Tetrahedron Vol. 42, No. 1, pp. 175 to 188, 1986
Printed in Great Britain.

0040-4020/86 $3.00+.00

Synthesis and Characterisation of E and Z α,β-Unsaturated Acyl Complexes [(η^5-C_5H_5)Fe(CO)(PPh_3)(COCH=CHR)] (R=H, Me, Et, n-Bu, t-Bu, Ph, vinyl, 2-furyl)

Stephen G. Davies,* Robert J.C. Easton,
Jonathan C. Walker and Peter Warner.

The Dyson Perrins Laboratory, South Parks Road, Oxford, OX1 3QY. UK.

(*Received in UK 7 October* 1985)

Summary: α,β-Unsaturated acyl complexes of the chiral auxiliary [(η^5-C_5H_5)Fe(CO)(PPh_3)]† can be generated in high yield as readily separable mixtures of E and Z isomers by the Peterson olefination reaction between [(η^5-C_5H_5)Fe(CO)(PPh_3)$COCH_2SiMe_3$] and aldehydes RCHO (R=H, Me, Et, n-Bu, t-Bu, Ph, vinyl, 2-furyl). The Wittig reaction between [(η^5-C_5H_5)Fe(CO)(PPh_3)COCH=PMe_3] and benzaldehyde stereoselectively generates E-[(η^5-C_5H_5)Fe(CO)(PPh_3)COCH=CHPh]. α-Trimethylsilylation of both diastereoisomers of the β-hydroxy complexes [(η^5-C_5H_5)Fe(CO)(PPh_3)$COCH_2CH(OH)R$] gives completely stereoselectively the corresponding E α,β-unsaturated acyl complexes [(η^5-C_5H_5)Fe(CO)(PPh_3)COCH=CHR]. These E α,β-unsaturated acyl complexes are also formed stereoselectively, in high yield via sodium hydride induced elimination of methanol from the β-methoxy complexes [(η^5-C_5H_5)Fe(CO)(PPh_3)$COCH_2CH(OMe)R$] (R=H, Me, Et, n-Bu, Ph, vinyl, 2-furyl).

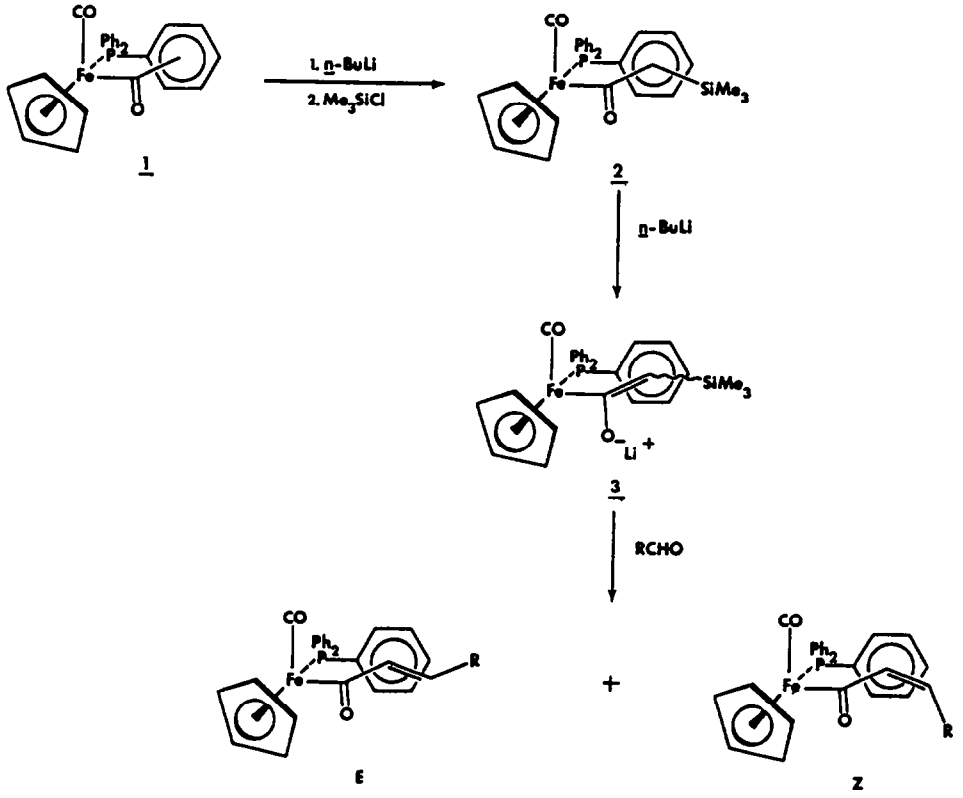
Enolates derived from acyl ligands bound to the chiral auxiliary [(η^5-C_5H_5)Fe(CO)(PPh_3)] undergo a variety of highly stereoselective carbon-carbon bond forming reactions such as alkylations[1,2] and aldol reactions.[3-5] Recently we demonstrated that E α,β-unsaturated acyl complexes of [(η^5-C_5H_5)Fe(CO)(PPh_3)] undergo tandem stereoselective Michael additions and subsequent alkylations which result in the stereocontrolled synthesis of α- and/or β-substituted iron acyl complexes.[6] This work has subsequently been confirmed by Liebeskind et al.[7]

To date, the occurrence of α,β-unsaturated metal acyl complexes in the chemical literature has been rare. Previous reported methods for the synthesis of such complexes have been (i) the interaction between the nucleophilic [(η^5-C_5H_5)$Fe(CO)_2$]$^-Na^+$ species and α,β-unsaturated acid chlorides,[8] (ii) the oxidatively catalysed carbon monoxide insertion reactions of (η^5-C_5H_5)Fe(CO)[$P(OPh)_3$](η^1-alkenyl) complexes,[9] (iii) the attack by phosphoranes on the carbon monoxide ligand of the cation [(η^5-C_5H_5)$Fe(CO)_3$]$^+$ PF_6^-[10] and (iv) the treatment of the rhenium methyl ester (η^5-C_5H_5)Re(NO)(PPh_3)(CO_2Me) with vinylmagnesium bromide.[11] In none of these examples, however, has any attempt to exploit the potential chemistry of the α,β-unsaturated acyl ligand been made. The obvious synthetic utility of E α,β-unsaturated iron acyl complexes as chiral synthons makes the development of convenient, large scale, stereoselective syntheses of these complexes desirable. We recently described the first general, but non-stereoselective, synthesis of complexes in which α,β-unsaturated acyl ligands are bound to the chiral auxiliary [(η^5-C_5H_5)Fe(CO)(PPh_3)].[6] An alternative, but also non-stereoselective, route to these complexes has subsequently appeared.[12] Here we detail our previously communicated[6] method for the synthesis and separation of E and Z α,β-unsaturated acyl complexes and describe completely stereoselective methods for the preparation of the E isomers.

† All complexes are racemic but for purposes of clarity only those having the R configuration at iron are shown.

Results and Discussion

The complex $[(\eta^5\text{-}C_5H_5)Fe(CO)(PPh_3)COCH_2SiMe_3]$ 2 can be prepared in large quantities from the acetyl complex $[(\eta^5\text{-}C_5H_5)Fe(CO)(PPh_3)(COCH_3)]$ 1. Deprotonation of 1 with n-butyllithium in tetrahydrofuran at -78°C followed by trapping of the resulting enolate with trimethylsilyl chloride generates complex 2.[13] The α-trimethylsilyl complex can be successfully employed in the Peterson olefination reaction.[14] Thus, deprotonation of the orange complex 2 with n-butyllithium in tetrahydrofuran at -78°C generates the corresponding α-trimethylsilyl enolate 3 as indicated by the immediate formation of a characteristic dark red colour. Addition of acetaldehyde to enolate 3 caused the reaction mixture to revert back to orange. Work-up by evaporation, extraction with dichloromethane and filtration through alumina gave, after removal of the solvent, a 2:1 mixture of E- and Z-$[(\eta^5\text{-}C_5H_5)Fe(CO)(PPh_3)(COCH{=}CHMe)]$, compounds 4 and 5, in 88% yield. The ratio of diastereoisomers 4 and 5 was deduced from integration of the methyl doublets and of the olefinic



	E	Z
R=Me	4	5
R=H	6	
R=Et	7	8
R=n-Bu	9	10
R=t-Bu	11	12
R=Ph	13	14
R=vinyl	15	16
R=2-furyl	17	18

protons in the ^1H n.m.r. spectrum. The E and Z isomers 4 and 5 are readily separable by chromatography on active alumina. Elution with dichloromethane gave the pure Z isomer 5 while subsequent elution with a 2:3 mixture of dichloromethane-ethylacetate gave the pure E isomer 4. Both compounds crystallised from dichloromethane-hexane as orange needles and were fully characterised by ^1H, ^{13}C and ^{31}P n.m.r. and infrared spectroscopy, mass spectrometry and elemental analysis. The double bond geometry was assigned as E for complex 4 and Z for complex 5 on the basis of the observed coupling constants between the olefinic protons, J = 15.0 and 11.2 Hz respectively.

To illustrate the generality of this methodology the reaction was repeated using formaldehyde, propionaldehyde, valeraldehyde, pivalaldehyde, benzaldehyde, acrolein and 2-furaldehyde. In each case the E and Z diastereoisomers were separable as described above and the pure orange crystalline complexes fully characterised. Table 1 summarises the overall yields obtained in these olefinations together with the E:Z isomer ratio and olefinic coupling constants.

Table 1 E:Z isomer ratios for $[(\eta^5\text{-}C_5H_5)Fe(CO)(PPh_3)COCH{=}CHR]$ prepared from 3 and RCHO.

R	Yield† %	E:Z	E isomer†† elutant	Z isomer elutant	J_E(Hz)†††	J_Z(Hz)
H	30	--	CH_2Cl_2/EtOAc(1:1)		17.0	10.2
Me	88	2:1	CH_2Cl_2	Et_2O/CH_2Cl_2(1:1)	15.0	11.2
Et	77	2:1	CH_2Cl_2/EtOAc(4:1)	Et_2O/CH_2Cl_2(1:1)	15.1	11.2
n-Bu	88	3:2	CH_2Cl_2	40:60% Et_2O (1:1)	15.1	11.2
t-Bu	63	100:0	CH_2Cl_2/EtOAc(6:1)		15.5	--
Ph	80	3:2	CH_2Cl_2	40:60% Et_2O(9:1)	15.6	12.7
vinyl	68	3:2	CH_2Cl_2/EtOAc(1:1)	CH_2Cl_2	14.4	11.1
2-furyl	78	3:2	CH_2Cl_2	Et_2O/CH_2Cl_2(4:1) • petrol	15.4	12.7

† Overall yield before separation (essentially no compound loss occurs during separation).

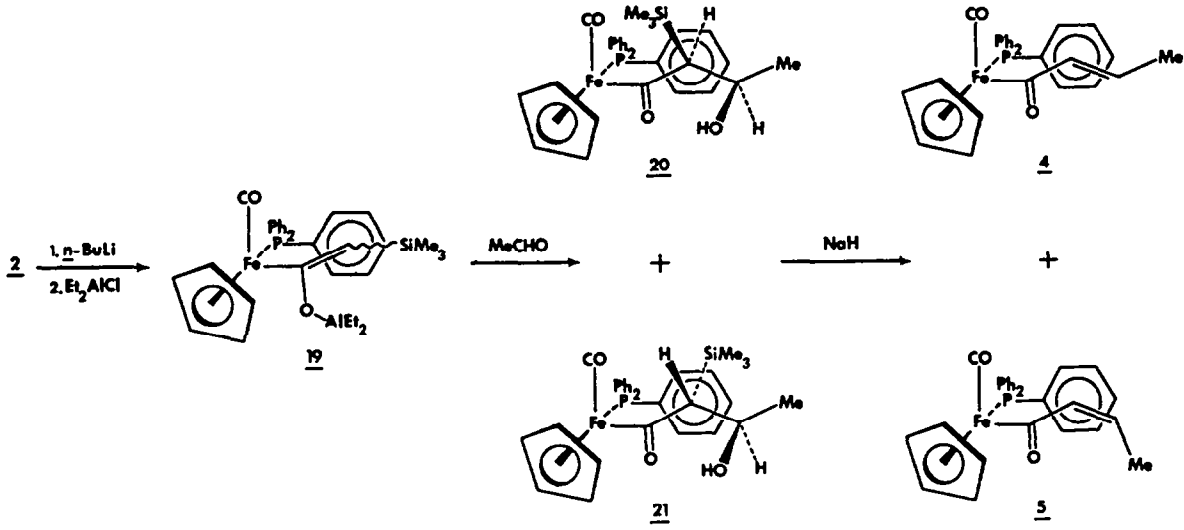
†† Column chromatography on alumina (Grade I).

††† Olefinic coupling constants.

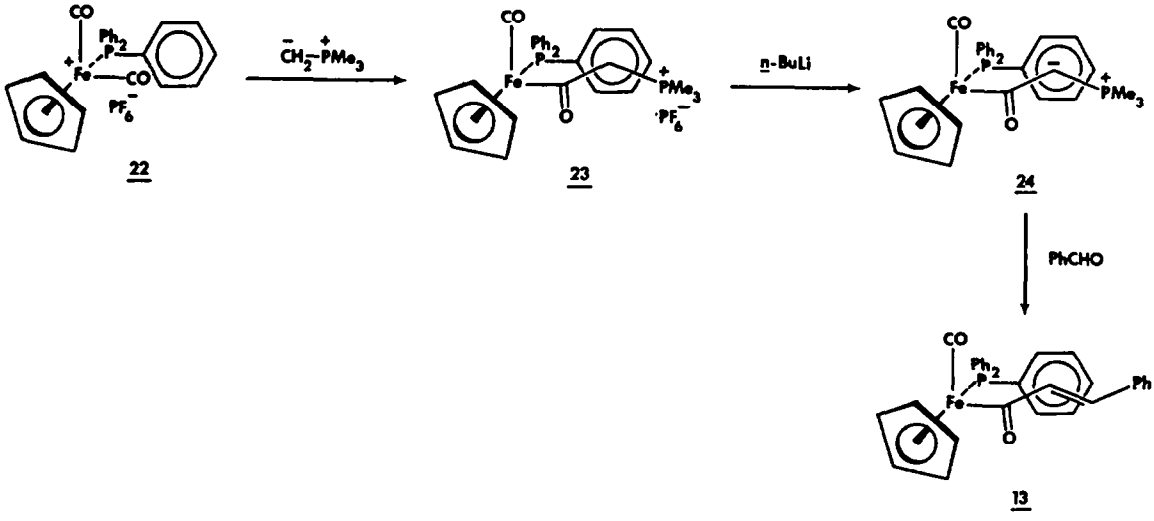
The α,β-unsaturated acyl complexes were obtained in good overall yields with the exception of the reaction with formaldehyde to generate 6 which suffered from problems due to base promoted polymerisation.

The addition of lithium enolates derived from iron acyl complexes to aldehydes has been shown to be essentially non-stereoselective[2-5] and therefore it is not surprising that the Peterson olefination reaction shows little stereoselectivity. Presumably addition of the lithium enolate 3 to aldehydes irreversibly generates a mixture of all four diastereoisomers of the intermediate α-trimethylsilyl-β-alkoxides each of which spontaneously undergoes stereospecific syn-elimination under the reaction conditions. The addition of the E-aluminium enolates derived from the complex $[(\eta^5\text{-}C_5H_5)Fe(CO)(PPh_3)COCH_2CH_3]$ to aldehydes is very stereoselective giving good stereochemical control over both the new α and β centres.[2-4] Deprotonation of 2 with n-butyl-lithium followed by transmetallation with diethylaluminium chloride generates the aluminium enolate 19. Addition of acetaldehyde to 19 gave, after methanolic work-up, a mixture of only two of the four possible diastereoisomeric α-trimethylsilyl-β-hydroxy acyl complexes 20 and 21. The aluminium is presumably protecting, by coordination, the initial alkoxide against the syn-elimination reaction. The tentative assignment of structures 20 and 21 to these diastereoisomers is consistent with the aluminium enolate 19 giving good stereochemical control at the β-centre, as before, but with the initial α-trimethylsilyl enolates 3 and 19 being formed as mixtures of E and Z isomers. This latter assumption is in agreement with the observed lack of stereoselectivity in the alkylation reactions of enolate 3.[15] Treatment of the mixture of 20 and

21 with sodium hydride in tetrahydrofuran to effect syn-elimination via the corresponding alkoxides, gave a mixture of the E and Z isomers 4 and 5 also consistent with the proposed structures for 20 and 21. Attempts to effect acid promoted anti-elimination from 20 and 21 (H^+ or BF_3) led to extensive decomposition.



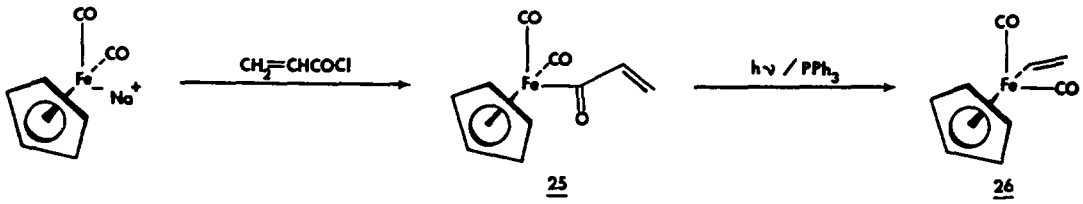
The Wittig reaction between phosphoranes and carbonyl compounds has now become one of the standard methods for the synthesis of carbon-carbon double bonds.[16] It was hoped to use this ubiquitous reaction in the preparation of the α,β-unsaturated iron acyl complexes $[(\eta^5\text{-}C_5H_5)Fe(CO)(PPh_3)COCH\text{=}CHR]$. Treatment of the cation $[(\eta^5\text{-}C_5H_5)Fe(CO)_2(PPh_3)]^+ PF_6^-$ 22, which has been shown to be susceptible to nucleophilic attack at one of the carbon monoxide ligands,[17] with one equivalent of $CH_2\text{=}PMe_3$ was anticipated to give the corresponding phosphonium salt 23 as observed in the analogous reaction of the cation $[(\eta^5\text{-}C_5H_5)Fe(CO)_3]^+ PF_6^-$.[10] Addition of n-butyllithium to 23 would generate the desired organometallic phosphorane 24 which when treated with an aldehyde would be expected to yield the corresponding α,β-unsaturated acyl complex. Indeed, addition of $CH_2\text{=}PMe_3$ to cation 22 in a mixture of tetrahydrofuran and dichloromethane, initially at



-78°C and then upon warming to 20°C, gave the phosphonium salt 23. Treatment of 23, without isolation, with n-butyllithium at -78°C and then benzaldehyde gave upon work up a single orange crystalline organometallic complex in 25% overall yield which was identified as the previously characterised complex 13. ^{1}H n.m.r. spectroscopy indicated that this Wittig reaction had led to the formation of only the thermodynamically more stable E isomer 13. The relatively poor yield of complex 13 by this route may have its origins in the fact that cation 22 is less susceptible to nucleophilic attack than $[(\eta^5\text{-}C_5H_5)Fe(CO)_2]^+ PF_6^-$ due to the presence of the electron donating triphenylphosphine ligand. Furthermore, nucleophilic addition to cation 22 is expected to be readily reversible.[10]

All attempts to synthesise $[(\eta^5\text{-}C_5H_5)Fe(CO)(PPh_3)COCH{=}CH_2]$ 6 by the action of vinylmagnesium bromide in tetrahydrofuran on the cation 22 or the corresponding methyl ester $[(\eta^5\text{-}C_5H_5)Fe(CO)(PPh_3)CO_2Me]$,[17] as in the preparation of the analogous chiral rhenium acyl complex,[11] proved unsuccessful. Complex mixtures of products were obtained which were not investigated further.

Addition of the nucleophile $[(\eta^5\text{-}C_5H_5)Fe(CO)_2]^-Na^+$ to acryloyl chloride gave the known complex $[(\eta^5\text{-}C_5H_5)Fe(CO)_2COCH{=}CH_2]$ 25.[8] In an attempt to generate 6 via ligand replacement, complex 25 was subjected to u.v. photolysis in the presence of triphenylphosphine. The disappearance of the infrared absorptions for 25 at 1910 cm^{-1}(CO), 1600 and 1555 cm^{-1} (acyl) to be replaced by CO absorptions at 2000 and 1930 cm^{-1} indicated that decarbonylation to the vinyl complex 26 had occurred as has been previously noted.[8] This result implies that intramolecular migration of the vinyl group to the vacant coordination site, following photo-induced loss of CO, occurs more rapidly than coordination of triphenylphosphine. Treatment of the vinyl complex 26 with triphenylphosphine in tetrahydrofuran under reflux also failed to give any of the desired α,β-unsaturated acyl complex 6.

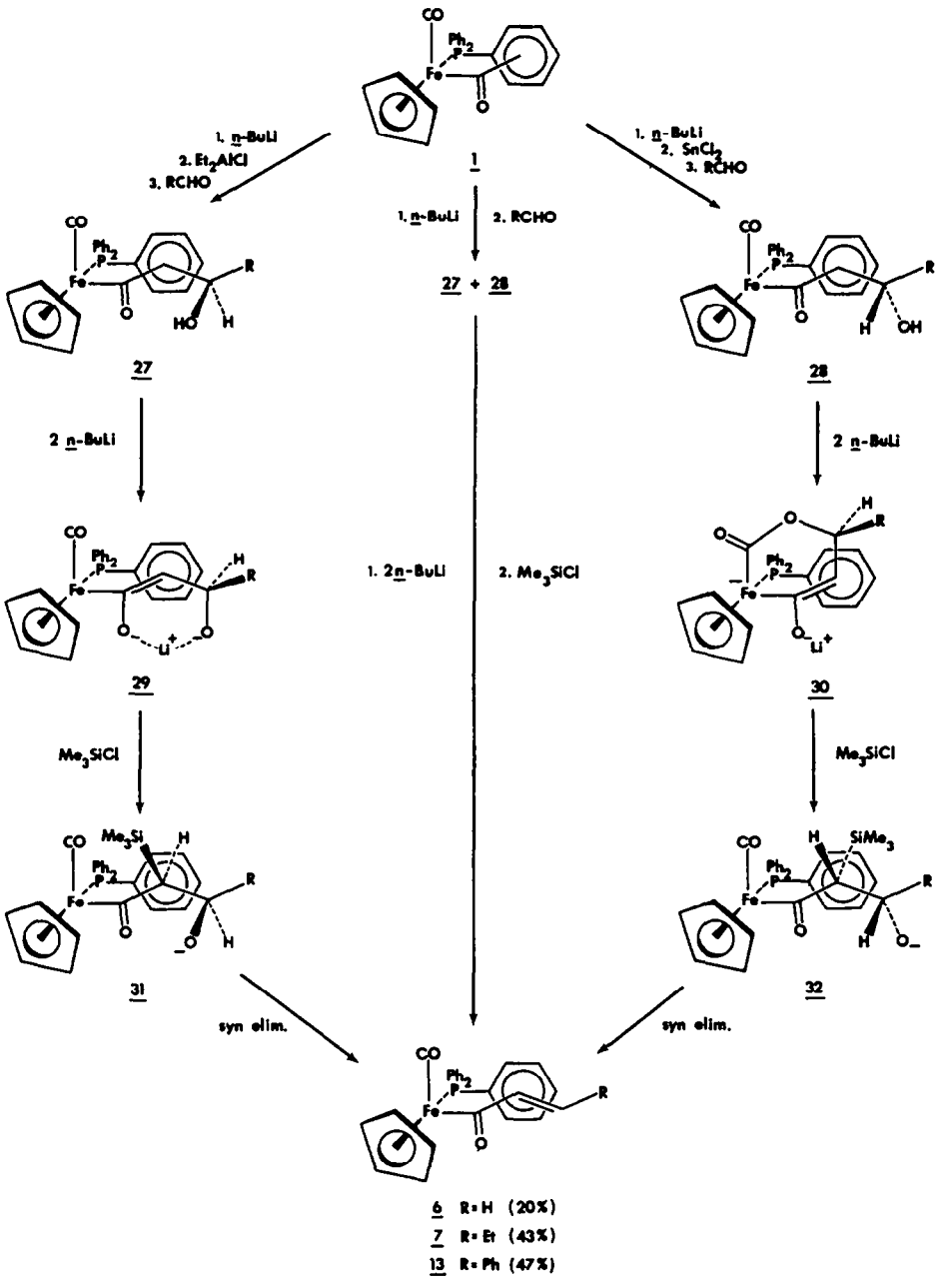


25 26

The stereospecific syn-elimination of the Si-O moiety in the base catalysed Peterson olefination reaction can be further utilised in the preparation of α,β-unsaturated acyl complexes from the corresponding β-hydroxy acyl complexes. The two diastereoisomers of the β-hydroxy acyl complexes are readily available from the reaction between enolates derived from the acetyl complex 1 and aldehydes. Essentially 1:1 mixtures of the two possible diastereoisomers of the β-hydroxy acyl complexes 27 and 28 are formed from the lithium enolate derived from 1,[2,3] whereas essentially single diastereoisomers can be obtained from the aluminium[3] or tin[5] enolates. Treatment of the β-hydroxy acyl complexes 27 and 28 (R=Et,Ph), either separately or as a mixture, with two equivalents of n-butyllithium in tetrahydrofuran at -78°C gave deep red solutions of the corresponding enolates. After quenching with one equivalent of trimethylsilyl chloride and the usual work up procedure, it was found that the E α,β-unsaturated acyl complexes 7 and 13 had been formed to the exclusion of any of the Z isomer (scheme 1).

We have already reported [2] the stereoselective synthesis of erythro-β-hydroxy carboxylic acids via the stereoselective α-methylation of both diastereoisomers of the β-hydroxyacyl complexes 27 and 28 (R=Ph) and decomplexation. This was attributed to the initial formation of a lithium chelate in the case of diastereoisomer 27 which subsequently formed the E-enolate 29, whereas initial lactone formation for 28 resulted in the formation of the Z-enolate 30. The stereoselective trimethylsilylation of enolates 29 and 30 from the unhindered face away from the triphenylphosphine ligand would give complexes 31 and 32 respectively each of which, upon

syn-elimination, would give the E α,β-unsaturated acyl complex as observed. The unprecedented stereoselectivity shown in this extension of the Peterson olefination reaction is overshadowed however by the poor yields (<50%) which may in part be due to competitive O-silylation.



Scheme 1

Finally, the base promoted elimination of methoxide from β-methoxy acyl complexes $[(\eta^5\text{-}C_5H_5)Fe(CO)(PPh_3)COCH_2CH(OMe)R]$ provides both a stereoselective and a high yielding synthesis of the E α,β-unsaturated iron acyl complexes. The required β-methoxy acyl complexes are prepared from the corresponding β-hydroxy acyl complexes by stirring with sodium hydride and methyl iodide in tetrahydrofuran. Sodium hydride was also chosen as the base to effect the elimination for the reasons that although it is sufficiently basic to deprotonate the acyl ligand, it is non-nucleophilic. Bases such as n-butyllithium or lithium dialkylamides are unsuitable because