv) of $NaBH_4$. After the addition was complete the reaction mixture was degassed under Ar and stirred at 0 °C for an additional 30 min. To the resulting pale yellow solution was added 4.36 mL (56.68 mmol, 2.0 equiv) of γ-butyrolactone (**10**) dissolved in 20 mL of anhydrous THF at 0 °C. The reaction was then heated at reflux overnight, cooled to room temperature and diluted with 150 mL of H_2O. The aqueous layer was separated, washed with Et_2O, and then acidified with 1 M HCl to pH 2. The acidified solution was extracted with Et_2O, and the combined organic extracts were dried over anhydrous Na_2SO_4, concentrated under reduced pressure and chromatographed (silica gel, hexane forerun, followed by 30% EtOAc/hexanes) to afford 12.43 g (79%) of acid **11** as a light pink solid: mp 102.3−2.5 °C; R_f 0.36 (silica gel, 50% EtOAc/hexanes); IR (film) 3100−2500, 3072, 2916, 1691 cm^{-1}; ^{1}H NMR ($CDCl_3$) δ 1.95−2.05 (m, 2H), 2.51 (t, J = 6.9 Hz, 2H), 2.94 (t, J = 7.2 Hz, 2H), 7.24 (d, J = 8.7 Hz, 2H), 7.43 (d, J = 8.7 Hz, 2H); ^{13}C NMR ($CDCl_3$) δ 25.05, 27.31, 33.71, 128, 129.49, 133.52, 134.41, 179.14. Anal. Calcd for $C_{10}H_{11}ClO_2Se$: C, 43.27; H, 3.99. Found: C, 43.32; H, 4.01.

1-[4-(4-Chlorophenylselanyl)butylamino]propan-2-one (14). A solution of 10.6 g (38.2 mmol, 1.0 equiv) of acid **11** in 70 mL of CH_2Cl_2 was treated dropwise with vigorous stirring with 3.5 mL (40.11 mmol, 1.05 equiv) of oxalyl chloride under N_2. The reaction was stirred at room temperature for an additional 4 h and concentrated under reduced pressure to give acid chloride **12**, which was used without further purification.

A solution of 7.13 g (45.8 mmol, 1.2 equiv) of 1-amino-2,2-dimethoxypropane hydrochloride (**13**) in 50 mL of CH_2Cl_2 was treated with 16 mL (114.2 mmol, 3.0 equiv) of freshly distilled Et_3N. The resulting mixture was stirred at room temperature for 20 min and then cooled to 0 °C. A solution of the crude acid chloride **12** from above in 25 mL of CH_2Cl_2 was then added dropwise to the reaction mixture over a period of 30 min. After addition was complete, the reaction was allowed to warm to room temperature and stirred for an additional 3.5 h. The reaction mixture was the diluted with 75 mL of 1 M HCl, and stirring was continued for 1 h. The aqueous layer was extracted with CH_2Cl_2, and the combined organic extracts were dried over anhydrous Na_2SO_4, concentrated under reduced pressure, and chromatographed (silica gel, 40% EtOAc/hexanes) to afford 10.17 g (80%) of amide **14** as a white solid: mp 73.4−3.6 °C; R_f 0.15 (silica gel, 50% EtOAc/hexanes); IR (film) 3312, 3073, 2954, 2924, 1724, 1635 cm^{-1}; ^{1}H NMR ($CDCl_3$) δ 1.95−2.05 (m, 2H), 2.19 (s, 3H), 2.36 (t, J = 7.2 Hz, 2H), 2.93 (t, J = 6.9 Hz, 2H), 4.13 (d, J = 4.5 Hz, 2H), 6.21 (bs, 1H), 7.21 (d, J = 8.4 Hz, 2H), 7.41 (d, J = 8.4 Hz, 2H); ^{13}C NMR ($CDCl_3$) δ 15.80, 27.54, 27.67, 35.67, 50.02, 18.24, 129.44, 133.34, 134.28, 172.07, 203.04. Anal. Calcd for $C_{13}H_{16}ClNO_2Se$: C, 46.93; H, 4.85; N, 4.21. Found: C, 47.12; H, 4.90; N, 4.19.

[4-(4-Chlorophenylselanyl)butyl](2-oxopropyl)carbamic Acid, *tert*-Butyl Ester (15). A solution of 9.00 g (27.1 mmol, 1.0 equiv) of amide **14** in 80 mL of CH_2Cl_2 was treated successively with 3.8 mL (27.1 mmol, 1.0 equiv) of Et_3N, 11.83 g (54.2 mmol, 2.0 equiv) of $(Boc)_2O$, and 3.36 g (27.1 mmol, 1.0 equiv) of DMAP. The reaction was then stirred at room temperature for 1 h before being concentrated to dryness under reduce pressure. The residue was chromatographed (silica gel, 10% EtOAc/hexanes) to afford 11.0 g (94%) of carbamic ester **15** as a white solid: mp 40.7−40.9 °C; R_f 0.37 (silica gel, 20% EtOAc/hexanes); IR (film) 2972, 2939, 1739, 1689 cm^{-1}; ^{1}H NMR ($CDCl_3$) δ 1.46 (s, 9H), 1.96−2.06 (m, 2H), 2.13 (s, 3H), 2.93 (t, J = 6.9 Hz, 2H), 3.06 (t, J = 7.2 Hz, 2H), 4.47 (s, 2H), 7.20 (d, J = 8.4 Hz, 2H), 7.41 (d, J = 8.4 Hz, 2H); ^{13}C NMR ($CDCl_3$) δ 25.61, 27.00, 27.55, 28.05, 37.83, 53.39, 83.93, 128.55, 129.35, 133.1, 134.11, 152.29, 174.90, 201.84. Anal. Calcd for $C_{18}H_{24}ClNO_4Se$: C, 49.95; H, 5.59; N, 3.24. Found: C, 49.95; H, 5.53; N, 3.31.

3-[2-(4-Chlorophenylselanyl)ethyl]-4-methyl-2-oxo-2,5-dihydropyrrole-1-carboxylic Acid, *tert*-Butyl Ester (16). A solution of 3.3 g (7.63 mmol, 1.0 equiv) of carbamic ester **15** in 150 mL of THF was cooled to −10 °C (NaCl/ice bath) and was treated with 1.71 g (15.26 mmol, 2.0 equiv) of freshly sublimed *t*-BuOK. The reaction mixture was stirred at −10 °C for an additional 20 min, poured into 100 mL of ice-cold H_2O, and extracted with CH_2Cl_2. The combined organic extracts were dried over Na_2SO_4, concentrated under reduced pressure, and chromatographed (silica gel, 20% EtOAc/hexanes) to afford 1.90 g (60%) of lactam **16** as a white solid: mp 114.5−14.8 °C; R_f 0.74 (silica gel, 50% EtOAc/hexanes); IR (film) 2971, 2928, 1769, 1721, 1708, 1669 cm^{-1}; ^{1}H NMR ($CDCl_3$) δ 1.56 (s, 9H), 1.95 (s, 3H), 2.07 (t, J = 6.9 Hz, 2H), 3.12 (t, J = 7.2 Hz, 2H), 4.00 (s, 2H), 7.21 (d, J = 8.7 Hz, 2H), 7.41 (d, J = 8.7 Hz, 2H); ^{13}C NMR ($CDCl_3$) δ 13.71, 24.99, 25.41, 28.33, 53.18, 82.92, 128.47, 129.36, 131.57, 132.98, 133.36, 149.72, 151.26, 169.71. Anal. Calcd for $C_{18}H_{22}ClNO_3Se$: C, 52.12; H, 5.35; N, 3.38. Found: C, 52.28; H, 5.52; N, 3.31.

2-(*tert*-Butyldimethylsilanyloxy)-3-[2-(4-chlorophenylselanyl)ethyl]-4-methylpyrrole-1-carboxylic Acid, *tert*-Butyl Ester (17). A solution of 2.05 g (4.95 mmol, 1.0 equiv) of lactam **16** in 20 mL of CH_2Cl_2 was treated successively with 1.72 mL (14.9 mmol, 3.0 equiv) of 2,6-lutidine and 1.26 mL (5.49 mmol, 1.11 equiv) of TBSOTf under N_2. The reaction was stirred at room temperature for 30 min, after which it was concentrated under reduced pressure, and the residue chromatographed (silica gel, 50%EtOAc/hexanes) to afford 2.2 g (84%) of siloxypyrrole **17** as a pale yellow solid: mp 34.1−

34.5 °C; R_f 0.91 (silica gel, 50% EtOAc/hexanes); IR (film) 2937, 2859, 1751, 1717 cm^{-1}; ^{1}H NMR ($CDCl_3$) δ 0.10 (s, 6H), 0.96 (s, 9H), 1.54 (s, 9H), 1.89 (d, J = 1.2 Hz, 3H), 2.60−2.97 (dt, 4H), 6.41 (q, J = 1.2 Hz, 1H), 7.22 (d, J = 8.4 Hz, 2H), 7.44 (d, J = 8.4 Hz, 2H); ^{13}C NMR ($CDCl_3$) δ −4.04, 11.36, 18.41, 24.95, 25.91, 26.04, 28.23, 82.48, 106.83, 110.09, 118.60, 128.58, 129.28, 133.15, 134.36, 139.60, 148.11. Anal. Calcd for $C_{24}H_{36}ClNO_3SeSi$: C, 54.49; H, 6.86; N, 2.65. Found: C, 54.75; H, 6.92; N, 2.61.

Aldol Adducts 18a−d. A solution of 1.63 g (5.52 mmol, 1.00 equiv) of pyrroloaldehyde **8**[50] in 40 mL of dry CH_2Cl_2 was cooled to −78 °C under Ar and was treated dropwise with vigorous stirring with 1.05 g (607 μL, 5.52 mmol, 1.00 equiv) of $TiCl_4$. The resulting orange/red suspension was stirred for an additional 15 min at −78 °C to ensure thorough mixing, and was then treated portionwise with a solution of 2.93 g (5.54 mmol, 1.00 equiv) of silyloxypyrrole **17** in 30 mL of dry CH_2Cl_2. The resulting dark red solution was stirred for an additional 10 min and was then quenched with saturated $NaHCO_3$ at −78 °C. The resulting mixture was warmed to 0 °C and extracted with CH_2Cl_2. The combined extracts were washed with H_2O and saturated brine, dried over anhydrous Na_2SO_4, concentrated under reduced pressure, and chromatographed (silica gel, 9:1 EtOAc/petroleum ether) to afford 1.81 g of **18a**, 170 mg of **18b**, 1.93 g of **18c**, and 160 mg of **18d** (combined yield 4.07 g, 97%), relative stereochemistry not assigned.

5-[[1-*tert*-Butoxycarbonyl-4-[2-(4-chlorophenylselanyl)ethyl]-3-methyl-5-oxo-2,5dihydro-1*H*-pyrrol-2-yl]-(*tert*-butyldimethylsilanyloxy)methyl]-3-(2-methoxycarbonylethyl)-4-methyl-1*H*-pyrrole-2-carboxylic Acid, *tert*-Butyl Ester 18a. Recrystallization from EtOAc/petroleum ether afforded **18a** as a white solid: mp 106−7 °C; R_f 0.90 (silica gel, 30% EtOAc/petroleum ether); UV−vis (MeOH) λ_{max}nm (log ϵ) 208 (4.24), 226 (4.23); 280 (4.13); IR (film) 3467, 2954, 2923, 2854, 1777, 1739, 1705 cm^{-1}; 500 MHz ^{1}H NMR ($CDCl_3$) δ 0.01 (s, 3H), 0.19 (s, 3H), 0.93 (s, 9H), 1.50 (s, 9H), 1.57 (s, 9H), 1.83 (s, 3H), 2.12 (s, 3H), 2.28 (m, 1H), 2.33−2.51 (m, 2H), 2.40 (t, J = 8.8 Hz, 2H), 2.65 (m, 1H), 2.82 (m, 1H), 2.96 (m, 1H), 3.65 (s, 3H), 4.53 (d, J = 3.9 Hz, 1H), 5.60 (d, J = 3.9 Hz, 1H), 7.22 (d, J = 8.6 Hz, 2H), 7.37 (d, J = 8.6 Hz), 8.49 (s, 1H); 125 MHz ^{13}C NMR ($CDCl_3$) δ −5.19, −4.88, 8.76, 15.21, 18.22, 20.81, 24.17, 24.59, 25.93, 28.35, 28.58, 35.25, 51.67, 67.23, 68.30, 81.10, 83.26, 117.80, 119.46, 128.21, 128.49, 129.19, 129.38, 132.93, 133.49, 133.55, 150.06, 153.45, 160.90, 168.10, 173.67. Anal. Calcd for $C_{39}H_{57}ClN_2O_8SeSi$: C, 56.82; H, 6.97; N, 3.39. Found: C, 57.07; H, 6.84; N, 3.40, relative stereochemistry not assigned.

5-[[1-*tert*-Butoxycarbonyl-4-[2-(4-chlorophenylselanyl)ethyl]-3-methyl-5-oxo-2,5dihydro-1*H*-pyrrol-2-yl]-(*tert*-butyl-dimethylsilanyloxy)methyl]-3-(2-methoxycarbonylethyl)-4-methyl-1*H*-pyrrole-2-carboxylic Acid, *tert*-Butyl Ester 18b. Column chromatography afforded **18b** as a clear gel: R_f 0.80 (silica gel 30% EtOAc/petroleum ether); UV−vis (MeOH) λ_{max}nm (log ϵ) 208 (4.24), 224 (4.23); 272 (4.13); IR (film): 3481, 3468, 2977, 2952, 2930, 2859, 1778, 1739, 1705, 1683 cm^{-1}; 500 MHz ^{1}H NMR ($CDCl_3$) δ −0.02 (s, 3H), 0.03 (s, 3H), 0.87 (s, 9H), 1.31 (s, 3H), 1.56 (s, 9H), 1.61 (s, 9H), 2.14 (s, 3H), 2.52−2.65 (m, 2H), 2.56 (t, J = 7.8 Hz, 2H), 2.93−3.03 (m, 2H), 3.06 (m, 1H), 3.13 (m, 1H), 3.66 (s, 3h), 4.54 (br s, 1H), 5.59 (d, J = 1.9 Hz, 1H), 7.22 (d, J = 8.9 Hz, 2H), 7.40 (d, J = 8.5 Hz, 2H), 8.77 (s, 1H); 125 MHz ^{13}C NMR ($CDCl_3$) δ −05.08, −5.00, 9.50, 13.32, 18.25, 20.75, 24.85, 25.42, 25.99, 28.53, 28.69, 35.22, 51.68, 66.99 (2), 80.93, 83.41, 114.79, 118.20, 128.39, 129.41, 130.36, 130.41, 133.03, 133.44, 133.47, 150.19, 153.12, 160.54, 169.22, 173.82. Anal. Calcd for $C_{39}H_{57}ClN_2O_8SeSi$: C, 56.82; H, 6.97; N, 3.39. Found: C, 57.08; H, 6.82; N, 3.28; relative stereochemistry not assigned.

5-[[1-*tert*-Butoxycarbonyl-4-[2-(4-chlorophenylselanyl)-ethyl]-3-methyl-5-oxo-2,5-dihydro-1*H*-pyrrol-2-yl]hydroxymethyl]-3-(2-methoxycarbonylethyl)-4-methyl-1*H*-pyrrole-2-carboxylic Acid, *tert*-Butyl Ester 18c. Recrystallization from EtOAc/petroleum ether afforded **18c** as fine white needles: mp 150−51 °C; R_f 0.40 (silica gel, 30% EtOAc/petroleum ether); UV−vis (MeOH) λ_{max}nm (log ϵ) 228 (4.27), 278 (4.17); IR (film) 3418, 2973, 2929, 1757, 1728, 1680 cm^{-1}; 500 MHz ^{1}H NMR ($CDCl_3$) δ 1.51 (s, 9H), 1.56 (s, 9H), 1.84 (s, 3H), 2.02 (s, 3H), 2.31 (m, 1H), 2.40 (t, J = 8.3 Hz, 2H), 2.48 (m, 2H), 2.74 (m, 1H), 2.85 (m, 1H), 2.93 (m, 1H), 3.67 (s, 3H), 4.32 (d, J = 2.9 Hz, 1H), 4.68 (d, J = 3.6 Hz, 1H), 5.59 (m, 1H), 7.23 (d, J = 8.8 Hz, 2H), 7.36 (d, J = 8.3 Hz, 2H); 125 MHz ^{13}C NMR ($CDCl_3$) δ 8.90, 14.67, 20.88, 24.49, 24.59, 28.28, 28.54, 35.23, 51.75, 67.36, 67.80, 81.60, 83.59, 117.73, 119.49, 128.19, 129.04, 129.42, 130.00, 133.01, 133.29, 133.51, 150.31, 153.79, 161.74, 168.38, 173.70. Anal. Calcd For $C_{33}H_{43}ClN_2O_8Se$: C, 55.82; H, 6.10; N, 3.94. Found: C, 56.05; H, 6. 09; N, 3.87, relative stereochemistry not assigned.

5-[[1-*tert*-Butoxycarbonyl-4-[2-(4-chlorophenylselanyl)-ethyl]-3-methyl-5-oxo-2,5-dihydro-1*H*-pyrrol-2-yl]hydroxymethyl]-3-(2-methoxycarbonylethyl)-4-methyl-1*H*-pyrrole-2-carboxylic Acid, *tert*-Butyl Ester 18d. Column chromatography afforded **18d** as a pale yellow solid: mp 76−8 °C; R_f = 0.35 (silica gel, 30% EtOAc/petroleum ether); UV−vis (MeOH) λ_{max}nm (log ϵ) 220 (4.32), 280 (4.32); IR (film) 3415, 2971, 2929, 1758, 1728, 1680, 1659 cm^{-1}; 500 MHz ^{1}H NMR ($CDCl_3$) δ 1.39 (s, 3H), 1.56 (s, 9H), 1.58 (s, 9H), 2.05 (s, 3H), 2.51 (t, J = 8.4 Hz, 2H), 2.56 (t, J = 7.0 Hz, 2H), 2.88−3.08 (m, 4H), 3.66 (s, 3H), 4.63 (s, 1H), 4.72 (br s, 1H), 5.56 (s, 1H), 7.190 (d, J = 8.4 Hz, 2H), 7.36 (d, J = 8.8 Hz, 2H), 9.35 (s, 1H); 125 MHz ^{13}C NMR ($CDCl_3$) δ 9.58, 13.31, 20.89, 24.78, 25.00, 28.45, 28.64, 35.33, 551.67, 66.60, 67.20, 81.43, 83.94, 114.92, 118.67, 128.27, 129.33, 129.82, 130.27, 132.97, 133.32, 133.40, 150.32, 152.96, 161.46, 169.40, 173.79. Anal. Calcd For $C_{33}H_{43}ClN_2O_8Se$; C, 55.82; H, 6.10; N, 3.94. Found: C, 55.95; H, 6.13; N, 3.98, relative stereochemistry not assigned.

3-[5-[4-[2-(4-Chlorophenylselanyl)ethyl]-3-methyl-5-oxo-1,5-dihydropyrrol-2-ylidenemethyl]-4-methyl-1*H*-pyrrol-3-yl]propionic Acid, Methyl Ester (19). A mixture consisting of 1.00 g (1.21 mmol, 1.00 equiv) of silanyloxypyrromethanes **18a** and **18b** and 860 mg (1.21 mmol, 1.00 equiv) of hydroxypyrromethanes **18c** and **18d** was treated with 27.6 g (18.6 mL, 242 mmol, 100 equiv) of neat TFA under Ar at 23 °C. The resulting deep red solution was kept at room temperature for 8 h and was then partitioned between 50 mL of ice-cold H_2O and 50 mL of CH_2Cl_2. The aqueous layer was extracted with CH_2Cl_2, and the combined organic extracts were washed with 2 × 20 mL of H_2O and saturated $NaHCO_3$, dried over anhydrous Na_2SO_4, concentrated under reduced pressure, and chromatographed (silica gel, 30% EtOAc/petroleum ether) to afford 1.15 g (96%) of pyrromethenone **19** as a yellow-green solid. Recrystallization from EtOAc/petroleum ether afforded **19** as yellow/green needles: mp 168−69 °C; R_f 0.55 (silica gel, 50% EtOAc/petroleum ether); UV−vis (MeOH) λ_{max}nm (log ϵ) 206 (4.16), 226 (4.02), 270 (3.85), 400 (4.44); IR (film) 3372, 2920, 1728, 1699, 1637, 1606 cm^{-1}; 500 MHz ^{1}H NMR ($CDCl_3$) δ 2.13 (s, 3H), 2.17 (s, 3H), 2.56 (t, J = 7.3 Hz, 2H), 2.78 (t, J = 7.3 Hz, 2H), 2.84 (t, J = 7.3 Hz, 2H), 3.20 (t, J = 7.3 Hz, 2H), 3.70 (s, 3H), 6.19 (s, 1H), 6.76 (d, J = 2.7 Hz, 1H), 7.13 (d, J = 8.6 Hz, 2H), 7.38 (d, J = 8.5 Hz, 2H), 10.34 (s, 1H), 11.01 (s, 1H); 125 MHz ^{13}C NMR ($CDCl_3$) δ 9.65, 10.24, 20.94, 25.10, 26.78, 35.01, 51.83; 102.57, 121.32, 123.18, 124.44, 124.59, 126.63, 128.53, 129.32, 129.51, 133.11, 133.95, 143.04, 173.63, 173.88. Anal. Calcd for $C_{23}H_{25}ClN_2O_3Se$: C, 56.16; H, 5.12; N, 5.70. Found: C, 55.88; H, 5.11; N, 5.67.

3-[5-[4-[2-(4-Chlorophenylselanyl)ethyl]-3-methyl-5-oxo-1,5-dihydropyrrol-2-ylidenemethyl]-2-formyl-4-methyl-1*H*-pyrrol-3-yl]propionic Acid, Methyl Ester (20). A degassed solution consisting of 1.04 g (1.07 mL, 9.76 mmol, 40.0 equiv) of trimethylorthoformate (TMOF) in 30 mL of freshly distilled CH_2Cl_2 was treated with 2.23 g (1.50 mL, 19.5 mmol, 80.0 equiv) of anhydrous TFA and was kept for 20 min at 23 °C under an Ar atmosphere. The reaction was then treated dropwise with vigorous stirring with a solution of 120 mg (0.244 mmol, 1.00 equiv) of pyrromethenone **19** in 10 mL of CH_2Cl_2. The resulting yellow-green solution was stirred for an additional 10 min following addition and was then partitioned between 15 mL of 10% $NaHCO_3$ and 15 mL of CH_2Cl_2. The aqueous layer was extracted with CH_2Cl_2, and the combined organic extracts were washed with 10 mL of H_2O, dried over anhydrous Na_2SO_4, concentrated under reduced

pressure, and chromatographed (silica gel, 30% EtOAc/petroleum ether) to afford 91 mg (72%) of **20** as a yellow-green solid. Recrystallization from EtOAc/petroleum ether afforded **20** as yellow-green needles: mp 180−80.5 °C; R_f 0.45 (silica gel, 40% EtOAc/petroleum ether); UV−vis (MeOH) λ_{max}nm (log ϵ) 206 (4.16), 270 (4.25), 398 (4.35); IR (film) 3345, 2939, 2854, 1732, 1694, 1662 cm^{-1}; 500 MHz ^{1}H NMR ($CDCl_3$) δ 2.08 (s, 3H), 2.15, (s, 3H), 2.62 (t, J = 7.6 Hz, 2H), 2.88 (t, J = 7.1 Hz, 2H), 3.10 (t, J = 7.6 Hz, 2H), 3.15 (t, J = 7.4 Hz, 2H), 3.67 (s, 3H), 5.97 (s, 3H), 7.14 (d, J = 8.5 Hz, 2H), 7.38, (d, J = 8.5 Hz, 2H), 9.74 (s, 1H), 10.74, (s, 1H), 10.96 (s, 1H); 125 MHz ^{13}C NMR ($CDCl_3$) δ 9.27, 10.28, 19.48, 24.88, 26.63, 35.51, 51.97, 97.23, 124.52, 128.73, 129.26, 130.67, 131.30, 132.83, 132.90, 133.59, 134.64, 136.31, 143.78, 172.99, 173.55, 177.87. Anal. Calcd For $C_{24}H_{25}ClN_2O_4Se$: C, 55.45; H, 4.85; N, 5.39. Found: C, 55.38; H, 4.85; N, 5.45.

3-[2-Formyl-4-methyl-5-(3-methyl-5-oxo-4-vinyl-1,5-dihydropyrrol-2-ylidenemethyl)-1*H*-pyrrol-3-yl]propionic Acid, Methyl Ester (21). A solution of 61 mg (0.12 mmol, 1.00 equiv) of pyrromethenone **20** in 4.0 mL of freshly distilled CH_2Cl_2 was cooled to −78 °C under Ar and was treated dropwise with vigorous stirring with a solution of 22.3 mg (0.13 mmol, 1.10 equiv) of recrystallized *m*-CPBA in 1.0 mL of CH_2Cl_2. After addition was complete, the reaction was stirred for an additional 1 h at −78 °C and was then treated with 119 mg (49 μL, 1.17 mmol, 10.0 equiv) of freshly distilled triethylamine. After addition was complete, the reaction was allowed to warm slowly to room temperature, and stirring was continued for an additional 2 h. The resulting solution was then partitioned between 5 mL of H_2O and 5 mL of CH_2Cl_2, and the aqueous layer was extracted with CH_2Cl_2. The combined organic extracts were washed with H_2O and saturated brine, dried over anhydrous Na_2SO_4, concentrated under reduced pressure, and chromatographed (silica gel, 30% EtOAc/petroleum ether) to afford 37 mg (96%) of **21** as a yellow-brown solid. Recrystallization from MeOH afforded **21** as yellow-green needles, having identical spectral and physical properties as an authentic sample:[5m] mp 192−92.5 °C; R_f 0.40 (silica gel, EtOAc/petroleum ether); UV−vis (MeOH) λ_{max}nm (log ϵ) 208 (4.12), 280 (4.22), 406 (4.31); IR (film) 3260, 2920, 2850, 1735, 1700, 1630 cm^{-1}; 500 MHz ^{1}H NMR ($CDCl_3$) δ 2.16 (s, 3H), 2.21 (s, 3H), 2.62 (t, J = 7.6 Hz, 2H), 3.10 (t, J = 7.6 Hz, 2H), 3.69 (s, 3H), 5.52 (dd, J_{AX} = 11.7 Hz, J_{BX} = 1.5 Hz, H_X), 6.02 (s, 1H), 6.30 (dd, J_{AB} = 17.7 Hz, J_{BX} = 1.5 Hz, H_B), 6.59 (dd, J_{AB} = 17.7 Hz, J_{AX} = 11.7 Hz, H_A), 9.74 (s, CHO), 10.00 (br s, NH), 10.64 (br s, NH). Anal. Calcd for $C_{18}H_{20}N_2O_4$: C, 65.84; H, 6.14; N, 8.53. Found: C, 65.80; H, 6.17; N, 8.49.

3-Butyryloxazolidin-2-one (27). A solution of 5.0 g (0.057 mol, 1.0 equiv) of 2-oxazolidone in 250 mL of THF was cooled to −78 °C under N_2 and was treated dropwise, and with vigorous stirring, with 22.8 mL (0.057 mol, 1.0 equiv) of 2.5 M *n*-BuLi/hexanes over a period of 10 min. The resulting solution was stirred at −78 °C for an additional 15 min and was then treated dropwise with 5.9 mL (0.057 mol, 1.0 equiv) of butyryl chloride over a period of 5 min. After addition was complete, the reaction mixture was allowed to stir an additional 15 min at −78 °C and was then warmed to 0 °C over a period of 30 min. The reaction was then diluted with 50 mL of 1 M aqueous K_2CO_3, and stirring was continued for 1 h to hydrolyze residual acid chloride. The resulting solution was concentrated under reduced pressure and extracted with CH_2Cl_2, and the combined organic extracts were dried over anhydrous Na_2SO_4, concentrated under reduced pressure, and chromatographed (silica gel, 30% EtOAc/hexanes) to afford 6.6 g (74%) of **27** as colorless needles: mp 39−40 °C (from EtOAc); R_f 0.35 (silica gel, 30% EtOAc/hexanes); IR (CCl_4) 2967, 1779, 1715 cm^{-1}; ^{1}H NMR ($CDCl_3$) δ 0.97 (t, J = 8.0 Hz, 3H), 1.68 (m, 2H), 2.88 (t, J = 8.0 Hz, 2H), 4.0 (t, J = 9.0 Hz, 2H), 4.39 (t, J = 9.0 Hz, 2H); ^{13}C NMR ($CDCl_3$) δ 13.5, 17.5, 36.8, 42.3, 61.9, 153.4, 173.1. Anal. Calcd for $C_7H_{11}NO_3$: C, 53.49; H, 7.05; N, 8.91. Found: C, 53.44; H, 7.01; N, 8.87.

(±)-*syn*-3-[2-Ethyl-3-methyl-5-(trimethylsilanyl)pent-4-ynoyl]oxazolidin-2-one (28). A solution of 1.97 g (0.013 mol, 2.0 equiv) of oxazolidinone **27** in 75 mL of CH_2Cl_2 was cooled to 0 °C under Ar and was treated dropwise, and with vigorous stirring, with 26.0 mL (0.026 mol, 4.0 equiv) of 1.0 M dibutylboron triflate/CH_2Cl_2 over a period of 5 min. After addition was complete, the reaction was treated with 2.2 mL (0.013 mol, 2.0 equiv) of *N*,*N*-diisopropylethylamine over a period of 5 min. The resulting solution was stirred for an additional 15 min at 0 °C, cooled to −78 °C, and treated with 2.77 g (6.27 mmol, 1.0 equiv) of **26**[5f] in 50 mL of CH_2Cl_2 over a period of 5 min. The reaction mixture was then stirred for an additional 10 min at −78 °C, warmed to 0 °C over 10 min, and quenched with 140 mL of pH 7.0 buffer. The aqueous layer was extracted with CH_2Cl_2, and the combined organic extracts were dried over anhydrous Na_2SO_4, concentrated under reduced pressure, and chromatographed (silica gel, 200 mL of hexane forerun, followed by10% EtOAc/hexanes), to afford 3.5 g (98%) of the cobalt complex of **28**−cobalt complex as a burgundy oil: R_f 0.58 (silica gel, 30% EtOAc/hexanes); IR (CCl_4) 3667, 3627, 2959, 2931, 2831, 2873, 1790, 1741, 1699 cm^{-1}; ^{1}H NMR ($CDCl_3$) δ 0.35 (s, 9H), 0.79 (t, 3H),1.20−1.70 (m, 5H), 1.90−2.00 (m,1H), 3.60−4.00 (m, 3H), 4.40−4.50 (m, 2H).

A solution of 3.5 g (6.2 mmol) of **28**−cobalt complex in 100 mL of acetone was treated portionwise, and with vigorous stirring, with ceric ammonium nitrate (CAN) until all gas evolution ceased. The resulting orange solution was diluted with 100 mL of H_2O and extracted with EtOAc. The combined organic extracts were dried over anhydrous Na_2SO_4, concentrated under reduced pressure, and chromatographed (silica gel, 30% EtOAc/hexanes) to afford 1.7 g (97%) of **28** as a colorless oil: R_f 0.60 (silica gel, 30% EtOAc/hexanes); IR (CCl_4) 2959, 2166, 1787, 1703 cm^{-1}; ^{1}H NMR ($CDCl_3$) δ 0.10 (s, 9H), 0.89 (t, J = 7.0 Hz, 3H), 1.20 (d, J = 6.5 Hz, 3H), 1.35 (m, 1H), 1.69 (m, 1H), 2.71 (m, 1H), 3.90−4.12 (m, 3H), 4.37 (m, 2H); ^{13}C NMR ($CDCl_3$) δ 0.0, 11.4, 17.9, 22.6, 29.4, 42.6, 48.7, 61.5, 84.9, 108.8, 153.1, 175.1. Anal. Calcd for $C_{14}H_{23}NO_3Si$: C, 59.75; H, 8.24; N, 4.98. Found: C, 60.12; H, 8.57; N, 4.59.

(±)-*syn*-2-Ethyl-3-methylpent-4-ynoic Acid (29). A solution of 1.43 g (5.08 mmol, 1.0 equiv) of **28** in 90 mL of 3:1 THF/H_2O, containing 4.6 mL (0.041 mol, 8.0 equiv) of 30% H_2O_2, was treated dropwise at 0 °C, with vigorous stirring, with a solution of 0.42 g (0.01 mol, 2.0 equiv) of LiOH·H_2O in 5 mL of H_2O over a period of 5 min. After addition was complete, the reaction mixture was stirred at 0 °C for an additional 40 min, at which time no starting material was detectable by TLC. The reaction was then treated with a solution of 5.74 g (0.046 mol, 8.8 equiv) of Na_2SO_3 in 10 mL of H_2O and concentrated under reduced pressure. The remaining aqueous solution was diluted with 30 mL of saturated $NaHCO_3$ and 20 mL of H_2O and extracted with CH_2Cl_2. The aqueous layer was then acidified to pH 1.0 with concentrated HCl and extracted with EtOAc. The combined EtOAc extracts were dried over anhydrous Na_2SO_4, concentrated to dryness under reduced pressure, and chromatographed (silica gel, 50% EtOAc/hexanes) to afford 0.48 g (67%) of acid **29** as a colorless oil: R_f 0.75 (silica gel, EtOAc); IR (CCl_4) 3307, 2966, 2878, 1737, 1711 cm^{-1}; ^{1}H NMR ($CDCl_3$) δ 1.0 (t, J = 8.0 Hz, 3H), 1.25 (d, J = 7.0 Hz, 3H), 1.73 (m, 2H), 2.11 (d, J = 2.5 Hz, 1H), 2.32−2.45 (m, 1H), 2.75−2.86 (m, 1H); ^{13}C NMR ($CDCl_3$) δ 11.7, 17.7, 22.0, 27.5, 51.9, 69.7, 85.7, 180.0; exact mass calcd for $C_8H_{12}O_2$ 140.0837, found 140.0811.

(±)-*syn*-2-Ethyl-3-methylpent-4-ynoic Acid Amide (30). A solution of 0.31 g (2.2 mmol, 1.1 equiv) of alkyne acid **29** in 35 mL of THF, and 0.28 mL (2.0 mmol, 1.0 equiv) of NEt_3, was cooled to 0 °C under N_2, and was treated dropwise, with vigorous stirring, with 0.26 mL (2.0 mmol, 1.0 equiv) of isobutyl chloroformate over a period of 5 min. The resulting solution was stirred at 0 °C for an additional 40 min. The solution was then cooled to −78 °C, and NH_3, generated from NH_4OH dried through a $CaCl_2$ drying tube, was bubbled into the solution for 1 h. The reaction was then allowed to warm to room temperature and stirred overnight before concentrating to dryness under reduced pressure. The residue was taken up in 50 mL of H_2O and 50 mL of EtOAc, and the aqueous layer was extracted with EtOAc. The combined organic extracts were dried over anhydrous Na_2SO_4, concentrated

under reduced pressure, and chromatographed (silica gel, EtOAc) to afford 0.25 g (90%) of **30**. Recrystallization from EtOAc/hexanes afforded colorless needles: mp 81−82 °C; R_f 0.61 (silica gel, EtOAc); IR (CCl_4) 3514, 3398, 3309, 2968, 2360, 1693, cm^{-1}; ^1H NMR ($CDCl_3$) δ 1.06 (t, J = 8.0 Hz, 3H), 1.35 (d, J = 7.0 Hz, 3H), 1.70−1.85 (m, 2H), 2.23 (m, 1H), 2.28 (d, J = 2.5 Hz, 1H), 2.83 (dt, J = 7.0, 3.0 Hz, 1H), 5.42 (br s, 1H), 5.99 (br s, 1H); ^{13}C NMR ($CDCl_3$) δ 11.9, 18.4, 23.8, 27.7, 53.7, 70.7, 86.3, 176.6. Anal. Calcd for $C_8H_{13}NO$: C, 69.03; H, 9.41. Found: C, 68.90; H, 9.38.

(±)-5-(4-Carbamoyl-3-methylhex-1-ynyl)-3-(2-methoxycarbonylethyl)-4-methyl-1*H*-pyrrole-2-carboxylic Acid, *tert*-Butyl Ester (31). A flame-dried flask was cooled to room temperature under an inert atmosphere and was charged with 39 mg (0.20 mmol, 0.2 equiv) of CuI, 0.12 g (0.102 mmol, 0.1 equiv) of $Pd(PPh_3)_4$, and a solution of 0.4 g (1.02 mmol, 1.0 equiv) of iodopyrrole **22** in 2 mL of DMF containing 0.43 mL (3.06 mmol, 3 equiv) of NEt_3. The resulting solution was then treated with 0.16 g (1.1 mmol, 1.1 equiv) of **30** in 2 mL of DMF, and the reaction was degassed thoroughly by five freeze−thaw cycles employing Ar and stirred for 19 h at room temperature under Ar. At the end of this period the reaction was filtered through Celite, washed with 100 mL of EtOAc, and concentrated under reduced pressure. The residue was partitioned between 30 mL of 5% $NaHCO_3$ and 30 mL of CH_2Cl_2, and the aqueous layer was extracted with CH_2Cl_2. The combined organic extracts were washed with 20 mL of H_2O, dried over anhydrous Na_2SO_4, concentrated under reduced pressure, and chromatographed (silica gel, 50% acetone/hexanes) to afford 0.41 g (99%) of **31**. Recrystallization from EtOAc/hexanes afforded **31** as yellow plates: mp 112−13 °C; R_f 0.58 (silica gel, 50% acetone/hexanes); IR (CCl_4) 3453, 2976, 2933, 2876, 2360, 1741, 1687, 1585 cm^{-1}; ^1H NMR ($CDCl_3$) δ 1.02 (t, J = 8.0 Hz, 3H), 1.35 (d, J = 7.0 Hz, 3H), 1.57 (s, 9H), 1.74 (m, 2H), 2.06 (s, 3H), 2.23 (m, 1H), 2.53 (t, J = 8.0 Hz, 2H), 2.98 (t, J = 8.0 Hz, 2H), 3.0 (m, 1H), 3.69 (s, 3H), 5.42 (s, 1H), 5.84 (s, 1H), 8.74 (s, 1H); ^{13}C NMR ($CDCl_3$) δ 9.5, 12.0, 18.7, 20.8, 23.9, 28.4, 28.9, 34.9, 51.5, 54.2, 74.0, 81.2, 96.4, 114.7, 120.2, 124.6, 127.8, 160.2, 173.5, 176.4; exact mass calcd for $C_{22}H_{32}N_2O_5$ 404.2311, found 404.2340.

(±)-5-(4-Ethyl-3-methyl-5-oxopyrrolidin-2-ylidenemethyl)-3-(2-methoxycarbonylethyl)-4-methyl-1*H*-pyrrole-2-carboxyl-ic acid, *tert*-butyl ester (25). A solution of 0.25 g (0.62 mmol) of alkyne amide **34** in 20 mL of degassed CH_3CN was treated dropwise at room temperature, with vigorous stirring, with 3.7 mL (3.7 mmol, 6 equiv) of 1 M n-Bu_4NF/THF. After addition was complete, the reaction was heated at refux for 3 h under Ar and then concentrated to dryness under reduced pressure. The residue was partitioned between 10 mL of H_2O and 10 mL of EtOAc, and the aqueous layer was extracted with EtOAc. The combined organic extracts were dried over anhydrous Na_2SO_4, concentrated under reduced pressure, and chromatographed (silica gel, 40% acetone/hexanes) to afford 0.15 g (60%) of **25** as a yellow oil: R_f 0.42 (silica gel, 30% acetone/hexanes); IR (CCl_4) 3453, 3338, 2965, 2930, 2874, 1739, 1677 cm^{-1}; ^1H NMR ($CDCl_3$) δ 1.00 (t, J = 7.0 Hz, 3H), 1.30 (d, J = 8.0 Hz, 3H), 1.51 (s, 9H), 1.61 (m, 1H), 1.81 (m, 1H), 1.93 (s, 3H), 2.15 (m, 1H), 2.49 (t, J = 8.0 Hz, 2H), 2.79 (m, 1H), 2.96 (t, J = 8.0 Hz, 2H), 3.65 (s, 3H), 5.23 (d, J = 3.0 Hz, 1H), 7.84 (s, 1H), 8.67 (s, 1H); ^{13}C NMR ($CDCl_3$) δ 9.1, 11.0, 19.6, 20.7, 23.4, 28.3, 35.0, 38.9, 49.9, 51.4, 80.5, 90.4, 117.7, 119.8, 128.3, 128.7, 143.1, 160.8, 173.6, 179.8; exact mass calcd for $C_{22}H_{32}N_2O_5$ 404.2311, found 404.2341.

5-(4-Ethyl-3-methyl-5-oxo-1,5-dihydropyrrol-2-ylidenemethyl)-3-(2-methoxycarbonylethyl)-4-methyl-1*H*-pyrrole-2-carboxylic Acid, *tert*-Butyl Ester (6). A solution of 0.25 g (0.62 mmol, 1.0 equiv) of lactam **25** in 40 mL of benzene was treated at room temperature, with vigorous stirring, with a solution of 0.15 g (0.68 mmol, 1.1 equiv) of DDQ in 5 mL of benzene under N_2. The resulting solution was stirred for 10 min at room temperature, diluted with 40 mL of H_2O, and extracted with CH_2Cl_2. The combined organic extracts were dried over anhydrous Na_2SO_4, concentrated under reduced pressure, and chromatographed (silica gel, 40% acetone/hexanes) to afford 0.18 g (72%) of **6**. Recrystallization from methanol afforded **6** as yellow plates: mp 207−208 °C (lit.[5k,o] mp 206−08 °C); R_f 0.45 (silica gel, 30% acetone/hexanes); IR (CCl_4) 3453, 3331, 2968, 2930, 2874, 1740, 1688 cm^{-1}; ^1H NMR ($CDCl_3$) δ 1.08 (t, J = 7.0 Hz, 3H), 1.56 (s, 9H), 2.06 (s, 3H), 2.10 (s, 3H), 2.40 (q J = 7.0 Hz, 2H), 2.51 (t, J = 8.0 Hz, 2H), 2.98 (t, J = 8.0 Hz, 2H), 3.66 (s, 3H), 5.91 (s, 1H), 8.74 (s, 1H), 9.29 (s, 1H); ^{13}C NMR ($CDCl_3$) δ 9.1, 9.6, 13.5, 16.5, 20.8, 28.2, 35.0, 51.4, 80.8, 97.7, 123.0, 123.1, 127.6, 128.1, 133.1, 134.5, 141.5, 160.4, 173.5, 174.1.

3-(4-Bromobutyryl)oxazolidin-2-one (32). A solution of 3.76 g (0.043 mol, 1.0 equiv) of 2-oxazolidone in 150 mL of THF was cooled to −78 °C under N_2 and was treated dropwise, and with vigorous stirring, with 17.2 mL (0.043 mol, 1.0 equiv) of 2.5 M n-BuLi/hexanes over a period of 10 min. The resulting solution was stirred at −78 °C for an additional 15 min and was then treated dropwise with 6.0 mL (0.050 mol, 1.2 equiv) of 4-bromobutyryl chloride over a period of 5 min. After addition was complete, the reaction was stirred for an additional 15 min at −78 °C and then warmed to 0 °C for 30 min. The resulting solution was diluted with 100 mL of H_2O and extracted with Et_2O. The combined organic extracts were dried over anhydrous $MgSO_4$, concentrated under reduced pressure, and chromatographed (silica gel, 50% EtOAc/hexanes) to afford 6.91 g (68%) of **32** as a light yellow oil: R_f 0.43 (silica gel, 50% EtOAc/hexanes); IR (CCl_4) 2968, 2921, 1792, 1705 cm^{-1}; ^1H NMR ($CDCl_3$) δ 2.21 (m, 2H), 3.10 (t, J = 7.5 Hz, 2H), 3.49 (t, J = 6.5 Hz, 2H), 4.01 (t, J = 8.0 Hz, 2H), 4.42 (t, J = 8.0 Hz, 2H); ^{13}C NMR ($CDCl_3$) δ 27.0, 33.0, 33.4, 42.4, 62.2, 153.5, 171.9; exact mass calcd for $C_7H_{10}NO_3Br$ 235.9922, found 235.9940.

(±)-*syn*-3-[2-(2-Bromoethyl)-3-methyl-5-(trimethylsilanyl)pent-4-ynoyl]oxazolidin-2-one (33). A solution of 1.57 g (6.65 mmol, 2.0 equiv) of 3-(4-bromobutyryl)oxazolidin-2-one **(32)** in 40 mL of CH_2Cl_2 was cooled to 0 °C under Ar and was treated dropwise, with vigorous stirring, with 13.3 mL (0.013 mol, 4.0 equiv) of 1.0 M dibutylboron triflate/CH_2Cl_2 over a period of 5 min. This was followed by dropwise addition of 1.15 mL (6.65 mmol, 2.0 equiv) of *N*,*N*-diisopropylethylamine over a period of 5 min. The resulting solution was stirred for an additional 15 min at 0 °C, cooled to −78 °C, and treated dropwise with 1.50 g (3.33 mmol, 1.0 equiv) of cobalt complex **26**[5f] in 20 mL of CH_2Cl_2 over a period of 5 min. After addition was complete, the reaction was stirred for 10 min at −78 °C and then warmed to 0 °C for 10 min before quenching with 75 mL of pH 7.0 buffer. The organic layer was separated and the aqueous layer was extracted with CH_2Cl_2. The combined organic extracts were dried over anhydrous Na_2SO_4, concentrated under reduced pressure, and chromatographed (silica gel, 200 mL of hexane forerun, 10% EtOAc/hexanes) to afford 1.75 g (99%) of **33**−cobalt complex as a burgundy oil: R_f 0.56 (silica gel, 30% EtOAc/hexanes); IR (CCl_4) 3670, 3630, 2959, 2931, 2873, 2087, 1791, 1742, 1697 cm^{-1}; ^1H NMR ($CDCl_3$) δ 0.4 (s, 9H), 1.3 (d, 3H), 2.2 (m, 1H), 2.55 (m,1H), 3.2−3.5 (m, 3H), 3.6−3.9 (m, 3H), 4.45 (m, 2H).

A solution of 1.75 g (3.31 mmol) of **33**−cobalt complex in 100 mL of acetone was treated portionwise, and with vigorous stirring, with ceric ammonium nitrate (CAN) until all gas evolution ceased. The resulting orange solution was diluted with 50 mL of H_2O and extracted with EtOAc. The combined organic extracts were dried over anhydrous Na_2SO_4, concentrated under reduced pressure, and chromatographed (silica gel, 40% EtOAc/hexanes) to afford 0.95 g (80%) of **33** as colorless needles: mp 69−70 °C (EtOAc/hexanes); R_f 0.49 (silica gel, 30% EtOAc/hexanes); IR (CCl_4) 2962.1, 2168.7, 1793.2, 1741.6, 1698.7 cm^{-1}; ^1H NMR ($CDCl_3$) δ 0.11 (s, 9H), 1.20 (d, J = 7.5 Hz, 3H), 2.19 (m, 1H), 2.36 (m, 1H), 2.80 (m, 1H), 3.29−3.41 (m, 2H), 3.95−4.15 (m, 2H), 4.20 (m, 1H), 4.39 (m, 2H); ^{13}C NMR ($CDCl_3$) δ 0.0, 17.7, 29.5, 30.7, 32.0, 42.7, 46.2, 61.7, 86.1, 107.6, 152.9, 173.7. Anal. Calcd for $C_{14}H_{22}BrNO_3Si$: C, 46.67; H, 6.15; N, 3.89. Found: C, 46.81; H, 6.18; N, 3.84.

(±)-syn**-3-[1-Methyl-3-(trimethylsilanyl)prop-2-ynyl]-tetrahydrofuran-2-one (34).** A solution of 0.50 g (1.39 mmol, 1.0 equiv) of oxazolidinone **33** in 100 mL of 3:1 THF/H_2O, containing 1.25 mL (0.011 mol, 8.0 equiv) of 30% H_2O_2, was

treated dropwise at 0 °C, with vigorous stirring, with a solution of 0.19 g (4.53 mmol, 3.3 equiv) of $LiOH·H_2O$ in 5 mL of H_2O over a period of 1 min. After addition was complete, the reaction mixture was stirred at 0 °C for an additional 5 min, at which time no starting material was detectable by TLC. The reaction was then treated with a solution of 1.55 g (0.012 mol, 8.8 equiv) of Na_2SO_3 in 10 mL of H_2O at 0 °C, and acidified to pH 1 with concentrated HCl (Caution: the reduction and acidification sequence should take no longer than 2 min or the yield of lactone **34** will be reduced). The reaction was then extracted with CH_2Cl_2, and the combined organic extracts were dried over anhydrous Na_2SO_4, concentrated under reduced pressure, and chromatographed (silica gel, 30% EtOAc/hexanes) to afford 0.23 g (79%) of silyl lactone **34** as a colorless oil: R_f 0.49 (silica gel, 30% EtOAc/hexanes); IR (CCl_4) 2962.5, 2168.4, 1779.1 cm^{-1}; ^1H NMR ($CDCl_3$) δ 0.11 (s, 9H), 1.21 (d, J = 6.5 Hz, 3H), 2.19−2.25 (m, 1H), 2.32−2.41 (m, 1H), 2.80 (dt, J = 10.0, 4.5 Hz, 1H), 3.00−3.06 (m, 1H), 4.21 (q, J = 8.0 Hz, 1H), 4.36 (dt, J = 10.0, 5.0 Hz, 1H); ^{13}C NMR ($CDCl_3$) δ 0.0, 16.6, 24.8, 27.0, 43.7, 66.6, 85.9, 107.7, 176.0; exact mass calcd for $C_{11}H_{18}O_2Si$ 210.1076, found 210.1067.

(±)-*syn*-3-(1-Methylprop-2-ynyl)tetrahydrofuran-2-one (35). A solution of 0.16 g (0.76 mmol, 1.0 equiv) of **34** in 15 mL of THF was cooled to 0 °C under N_2, and was treated with vigorous stirring over a period of 10 min with 0.84 mL (0.84 mmol, 1.1 equiv) of 1 M *n*-Bu_4NF/THF. The reaction mixture was then diluted with 10 mL of H_2O and extracted with CH_2Cl_2. The combined organic extracts were dried over anhydrous Na_2SO_4, concentrated under reduced pressure, and chromatographed (silica gel, 30% EtOAc/hexanes) to afford 90 mg (86%) of **35** as a colorless oil: R_f 0.51 (silica gel, 30% EtOAc/hexanes); IR (CCl_4) 3311.8, 2983.3, 2908.3, 1789.3, 1462.8, 1374.2, 1166.4 cm^{-1}; ^1H NMR ($CDCl_3$) δ 1.29 (d, J = 7.5 Hz, 3H), 2.11 (d, J = 2.5 Hz, 1H), 2.22−2.31 (m, 1H), 2.36−2.45 (m, 1H), 2.84 (dt, J = 10.0, 4.0 Hz, 1H), 3.05 (m, 1H), 4.25 (m, 1H), 4.40 (dt, J = 9.0, 3.0 Hz, 1H); ^{13}C NMR ($CDCl_3$) δ 16.6, 24.8, 25.8, 43.6, 66.5, 69.8, 85.2, 176.6. Anal. Calcd for $C_8H_{10}O_2$: C, 69.53; H, 7.30. Found: C, 69.65; H, 7.27.

(±)-*syn*-2-[2-(4-Chlorophenylselanyl)ethyl]-3-methylpent-4-ynoic Acid (36). A solution of 0.26 g (0.69 mmol, 0.6 equiv) of bis(4-chlorophenyl)diselenide and 33 mg (1.38 mmol 1.2 equiv) of NaH in 2.0 mL of dry THF was thoroughly degassed under Ar, heated at reflux for a period of 1.5 h, cooled to room temperature, and treated with a degassed solution of 0.16 g (1.15 mmol, 1.0 equiv) of **35** in 0.1 mL of HMPA. The reaction was then heated at reflux for 3 h, cooled to room temperature, treated with 1.0 mL of MeOH, and concentrated under reduced pressure. The residue was taken up in 4 mL of H_2O and extracted with Et_2O to remove HMPA. The aqueous layer was then acidified to pH 1.0 with 10% HCl, and re-extracted with Et_2O. The latter Et_2O extracts were combined, dried over anhydrous $MgSO_4$, concentrated under reduced pressure, and filtered through a short column (silica gel, 50% EtOAc/hexanes) to afford 0.27 g (72%) of alkyne acid **36** as a light yellow oil: R_f 0.37 (silica gel, 50% acetone/hexane); IR (CCl_4) 3311.0, 2927.3, 1708.1, 1548.7 cm^{-1}; ^1H NMR ($CDCl_3$) δ 1.21 (d, J = 6.0 Hz, 3H), 1.90−2.00 (m, 1H), 2.10 (d, J = 2.5 Hz, 1H), 2.10−2.20 (m, 1H), 2.70−2.75 (m, 1H), 2.82−2.90(m, 2H), 2.98−3.05 (m, 1H), 7.20 (d, J = 8.0 Hz, 2H), 7.43 (d, J = 8.0 Hz, 2H); ^{13}C NMR ($CDCl_3$) δ 17.5, 25.6, 27.7, 28.6, 49.4, 70.3, 85.1, 129.1, 133.9, 179.3; exact mass calcd for $C_{14}H_{15}ClO_2Se$ 329.9926, found 329.9932.

(±)-*syn*-2-[2-(4-Chlorophenylselanyl)ethyl]-3-methylpent-4-ynoic Acid Amide (37). A solution of 0.13 g (0.395 mmol, 1.1 equiv) of **36** in 5 mL of THF and 0.05 mL (0.358 mmol, 1.0 equiv) of NEt_3 was cooled to 0 °C under N_2 and was treated dropwise, with vigorous stirring, with 0.05 mL (0.358 mmol, 1.0 equiv) of isobutylchloroformate over a period of 5 min. The resulting solution was stirred at 0 °C for 40 min, cooled to − 78 °C, and treated with an excess of dry NH_3 (from NH_4OH dried through a $CaCl_2$ drying tube) over a period of 1 h. The reaction solution was then allowed to warm to room temperature and stirred overnight before being concentrated to dryness under reduced pressure. The residue was partitioned between 25 mL of H_2O and 25 mL of EtOAc and extracted with EtOAc. The combined organic extracts were dried over anhydrous Na_2SO_4, concentrated under reduced pressure, and chromatographed (silica gel, 50% acetone/hexanes) to afford 0.11 g (93%) of **37** as a light yellow oil: R_f 0.73 (silica gel, 50% acetone/hexane); IR (CCl_4) 3507, 3310, 2960, 2360, 1698, 1583 cm^{-1}; ^1H NMR ($CDCl_3$) δ 1.21 (d, J = 6.0 Hz, 3H), 1.82−1.95 (m, 1H), 2.00−2.15 (m, 1H), 2.09 (d, J = 2.5 Hz, 1H), 2.35−2.49 (m, 1H), 2.69−2.86 (m, 2H), 2.95−3.09 (m, 1H), 5.80 (s, 1H), 5.99 (s, 1H), 7.21 (d, J = 8.0 Hz, 2H), 7.41 (d, J = 8.0 Hz, 2H); ^{13}C NMR ($CDCl_3$) δ 18.1, 19.0, 25.5, 27.8, 30.3, 70.6, 85.8, 127.6, 129.1, 133.0, 133.9, 175.3; exact mass calcd for $C_{14}H_{16}ClNOSe$ (MSCI M + 1) 330.0165, found 330.0117.

(±)-*syn*-5-[4-Carbamoyl-6-(4-chlorophenylselanyl)-3-methylhex-1-ynyl]-3-(2-methoxycarbonylethyl)-4-methyl-1*H*-pyrrole-2-carboxylic Acid, *tert*-Butyl Ester (38). A flame-dried flask was cooled to room temperature under an inert atmosphere and was charged with 19 mg (0.098 mmol, 0.2 equiv) of CuI, 56 mg (0.049 mmol, 0.1 equiv) of $Pd(PPh_3)_4$, a solution of 0.19 g (0.49 mmol, 1.0 equiv) of iodopyrrole **22** in 2 mL of DMF containing 0.20 mL (1.46 mmol, 3.0 equiv) of NEt_3, and a solution of 0.16 g (0.49 mmol, 1.0 equiv) of alkyne amide **37** in 2 mL of DMF. The reaction was degassed thoroughly by five freeze−thaw cycles employing Ar and stirred for 20 h at room temperature under Ar. At the end of this period, the reaction was filtered through Celite, washed with 100 mL of EtOAc, and concentrated under reduced pressure. The residue was partitioned between 15 mL of 10% aqueous $NaHCO_3$ and 15 mL of CH_2Cl_2 and stirred for 10 min. The mixture was then extracted with CH_2Cl_2, and the organic extracts were washed with 20 mL of H_2O, dried over anhydrous Na_2SO_4, concentrated under reduced pressure, and chromatographed (silica gel, 50% acetone/hexanes) to afford 0.27 g (93%) of **38** as a yellow oil: R_f 0.67 (silica gel, 50% acetone/hexane); IR (CCl_4) 3450, 2975, 1741, 1691, 1580 cm^{-1}; ^1H NMR ($CDCl_3$) δ 1.25 (d, J = 7.0 Hz, 3H), 1.53 (s, 9H), 1.85−1.95 (m, 2H), 2.00 (s, 3H), 2.10 (m, 1H), 2.49 (t, J = 8.0 Hz, 2H), 2.80 (m, 1H), 2.95 (t, J = 8.0 Hz, 2H), 2.95−3.03 (m, 2H), 3.65 (s, 3H), 5.88 (s,1H), 5.98 (s, 1H), 7.17 (d, J = 8.5 Hz, 2H), 7.39 (d, J = 8.5 Hz, 2H0, 9.1 (s, 1H); ^{13}C NMR ($CDCl_3$) δ 9.6, 18.4, 19.0, 20.8, 27.9, 28.4, 29.0, 34.8, 51.5, 71.3, 74.3, 81.3, 96.0, 114.3, 120.3, 124.9, 127.5, 127.8, 129.2, 133.3, 134.0, 157.3, 160.1, 173.5; exact mass calcd for $C_{28}H_{35}ClN_2O_5Se$ 594.1400, found 594.1393.

(±)-*trans*-5-[4-[2-(4-Chlorophenylselanyl)ethyl]-3-methyl-5-oxopyrrolidin-2-ylidenemethyl]-3-(2-methoxycarbonylethyl)-4-methyl-1*H*-pyrrole-2-carboxylic Acid, *tert*-Butyl Ester (39). A solution of 38 mg (0.007 mmol, 1.0 equiv) of **38** in 4 mL of degassed CH_3CN was treated at room temperature, with vigorous stirring, with 0.38 mL (0.04 mmol, 6 equiv) of 1 M *n*-Bu_4NF/THF and was then heated at refux for 3.5 h under Ar. The reaction was then concentrated under reduced pressure, and the residue was partitioned between 10 mL of H_2O and 10 mL of EtOAc. The aqueous layer was extracted with EtOAc, and the combined organic extracts were dried over anhydrous Na_2SO_4, concentrated under reduced pressure, and chromatographed (silica gel, 50% acetone/hexanes) to afford 23 mg (61%) of **39** as a yellow oil: R_f 0.79 (silica gel, 50% acetone/hexane); IR (CCl_4) 3449, 2958, 2929, 2872, 1739, 1717, 1685 cm^{-1}; ^1H NMR ($CDCl_3$) δ 1.29 (d, J = 7.5 Hz, 3H), 1.52 (s, 9H), 1.80−2.12 (m, 2H), 1.91 (s, 3H), 2.38 (q, J = 7.0 Hz, 1H), 2.49 (t, J = 8.5 Hz, 2H), 2.71 (m, 1H), 2.90−3.12 (m, 4H), 3.65 (s, 3H), 5.25 (s, 1H), 7.20 (d, J = 8.5 Hz, 2H), 7.40 (d, J = 8.5 Hz, 2H), 7.99 (s, 1H), 8.78 (s, 1H); ^{13}C NMR ($CDCl_3$) δ 9.2, 14.1, 19.1, 20.7, 25.0, 28.4, 31.1, 35.0, 39.6, 48.2, 51.5, 80.8, 90.8, 118.0, 120.0, 127.8, 128.1, 129.2, 133.1, 133.9, 142.5, 158.5, 160.9, 173.6; exact mass calcd for $C_{28}H_{35}IN_2O_5Se$ 594.1400, found 594.1289.

5-[4-[2-(4-Chlorophenylselanyl)ethyl]-3-methyl-5-oxo-1,5-dihydropyrrol-2-ylidenemethyl]-3-(2-methoxycarbonylethyl)-4-methyl-1*H*-pyrrole-2-carboxylic Acid, *tert*-Butyl Ester (40). A solution of 64 mg (0.11 mmol, 1.0 equiv) of **39** in 20 mL of benzene was treated at room temperature, with vigorous stirring, with a solution of 27 mg (0.12 mmol, 1.1 equiv) of DDQ in 5 mL of benzene under N_2. The reaction

was stirred for an additional 10 min at room temperature, diluted with 20 mL of H_2O, and extracted with CH_2Cl_2. The combined organic extracts were dried over anhydrous Na_2SO_4, concentrated under reduced pressure, and chromatographed (silica gel, 50% acetone/hexanes) to afford 50 mg (78%) of **40** as a yellow solid. Recrystallization from CH_2Cl_2/Et_2O/hexanes afforded **7** as yellow plates: mp 194−95 °C (lit.[5m] mp 195 °C); R_f 0.84 (silica gel, 50% acetone/hexane); IR (CCl_4) 3353, 2975, 2929, 1738, 1688, 1648 cm^{-1}; ^{1}H NMR ($CDCl_3$) δ 1.55 (s, 9H), 2.04 (s,3H), 2.09 (s, 3H), 2.51 (t, J = 9.0 Hz, 2H), 2.81 (t, J = 7.0 Hz, 2H), 2.99 (t, J = 9.0 Hz, 2H), 3.11 (t, J = 7.0 Hz, 2H), 3.67 (s, 3H), 5.97 (s, 1H), 7.12 (d, J = 8.0 Hz, 2H), 7.39 (d, J = 8.0 Hz, 2H), 9.20 (s, 1H), 9.45 (s, 1H).

***Z*-1-(2-oxo-4,5-dihydrofuran-3-ylidene)trifluoromethanesulfonic Acid Ethyl Ester (42).** A solution of 7.26 g (6.1 mL, 0.057 mol) of 2-acetylbutyrolactone (**41**) in 250 mL of freshly distilled anhydrous THF was cooled to −78 °C under Ar using a dry ice/acetone bath. This solution was then treated dropwise, with efficient stirring, with 22.6 mL (0.057 mol, 1.0 equiv) of a 2.5 M solution of *n*-BuLi in hexanes over a period of 10 min. After addition was complete, the resulting white slurry was stirred at −78 °C for an additional 30 min, and then treated with 15.9 g (9.50 mL, 0.057 mol, 1.0 equiv) of trifluoromethanesulfonic anhydride added over a period of 5 min. The resulting yellow solution was stirred at −78 °C for an additional 20 min, quenched by careful addition of 200 mL of ice-cold 1:1 saturated $NaHCO_3$/brine, and extracted with Et_2O. The combined organic extracts were dried over $MgSO_4$, concentrated under reduced pressure, and the residue crystallized from Et_2O to give 7.4 g (50%) of **42** as a colorless crystalline solid: mp 65−66 °C; R_f 0.19 (silica gel, 30% EtOAc/hexanes); IR (CH_2Cl_2) 2964, 1753, 1695 cm^{-1}; ^{1}H NMR ($CDCl_3$) δ 2.19 (s, 3H), 3.03−3.08 (m, 2H), 4.37−4.42 (m, 2H); ^{13}C NMR ($CDCl_3$) δ 20.0, 27.2, 65.1, 118.4, 118.9 (q, J = 318 Hz, CF_3), 150.2, 166.2. Anal. Calcd for $C_7H_7F_3O_5S$: C, 32.31; H, 2.71. Found: C, 32.27; H, 2.74.

***Z*-3-[1-Methyl-3-(trimethylsilanyl)prop-2-ynylidene]-tetrahydrofuran-2-one (43).** A flame dried flask was cooled to room temperature under an inert atmosphere (glovebox), and was charged with 163 mg (0.86 mmol, 0.1 equiv) of CuI, 301 mg (0.43 mmol, 0.05 equiv) of $Pd(Ph_3P)_2Cl_2$, a solution 2.23 g (8.57 mmol, 1.0 equiv) of triflate **42** in 56 mL of THF containing 3.6 mL (25.71 mmol, 3.0 equiv) of NEt_3, and 1.70 mL (12.0 mmol, 1.4 equiv) of trimethylsilylacetylene. The resulting black solution was degassed thoroughly (freeze−thaw) employing Ar and stirred for 2.5 h at room temperature under Ar. At the end of this period, the reaction was diluted with 100 mL of brine and extracted with Et_2O. The combined organic extracts were washed with 10% w/w aqueous NH_4Cl and brine, dried over $MgSO_4$, concentrated under reduced pressure, and chromatographed (silica gel, 20% EtOAc/hexanes) to afford 1.67 g (94%) of **43** as an off-white solid: mp 82−83 °C; R_f 0.38 (silica gel, 30% EtOAc/hexanes); IR (CH_2Cl_2) 2951, 2143, 1752 cm^{-1}; ^{1}H NMR ($CDCl_3$) δ 0.23 (s, 9H), 2.01 (s, 3H), 2.91−2.96 (m, 2H), 4.26−4.31 (m, 2H); ^{13}C NMR ($CDCl_3$) δ 0.2, 23.4, 28.4, 64.6, 103.2, 107.2, 128.4, 130.4, 168.6. Anal. Calcd for $C_{11}H_{16}O_2Si$: C, 63.41; H, 7.74. Found: C, 63.17; H, 7.75.

***Z*-2-[2-(4-Chlorophenylselanyl)ethyl]-3-methylpent-2-en-4-ynoic Acid (44).** A degassed solution of 2.74 g (7.20 mmol, 0.50 equiv) of bis(4-chlorophenyl)diselenide and 576 mg (14.4 mmol, 1.0 equiv) of 60% NaH/mineral oil in 30 mL of anhydrous THF was heated at reflux under Ar for a period of 1.5 h, cooled to room temperature, and treated portionwise with 3.00 g (14.40 mmol, 1.0 equiv) of lactone **43**. The resulting black solution was then heated at reflux for 4 h, cooled to room temperature, and quenched by careful dropwise addition of 1 mL of MeOH, resulting in effervescence. The solution was then concentrated under reduced pressure, and the resulting black oil was dissolved in H_2O and extracted with Et_2O to remove selenide byproducts. The aqueous layer was acidified to pH 1 using 10% HCl and re-extracted with Et_2O. The combined Et_2O extracts were dried over $MgSO_4$ and concentrated under reduced pressure to afford an orange oil that was used directly for the synthesis of amide **45** (below). Chromatography (silica gel, 20% EtOAc/hexanes, increasing to 100% EtOAc) afforded **39** as an unstable tan solid: ^{1}H NMR ($CDCl_3$) δ 2.28 (s, 3H), 2.92−3.12 (m, 4H), 3.45 (s, 1H), 7.20−7.60 (m, 4H).

***Z*-2-[2-(4-Chlorophenylselanyl)ethyl]-3-methylpent-2-en-4-ynoic Amide (45).** The crude acid **44** from above was taken up in 5.0 mL of $(COCl)_2$, and the resulting solution was stirred overnight at room temperature. The excess $(COCl)_2$ was then removed under reduced pressure, and the residue was dissolved in 15 mL of freshly distilled anhydrous THF. The resulting solution was added dropwise, with vigorous stirring, to 120 mL of ice-cold 30% aqueous NH_4OH. The resulting suspension was stirred at 0 °C for 15 min and then extracted with EtOAc. The combined organic layers were washed with H_2O and brine, dried over $MgSO_4$, concentrated under reduced pressure, and chromatographed (silica gel, 5:1 CH_2Cl_2/EtOAc) to afford 2.3 g (49%) of amide **45** as a yellow solid. Recrystallization from CH_2Cl_2 afforded **45** as a colorless crystalline solid: mp 128−130 °C; R_f 0.17 (silica gel, 40% EtOAc/hexanes); IR (CH_2Cl_2) 3371, 3295, 3180, 1643, 1600 cm^{-1}; ^{1}H NMR ($CDCl_3$) δ 2.01 (s, 3H), 2.90 (t, J = 7.7 Hz, 2H), 3.06, (t, J = 7.7 Hz, 2H), 3.18 (s, 1H), 5.60 (br s, 1H), 6.00, (br s, 1H), 7.20−7.50 (m, 4H); ^{13}C NMR ($CDCl_3$) δ 20.97, 26.24, 34.13, 82.83, 84.73, 84.78, 120.55, 128.42, 129.73, 134.70, 142.79, 171.54. Anal. Calcd for $C_{14}H_{14}ClNOSe$: C, 51.47; H, 4.32; N, 4.29. Found: C, 51.36; H, 4.31; N, 4.20.

***Z*-3-Methyl-2-vinylpent-2-en-4-ynoic Acid Amide (46).** A solution of 500 mg (1.53 mmol, 1.0 equiv) of alkyne amide **45** in 20 mL of THF was diluted with 2 mL of H_2O and 0.4 mL of HOAc. The resulting solution was then treated dropwise, and with efficient stirring, with 1.74 mL (15.30 mmol, 10.0 equiv) of 30% aqueous H_2O_2. After being stirred for a total of 50 min at room temperature, the initial brown solution had turned to bright yellow. The reaction was then poured into 50 mL of saturated aqueous $NaHCO_3$ and extracted with Et_2O. The combined Et_2O extracts were washed with brine, dried over $MgSO_4$, and concentrated under reduced pressure to afford 204 mg (98%) of **46** as an unstable yellow oil (*Caution*: do not concentrate completely to dryness or the residue may decompose exothermically). Amide **46** is labile to polymerization and is best used immediately without further purification: R_f 0.34 (silica gel, 40% acetone/hexanes); ^{1}H NMR ($CDCl_3$) δ 2.03 (s, 3H), 3.39 (s, 1H) 5.33 (d, J = 11 Hz, 1H), 5.44 (d, J = 17 Hz, 1H), 5.85 (br s, 1H), 6.60 (br s, 1H), 6.92 (dd, J = 11 Hz, 17 Hz, 1H).

***Z*-5-[4-Carbamoyl-6-(4-chlorophenylselanyl)-3-methylhex-3-en-1-ynyl]-3-(2-methoxycarbonylethyl)-4-methyl-1*H*-pyrrole-2-carboxylic Acid, *tert*-Butyl Ester (47).** This material was prepared following an identical procedure to that described above for ester **38**, utilizing 1.00 g (2.54 mmol) pyrrole **22**, 1.25 g (3.82 mmol) amide **45** in 10 mL of DMF/1.0 mL of Et_3N, 293.9 mg (0.254 mmol) $Pd(Ph_3P)_4$, and 96.9 mg (0.509 mmol) CuI. The reaction mixture was thoroughly degassed and stirred at room temperature under argon for 24 h. After this period, the reaction was quenched with saturated NH_4Cl and extracted with EtOAc. The combined extracts were washed with H_2O and brine, dried over anhydrous $MgSO_4$, concentrated under reduced pressure, and chromatographed (silica gel, 2:1 hexanes/acetone) to afford 1.37 g (91%) of amide **47** as a yellow solid: mp 149−50 °C; R_f 0.42 (silica gel, 50% acetone/hexanes); IR (CH_2Cl_2) 3427, 3341, 3179, 2978, 2930, 2854, 2194, 1738, 1724, 1662 cm^{-1}; ^{1}H NMR ($CDCl_3$) δ 1.58 (s, 9H), 2.04 (s, 3H), 2.10 (s, 3H), 2.55 (t, J = 8.0 Hz, 2H), 2.93−3.03 (m 4H), 3.11 (t, J = 7.7 Hz, 2H), 3.68 (s, 3H), 5.64 (br s, 1H), 5.92 (br s, 1H), 7.11 (d, J = 8.4 Hz, 2H), 7.41 (d, J = 8.4 Hz, 2H), 8.86 (br s, 1H); ^{13}C NMR ($CDCl_3$) δ 10.3, 21.1, 21.3, 26.5, 28.9, 34.4, 35.4, 52.0, 82.1, 88.3, 94.0, 114.5, 121.7, 122.2, 126.8, 128.5, 128.6, 129.7, 133.7, 134.4, 140.5, 160.5, 171.4, 174.0. Anal. Calcd for $C_{28}H_{33}ClN_2O_5Se$: C, 56.81; H, 5.62; N, 4.73. Found: C, 56.99; H, 5.69; N, 4.66.

***Z*-5-(4-Carbamoyl-3-methylhexa-3,5-dien-1-ynyl)-3-(2-methoxycarbonylethyl)-4-methyl-1*H*-pyrrole-2-carboxylic Acid, *tert*-Butyl Ester (48). Method A.** This material was prepared following an identical procedure to that described above for ester **38**, utilizing iodopyrrole **22** and alkyne amide **46**. On small scales amide **48** was obtained in 90−95%

yield as a yellow solid: mp 155−56 °C dec; R_f 0.29 (silica gel, 40% acetone/hexanes); IR ($CDCl_3$) 3439, 3323, 3187, 2983, 2185, 1733, 1670 cm^{-1}; ^1H NMR ($CDCl_3$) δ 1.57 (s, 9H), 2.11 (s, 6H), 2.53 (t, J = 8.0 Hz, 2H), 3.00 (t, J = 8.0 Hz, 2H), 3.68 (s, 3H), 5.34 (d, J = 11 Hz, 1H), 5.46 (d, J = 17 Hz, !H), 5.62 (br s, 1H), 5.79 (br s, 1H), 6.95 (dd, J = 11,17 Hz, 1H), 8.80 (br s, 1H). Anal. Calcd for $C_{22}H_{28}N_2O_5$: C, 65.98; H, 7.05; N, 7.00. Found: C, 65.86; H, 7.01; N, 6.92.

Method B. A solution of 1.30 g (2.20 mmol) of amide **47** in 20 mL of THF was diluted with 2.0 mL of H_2O and 0.4 mL of HOAc and was treated dropwise, with vigorous stirring, with 2.5 mL of 30% aqueous H_2O_2. After being stirred for a total of 1 h at room temperature, the reaction was poured into saturated aqueous $NaHCO_3$ and extracted with Et_2O. The combined extracts were washed with brine, dried over anhydrous $MgSO_4$, concentrated under reduced pressure, and chromatographed (silica gel, 3:2 hexanes/acetone) to afford 792 mg (90%) of amide **48** as a yellow solid, identical in all respects to the material prepared following method A above.

3-(2-Methoxycarbonylethyl)-4-methyl-5-(3-methyl-5-oxo-4-vinyl-1,5-dihydropyrrol-2-ylidenemethyl)-1*H*-pyrrole-2-carboxylic Acid, *tert*-Butyl Ester (7). A mixture of 100.0 mg (0.250 mmol) of alkyne amide **48** and 189.6 mg (1.25 mmol) of CsF in 5.0 mL of dry THF was treated with 0.74 mL (4.99 mmol) of $Si(OMe)_4$, and the resulting mixture was heated at reflux under Ar for a period of 6 h. The reaction was then cooled, diluted with CH_2Cl_2, and washed with H_2O. The organic layer (containing suspended material) was filtered through Hyflo-Super Cel, dried over anhydrous $MgSO_4$, concentrated under reduced pressure, and chromatographed (silica gel, hexanes/acetone 3:1) to afford 60.6 mg (60%) of dihydropyrromethenone **7** as a yellow solid, having identical spectral data as an authentic sample:[5m] ^1H NMR ($CDCl_3$) δ 1.56 (s, 9H), 2.10 (s, 3H), 2.19 (s, 3H), 2,53 (t, J = 9.0 Hz, 2 H), 3.01 (t, J = 9.0 Hz, 2H), 3.68 (s, 3H), 5.46 (d, J = 11 Hz,1H), 6.03 (s, 1H), 6.29 (d, J = 17 Hz 1H), 6.57 (dd, J = 11,17 Hz 1H), 8.67 (br s, 1H), 9.20 (br s, 1H); ^{13}C NMR ($CDCl_3$) δ 9.8, 10.4, 21.3, 28.9, 35.5, 52.0, 81.9, 100.0, 120.7, 124.1, 124.4, 126.5, 126.7, 128.2, 129.4, 134.9, 142.3, 161.0, 173.4, 174.1. This material was identical to **7** obtained by oxidative elimination of selenide **40**.[5m]

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Supporting Information Available: Copies of ^1H- and ^{13}C NMR spectra for compounds **6**, **7**, **11**, **14**, **15**, **16**, **17**, **18a**−**d**, **19**, **20**, **21**, **28**−cobalt complex, **33**−cobalt complex, **33**, **36**, **40**, **45**, and **46**. This material is available free of charge via the Internet at http://pubs.acs.org.

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