downshift of ν(Fe–O) of the oxyferryl fragment. It should be noted that Spiro and co-workers[25] have recently observed an *upshift* of ν(V–O) of vanadyloctaethylporphine [OV(OEP)] upon formation of [OV(OEP$^+$)$^+$]. This complex forms an "a_{1u}-like" radical while HRP-I and [OFe(TMP$^+$)$^+$] are best characterized as "a_{2u}-like".[12,26] While further studies will be needed to evaluate this issue, the weakening of Fe–O in "a_{2u}-like" and strengthening in "a_{1u}-like" radicals may prove to hold generally. Thus, the inherent reactivity of the Fe–O fragment in the enzyme systems may be indirectly controlled by any steric and environmental factors which affect the orbital character of the metalloporphyrin radical fragment.

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Activation of Methane by the Reactive Intermediate Tris(trimethylphosphine)osmium(0)

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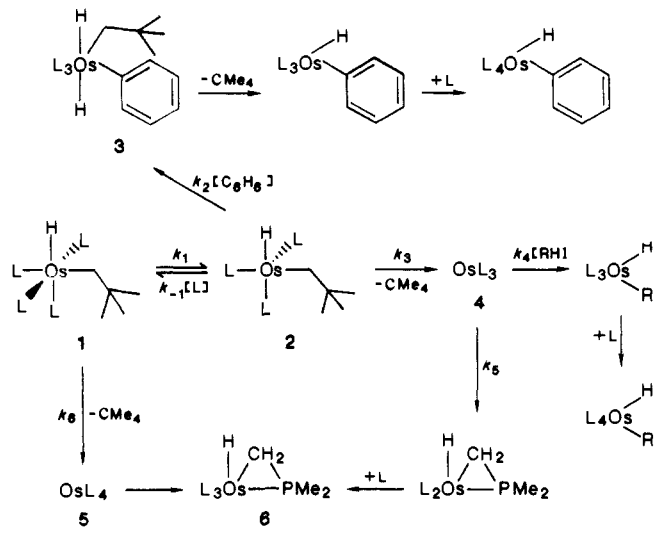
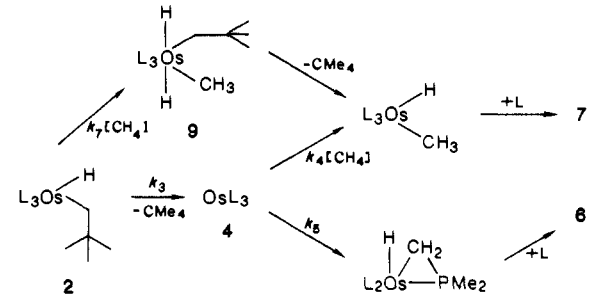
The activation of hydrocarbon C–H bonds by soluble metal complexes has been a significant goal of organometallic chemists for two decades. In the past few years substantial progress has been made.[1,2] We have recently described the mild intermolecular activation of carbon–hydrogen bonds in benzene by intermediates generated in the thermolysis of *cis*-$L_4Os(H)(CH_2CMe_3)$, L = $P(CH_3)_3$, **1**.[3] We have also studied the activation of C–H bonds in $SiMe_4$, in the benzylic position of mesitylene, and intramolecularly in L.[4,5] A summary of the essential features of our conclusions is shown in Scheme I.

While the intermediate L_3Os (**4**) is intercepted by $SiMe_4$ to afford *cis*-$L_4Os(H)(CH_2SiMe_3)$, **8**, and by mesitylene to give only benzylic C–H activation, it does not afford an isolable alkyl hydride complex from reaction with any alkane solvent that we have used, including pentane, cyclopentane, hexane, cyclohexane, and octane. We have previously concluded that both dissociation of L from **1**[3] (path 1)[6] and neopentane reductive elimination from **1**[3-5] (path

Scheme I



Scheme II



6) are driven by the steric crowding in **1**. It is possible that even L_3Os is subject to some steric inhibition of reaction with alkanes; hence, the smallest alkane, methane, might have the greatest chance of competing with cyclometalation (path 5) to give C–H activation via path 4. We report here that methane is activated by L_3Os, albeit in low yield, affording **7**. This is one of the first examples of observation of a non-cyclopentadienyl-containing methyl hydride complex from reaction of a soluble complex with methane.[7]

Pyrolysis of **1** in cycloalkane solvent at 80 °C under methane gas at pressures sufficient to give up to ca. 2 M solutions results in formation of a mixture of cyclometalation product **6** and methylhydride **7** as the only significant products with the latter in yields up to ca. 16%.[8] The ^{31}P NMR resonances of **7** are never observed in thermolyses of **1** when methane is absent, and use of ^{13}C-CH_4 yielded (methyl-^{13}C)-**7**.

Methane activation could reasonably proceed by reaction with L_3Os^0, **4**, (path 4), $L_3Os(H)Np$, **2**, (path 7, Scheme II), or L_4Os^0, **5**. Reaction with **5** can be ruled out as follows. We have previously measured k_1 to be 7.3×10^{-4} s^{-1}, at least 200 times faster than k_{obsd}, so some subsequent step is rate-determining. A plot of k_{obsd} vs 1/[L] affords a line with slope (k_1k_3/k_{-1}) of 2.7×10^{-9} and an intercept (k_6) of 1.1×10^{-6}. Thus, with excess added L (0.16 M), only the L-independent path 6 functions, and we observe that this path leads only to **6**; no **7** is formed.

Distinguishing between paths 4 and 7 is more difficult. The overall rate of reaction proceeding via path 7 should be dependent

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(2) For examples specifically of activation of methane by soluble metal complexes, see: (a) Shilov, A. E.; Shteinman, A. A. *Coord. Chem. Rev.* **1977**, *24*, 97. (b) Watson, P. L. *J. Am. Chem. Soc.* **1983**, *105*, 6491–6493. (c) Hoyano, J. K.; McMaster, A. D.; Graham, W. A. G. *Ibid.* 7190–7191. (d) Wax, M. J.; Stryker, J. M.; Buchanan, J. M.; Kovac, C. A.; Bergman, R. G. *Ibid.* **1984**, *106*, 1121–1122. (e) Fendrick, C. M.; Marks, T. J. *Ibid.* 2214–2216. (f) Wenzel, T. T.; Bergman, R. G. *Ibid.* **1986**, *108*, 4856–4867. (g) Thompson, M. E.; Baxter, S. M.; Bulls, A. R.; Burger, B. J.; Nolan, M. C.; Santarsiero, B. D.; Schaefer, W. P.; Bercaw, J. E. *Ibid.* **1987**, *109*, 203–219. (h) Hackett, M.; Whitesides, G. M. *Ibid.* **1988**, *110*, 1449–1462.
(3) Desrosiers, P. J.; Shinomoto, R. S.; Flood, T. C. *J. Am. Chem. Soc.* **1986**, *108*, 7964–7970.
(4) Part of the work outlined in Scheme I has been the subject of a communication: Desrosiers, P. J.; Flood, T. C. *J. Am. Chem. Soc.* **1986**, *108*, 1346–1347. The activation of $SiMe_4$ and the phosphine-dependent intramolecular activation of PMe_3 were suggested in this communication to proceed via Os(IV) intermediates. However, more extensive new data clearly point to the presence of path 3. These data will be presented in detail.[5]
(5) Desrosiers, P. J.; Shinomoto, R. S.; Harper, T. G. P.; Deming, M. A.; Flood, T. C., manuscript in preparation.
(6) Each reaction path in Scheme I will be referred to in the text by the numerical subscript of the rate constant for that path.
(7) The only other example known to us is that of ref 2h wherein methane is activated by an intermediate in the thermolysis of [bis(dicyclohexylphosphino)ethane](hydrido)neopentylplatinum(II). This intermediate is proposed to be [bis(dicyclohexylphosphino)ethane]platinum(0).
(8) Pyrolyses were carried out in sealed, thick-walled NMR tubes under 40–65 atm of methane pressure heated by total immersion in an oil bath at 80 °C. Product analysis and kinetics measurements were easily made by following the characteristic ^{31}P NMR resonances of components of the reactions, all of which are known.[3]

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on methane concentration, while that proceeding via path 4 should not. Although there appears to be no dependence of k_{obsd} on $[CH_4]$, changes of 10–15% in the rate are at the limits of the precision of our rate measurements.[9]

An experiment which probably does distinguish between paths 4 and 7 is as follows. It can be seen from Scheme II that in thermolysis of $[(CD_3)_3P]_4Os(H)Np$, **1**-d_{36}, there will be a primary kinetic isotope effect only in the step of k_5. If methane activation proceeds through intermediate **4** (path 4), then there will be an increase in the ratio of **7**/**6** which results from path 3, i.e., an increase in k_4/k_5 because of the primary isotope effect on k_5. If **7** forms via intermediate **9** (path 7), then the **7**/**6** ratio should be unchanged since it is determined by k_7/k_3 and not k_5. The average of four pyrolyses of **1**-d_{36} yielded **7**-d_{36}/**6**-d_{36} corresponding to $k_4/k_5 = 1/2.7$ (compared to 1/6.6 for the average of four thermolyses of **1**-d_0), consistent with an isotope effect of 2.4 on k_5. Independent measurement of this isotope effect yields a value close to 2.5.[5]

Knowing $k_5/k_{4(SiMe_4)}$[5] and $k_5/k_{4(CH_4)}$ one can calculate the per-hydrogen relative reactivity of the C–H bonds in CH_4 and $SiMe_4$ to be 1.5/1.

Thus, this non-cyclopentadienyl-containing osmium system effects intermolecular oxidative additions of C–H bonds of both sp^2 and sp^3 carbon centers, the former to five-coordinate Os(II)[3] and the latter to three-coordinate Os(0). Investigations of reactions with other hydrocarbons and the effects of other phosphine and phosphite ligands on this chemistry are under way.

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(9) Free L forms in these reactions at concentrations of 7×10^{-4}–3×10^{-3} molar and the ratio of paths 1 and 6 depends on [L]. Thus, detection of a dependence on $[CH_4]$ for a 10–15% component of the total reaction means determining [L] with high precision. It is not possible to do this by NMR at these low concentrations.

New Strategies for Annulations: A Highly Convergent and Stereoselective Synthesis of an Octahydronaphthalene Synthon for Dihydrocompactin

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For some time, synthetic chemists have sought efficient and stereospecific methods for carbocyclic annulations. Our recent reports on the fluoride-induced cleavage of 1-(trimethylsilyl)-oxy-2-carbalkoxycyclopropanes have demonstrated the synthetic utility of γ-oxo-α-ester enolates or homoenolates in intermolecular pentannulations.[1,2] At this time we wish to describe a new strategy for annulations based on intramolecular trapping of homoenolates with a Michael acceptor (Scheme I). The protocol begins with a conjugate addition of a chain A containing a potential Michael acceptor and the in situ trapping of the enolate to form the silyl enol ether B. A crucial cyclopropanation of the enol ether sets the trans stereochemistry of the ring juncture in the eventual bicyclic system D. One of the inherent uncertainties in this strategy lies in the stereochemical disposition of the substituents E and CH_2W in various ring systems D.

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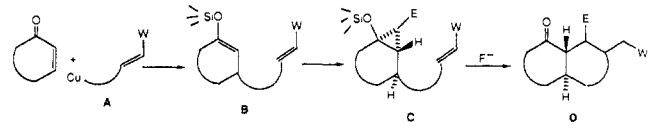
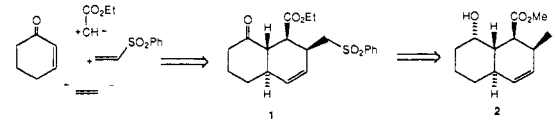
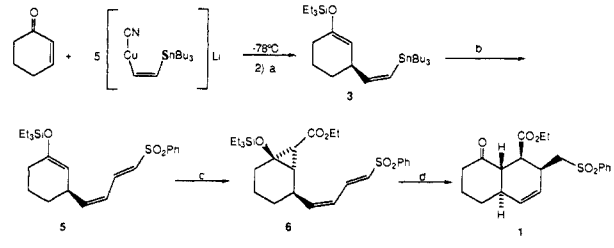
Scheme I



Scheme II



Scheme III[a]



[a] a. 5 equiv of Et_3SiCl, 6 equiv of Et_3N, THF, −78 °C to 0 °C; b. 1 equiv of *trans*-$PhSO_2CH{=}CHOTs$ (**4**) 2–3 mol% $PdCl_2(PPh_3)_2$, 6–10 mol% CuI, 3 equiv of LiCl, THF, 67 °C; c. N_2CHCO_2Et, 2 M solution in PhH, 0.5 mol% bis(*N*-benzylsalicylaldiminato)copper(II), 85 °C; d. 5 equiv of CsF, CH_3CN, 80 °C.

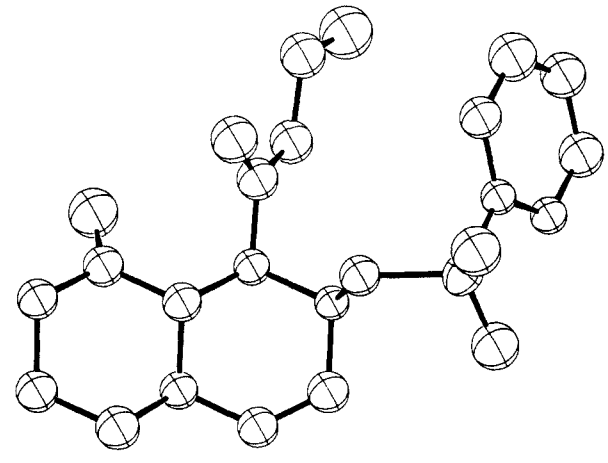


Figure 1. ORTEP drawing of compound **1**.

In this communication we report the successful execution of this strategy in the stereoselective synthesis of an octahydronaphthalene synthon of dihydrocompactin. The clinical importance of the mevinic acids as HMG-CoA reductase inhibitors[3] has prompted a flurry of synthetic activity in recent years.[4] We envisioned a four-step process to the octahydronaphthalene **1** which could easily be transformed into a known synthon **2** for dihydrocompactin.[5] A retrosynthetic analysis is shown in Scheme II with a unique combination of new synthons to introduce the dienyl sulfone chain.

Our synthesis first involved the conjugate addition of a *cis*-2-tri-*n*-butylstannylvinyl cuprate (generated in situ from tri-*n*-bu-

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