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Ring-closing metathesis for the synthesis of substituted indenols, indenones, indanones and indenes: Tandem RCM-dehydrogenative oxidation and RCM-formal redox isomerization

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Abstract

A number of substituted indenols have been synthesized using ruthenium-mediated ring-closing metathesis (RCM) with Grubbs second generation catalyst as the key step. The required dienes were synthesized by two strategies. The first entailed the isomerization of 2-allyl-3-isopropoxy-4-methoxybenzaldehyde to its styrene derivative, isopropoxy-4-methoxy-2-propenylbenzaldehyde using [RuClH-(CO)(PPh_3)$_3$]. This compound and 3-isopropoxy-4-methoxy-2-(1-phenyl-propenyl)-benzaldehyde were then treated with vinyl- or isopropenyl-magnesium bromide to afford four of the scaffolds required for the metathesis. As the compound 3-isopropoxy-4-methoxy-2-(1-methyl-2-propenyl)benzaldehyde proved to be difficult to isomerize, the diene substrates 1-[3-isopropoxy-4-methoxy-2-(1-methylpropenyl)-phenyl]-prop-2-en-1-ol and 1-[3-isopropoxy-4-methoxy-2-(1-methylpropenyl)-phenyl]-2-methylprop-2-en-1-ol were synthesized by the addition of the Grignard reagents to 3-isopropoxy-4-methoxy-2-(1-methyl-2-propenyl)benzaldehyde, followed by isomerization of the arylallyl group to the thermodynamically favoured isomer with potassium *t*-butoxide. The use of harsher conditions (higher temperature and catalyst loadings) for the metathesis reactions resulted in the formation of substituted indenones, formed by a tandem RCM-dehydrogenative oxidation in the absence of a hydrogen acceptor. Further manipulations of the reaction conditions generated two substituted indanones by way of a tandem RCM-formal redox isomerization sequence. Finally the synthesis of some substituted indenes was accomplished from their corresponding dienes by the use of RCM.

Keywords: Metathesis; Ruthenium; Grubbs catalyst; Tandem reactions; Oxidative dehydrogenations; Formal redox isomerizations; Indenols; Indenones; Indanones; Indenes

1. Introduction

Substituted indenols **1**, indenones **2**, indanones **3** and indenes **4** are classes of compounds that have seen increasing importance in organic chemistry [1,2]. Reasons for this trend include that these structural motifs have been found in an increasing number of natural products (Fig. 1).

Representative examples include indenol **5** (e.g. a compound isolated from the plant Adlay *Coix lachryma-jobi* L. var. *ma-yuen* Stapf) [3] and indenone **6** (a compound, isolated from the fruits of *Virola sebifera*) [4]. Examples of naturally-occurring indene compounds include trikentramine **7**, isolated from the sponge *Trikentrion loeve* [5], and dilemmaone A **8** (from *Ectyonanchora flabellate*), an unusual indanone alkaloid isolated from sponges collected near Cape Town, South Africa [6] (Fig. 2).

In addition to their natural occurrence, indanes have also been used as intermediates towards the synthesis of potential pharmaceutical candidates. For example, indenone **9** was synthesized as a structural analogue of the

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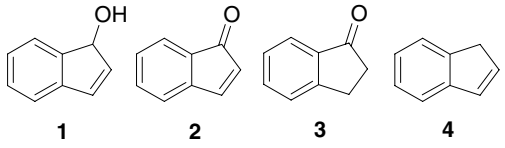


Fig. 1. General indane skeletons.

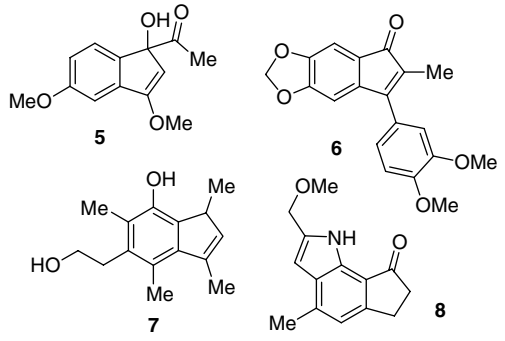


Fig. 2. Indane-based natural products.

selective COX-2 inhibitor nimesulid [7]. Another indenone **10** was found to be a potent reversible 3CP inhibitor (albeit without demonstrable antiviral activity) [8]. A topical example demonstrating a pharmaceutical application of an indanone compound would be flusolide **11**, another potent and selective COX-2 inhibitor [9]. A representative of a medicinal indene is racemic dimethindene **12**, a compound which penetrates readily into the brain; analogues of this compound have been investigated as muscarinic and histaminic H_1 receptor antagonists [10] (Fig. 3).

Finally compounds with the indene skeleton have also found application as ligands for single-center zirconium polymerization catalysts. An example of this would be compounds with the general indene backbone **13**, which have been used together with MAO as a co-catalyst in ethene polymerization reactions [11,12] (Fig. 4).

In light of the recent interest vested in the indanes much work has been done in the development of novel strategies towards their synthesis. Recent reported methods towards the synthesis of indenols include transition metal-catalyzed

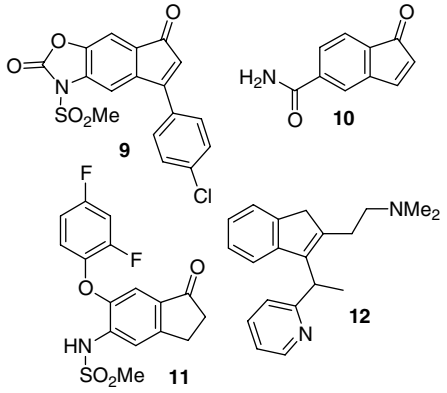


Fig. 3. Indane-based medicinal compounds.

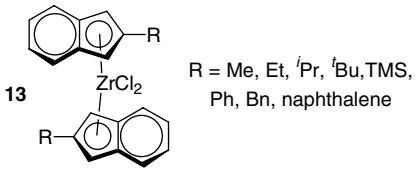
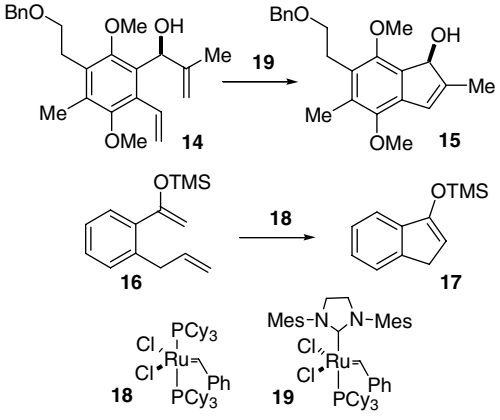


Fig. 4. Indane-based polymerization catalysts.

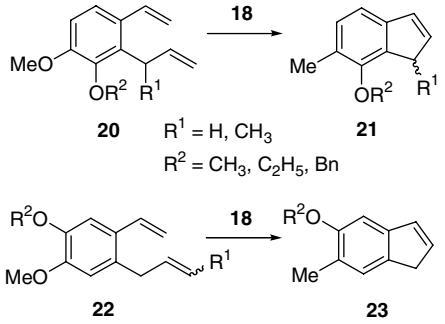
carbocyclizations utilizing nickel [13], manganese [14–17], cobalt [13,18] and palladium [19–23], while examples of substituted indene syntheses include zirconocene- [24] and ytterbium-mediated [25], and Grignard [26] approaches. Indenones on the other hand have been synthesized by ruthenium-, [27] palladium- [28] and rhodium-mediated cyclizations [29], amongst others, as well as the treatment of suitable precursors with acids [30,31]. The synthesis of indanones has also attracted attention with microwave-assisted cyclizations [32,33], photochemical- [34] and rhodium-mediated [35,36] syntheses being published recently.

There are only a few reports concerning the use of ruthenium-mediated RCM for the synthesis of unsaturated indane skeletons. The first of these synthetic applications involved the synthesis of indenol **15** as published by Clive and co-workers [37,38]. Their synthesis of (+)-puraquinonic acid included the metathesis of diene **14** using Grubbs II catalyst **19** to form substituted indenol **15** (Scheme 1). In addition, as part of a study investigating the metathesis of enol silyl ethers, Shibasaki and co-workers demonstrated that the RCM of the enol silyl ether **16** with Grubbs I catalyst **18** could afford indene **17** in excellent yield [39].

Another group that has published general synthetic methodology towards substituted indenes, involving RCM, is that of Huang and Wang [40]. Utilizing vanillin as a starting material they readily synthesized the two differently substituted diene precursors **20** and **22** (Scheme 2). These compounds were then readily converted into the corresponding indenes **21** and **23** in excellent yields by using the first generation Grubbs I catalyst **18**. Finally, Krafft and co-workers have demonstrated that a substituted indenol could be synthesized by way of a Morita–Baylis–Hillman reaction followed by an RCM reaction [41].



Scheme 1. Synthesis of indenol **15** by Clive and co-workers [37,38] and silyl-enol **17** by Shibasaki and co-workers [39].



Scheme 2. Synthesis of indenes **21** and **23** by Huang and Wang [40].

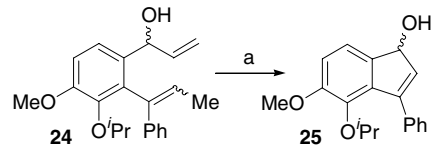
The significant scientific impact of metathesis by the catalysis of ruthenium compounds cannot be denied [42–44]. In addition, the subsequent observation of related non-metathetic [45] catalytic activities of these same catalysts, their hydride derivatives [46,47] or decomposition products has become much more relevant. It is these interesting developments that has thus prompted us to provide full details of our investigation into the synthesis of the indenol, indenone, indanone and indene skeletons using Grubbs second generation ruthenium complex **19** as catalyst [48]. Part of our research program is dedicated to the use of the versatile metathesis reaction [42,43], using the Grubbs second generation catalyst **19**, for the synthesis of *benzo-fused* bicyclic molecules such as substituted benzofurans [49], 4*H*-chromenes [50], 2*H*-chromenes [50], 1*H*-isochromenes [51], benzo[1,4]dioxins [51], naphtho[2,3-*b*]dioxins [51], 1,2-dihydroisoquinolines [52] and other 7- and 8-membered benzo-fused heterocyclic compounds [53,54].

2. Results and discussion

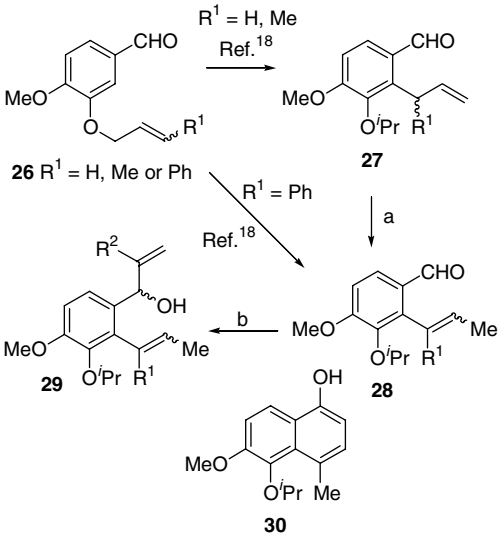
2.1. Preparations of substrates

We have previously communicated, how when alcohol **24** was subjected to Grubbs II catalyst **19**, indenol **25** was obtained in reasonable yield of 67% after chromatography (Scheme 3) [53].

A further challenge was then to see if we could adapt this methodology to give indenols with a wider range of substitution patterns on the cyclopentene part of the nucleus [48,55]. Scheme 4 describes how we were able to vary the substituent on the 3-position of the indenol by either starting with an allyl (R = H), a crotyl (R = Me) or a cinnamyl group (R = Ph) on the benzaldehyde skeleton **26**.



Scheme 3. Reagents and conditions: (a) 5% catalyst **19**, dichloromethane (67%).



Scheme 4. Reagents and conditions: (a) $R^1 = H$, 2% [RuClH-$(CO)(PPh_3)_3$], toluene, 80 °C, **28a** (quantitative) or 5% $PdCl_2$, MeOH, rt, **28a** (44%); $R^1 = Me$, KOBu^t, DMF, 60 °C, 0.4 mmol scale: **28b** (44%), 2.0 mmol scale: **28b** (8%) and **30** (12%), [$RuClH(CO)(PPh_3)_3$], toluene, 80 °C, only s.m. recovered; (b) vinylmagnesium bromide or isopropenylmagnesium bromide, THF, 0 °C, **29a**, R^1, $R^2 = H$ (99%); **29c**, $R^1 = Ph$, $R^2 = H$ (54%); **29d**, $R^1 = H$, $R^2 = Me$ (85%); **29f**, $R^1 = Ph$, $R^2 = Me$ (57%).

We started with the simplest allyl system **27a** (R = H) and this compound was quantitatively converted to the more thermodynamically favoured styrene **28a** (see Scheme 4) by using ruthenium catalyst, [$RuClH(CO)(PPh_3)_3$] [56–58], an isomerization catalyst successfully used before in our work. However the application of the same catalyst to the isomerization of compound **27b** (R = Me), under a variety of different reaction conditions, resulted in no desired product. We also attempted other well-known isomerization methods such as the use of palladium catalysts, $PdCl_2$ or $PdCl_2(MeCN)_2$, but these also failed to facilitate conversion to the desired compound **28b** (R = Me). A base-mediated method, using potassium *t*-butoxide, did result in the formation of the isomerized product **28b** (R = Me), albeit in poor synthetic yields (44% on small scale and only 8% on a larger scale). The major problem with the use of potassium *t*-butoxide was that it led to the formation of unwanted naphthalene **30**, a reaction previously exploited in our research group [59]. Finally, compound **28c** (R = Ph) was formed directly from material **26c** as described previously in the literature [59].

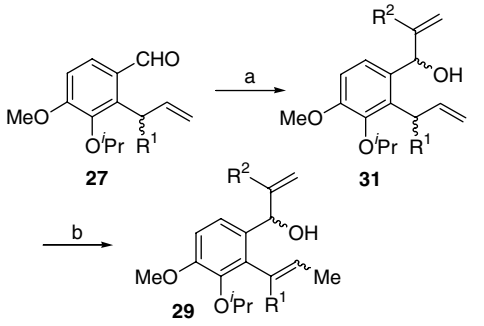
Now with the three styrene-containing compounds in hand, the vinyl groups could be introduced by using the appropriate Grignard reagent to give dienes **29** (Scheme 4), required for the metathesis reaction. To this end, the two isomerized substrates **28a** and **28c** were treated with vinylmagnesium bromide to afford the respective dienes **29a** (R^1, $R^2 = H$) and **29c** ($R^1 = Ph$, $R^2 = H$) in excellent to moderate yields, respectively. In a similar manner, treatment of compounds **28a** and **28c** with isopropenylmagnesium bromide afforded the RCM substrates **29d** ($R_1 = H$, $R_2 = Me$) and **29f** ($R^1 = Ph$, $R^2 = Me$).

After experiencing problems with the isomerization reaction of the methyl substituted benzaldehyde **27b**, as described, we decided to reverse the order of the steps involved necessary to obtain dienes **29** (Scheme 5). Benzaldehyde **27b** was thus treated with vinyl- and isopropenylmagnesium bromide to give alcohols **31b** ($R^1 = Me$, $R^2 = H$) and **31e** (R^1, $R^2 = Me$), respectively. This time, much to our delight, reaction of both compounds **31b** and **31e** with potassium *t*-butoxide gave styrenes **29b** and **29e** in excellent yields after purification. Finally we also tested this approach on the simplest substrate **27a**. In the same manner as before, treatment of this compound with the commercially available Grignard reagent, vinylmagnesium bromide, gave rise to compound **29a** after isomerization of the intermediate compounds **31a** with potassium *t*-butoxide. In this way, by changing the order of the Grignard and isomerization reactions, we were able to synthesize the full range of diene substrates that we required for the testing of the metathesis reactions.

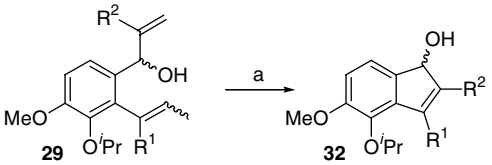
2.2. Synthesis of indenols

Finally, with all the required substrates in hand we were able to investigate the scope of the indenol synthesis by way of RCM. Dienes **29** were therefore subjected to metathesis with catalyst **19** under relatively mild conditions (normally room temperature) to afford indenols **32** in a range of yields after purification by silica gel column chromatography (see Scheme 6 and Table 1). NMR spectroscopic evidence clearly indicated that the terminal alkenes were no longer present in the spectra of the product indenols. In addition, for the cyclopentenol portions of the indenols, characteristic protons signals were observed at $\delta = 6$–7 ppm, indicative of the olefin proton(s).

From the table it can be seen that the isolated yield of indenol was significantly lower when the metathesis reaction afforded a tetra-substituted alkene (**entries e** and **f**). It would also appear for the small set of compounds synthesized that the RCM reaction was more sensitive to substitution in the 2-position (numbering relative to the product indenol) than to that in the 3-position when comparing **entry b** (64%) to **entry d** (34%) under similar reaction conditions. In fact, to achieve a reasonable yield of indenol **3d** we needed to use a much higher temperature (**entry d″**). The reactions were monitored by tlc to optimize the reaction yields but in general, longer reaction times resulted in a decrease in the yield of the desired indenols.



Scheme 5. Reagents and conditions: (a) vinylmagnesium bromide or isopropenylmagnesium bromide, THF, 0, −20 or −60 °C: **31a**, R^1, $R^2 = H$ (49%) and recovered **27a** (25%); **31b**, $R^1 = Me$, $R^2 = H$ (95%); **31e**, R^1, $R^2 = Me$ (83%); (b) KOBu^t, DMF, 60 °C, **29a**, R^1, $R^2 = H$ (81%); **29b**, $R^1 = Me$, $R^2 = H$ (94%); **29e**, R^1, $R^2 = Me$ (84%).



Scheme 6. Reagents and conditions: (a) 5% catalyst **19**, dichloromethane or toluene (see Table 1 for yields and conditions).

For the synthesis of the indenols with substituents in both the 2- and 3-positions, involving the RCM reaction of the more sterically demanding substrates, it was often necessary to use reactions conditions with much higher temperatures. However this inevitably led to the formation of undesired indenone compounds (discussed in the following section). One strategy we investigated to circumvent this problem of over-oxidation was to protect the alcohol functionality of compound **29d**, as the *O*-acetate, to give RCM substrate **33** (Scheme 7). However, acetate **33** would not give the protected indenonol **34** under moderate or even harsh metathesis reaction conditions [60].

2.3. Synthesis of indenones

During initial attempts at the synthesis of indenol **32a** we observed a minor, highly fluorescent spot on the tlc plate of the reaction mixture that grew in intensity with the passage of time. The reaction mixture was stirred for a further 15 h, at room temperature, to reveal that the tlc spot representing the indenol had been completely converted to the fluorescent spot. Silica gel column chromatography of the reaction mixture then led to the isolation of a crystalline material that was subjected to spectroscopic investigation. Evidence from the NMR spectrum pointed to the formation of the corresponding indenone **35a** that was subsequently confirmed by mass spectroscopy.

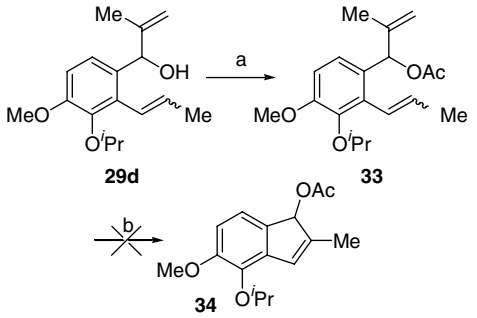
We were surprised to isolate this product as the reaction was done under anaerobic conditions and in the absence of a hydrogen transfer acceptor, causing us to believe that a dehydrogenative oxidation process was occurring without a hydrogen acceptor (an investigation into this process is described later in the paper) [61,62]. This encouraged us to investigate the potential of catalyst **19** (or its degradation products) to effect dehydrogenation of indenols into indenones [45]. The discovery that the reaction conditions were also able to furnish indenones, by way of a tandem RCM-dehydrogenative oxidation process [63], prompted us to reinvestigate the RCM of substrates **29a**–**f** under higher temperature conditions.

The same substrates **29**, initially used for the indenol syntheses, were thus subjected to metathesis under harsher

Table 1
The synthesis of indenols **32**

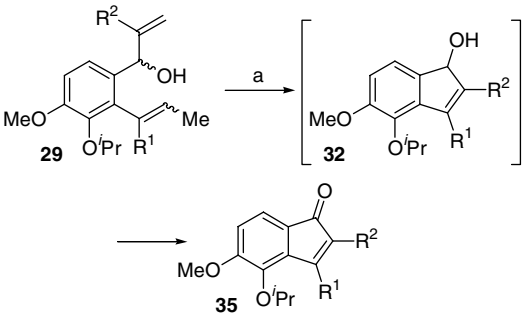
	Indenols **32**	Solvent	Conditions	mol% Catalyst **19**	Yield (%)
a	$R^1 = R^2 = H$	CH_2Cl_2	3 h, rt	5	87
b	$R^1 = Me$, $R^2 = H$	CH_2Cl_2	2 h, rt	5	64
c	$R^1 = Ph$, $R^2 = H$	CH_2Cl_2	2 h, rt	5	67
d	$R^1 = H$, $R^2 = Me$	CH_2Cl_2	2 h, rt	5	[a]
d′		CH_2Cl_2	24 h, rt	5+5	34[b]
d″		Toluene	24 h, 60 °C	10	49[c]
e	$R^1 = Me$, $R^2 = Me$	Toluene	16 h, 80 °C	10	43[d]
f	$R^1 = Ph$, $R^2 = Me$	CH_2Cl_2	2 h, rt	12	[a]
f′		CH_2Cl_2	8 h, 40 °C	10	16[e]
f″		Toluene	2–16 h, 80 °C	5	[f]

[a] No product formation evident from tlc.
[b] Also isolated indenone **35c** (7%) and diene **29d** (34%).
[c] Also isolated indenone **35d** (24%).
[d] Also isolated indenone **35e** (45%).
[e] Starting material **29f** (84%) was also recovered.
[f] Only indenone **35f** obtained.



Scheme 7. Reagents and conditions: (a) Ac_2O, pyridine, **33** R = H (82%); (b) 5% catalyst **19**, dichloromethane, rt, 24 h or 10% catalyst **19**, toluene, 110 °C, 24 h, only recovered s.m.

conditions in a higher boiling point solvent (usually toluene). In this manner we were able to isolate the substituted indenones **35** in excellent to reasonable yields as summarized in Scheme 8 and Table 2. Careful tlc analysis during the reaction process showed consumption of starting materials **29** and formation of the indenol intermediates **32** followed by a facile *in situ* oxidation to the corresponding indenone compounds **35**. To ensure acceptable yields the reactions were allowed to continue overnight (16–24 h) so that the bulk of the indenol intermediates were oxidized



Scheme 8. Reagents and conditions: (a) 5% catalyst **19**, toluene (see Table 2 for yields and conditions).

to the desired indenones. Quite surprisingly, this time the yields for indenones containing a phenyl substituent in position C-3 were also very good (**entries c** and **f**).

NMR spectroscopic evidence proving that the substituted indenones had been formed included the ketone signals at approximately $\delta = 195$ ppm in the ^{13}C NMR spectra. This functional group's signature was also clearly evident in the compound's IR spectra. In addition, some of the resultant indenones were found to by crystalline and a structural determination of a suitable single crystal of indenone **35c** by X-ray crystallographic methods confirmed the structure of this compound (Fig. 5) [64,65].

2.4. Synthesis of indanones

It is well known that Grubbs catalysts **18** and **19** [66–68] (or their degradation products) and other ruthenium catalysts [69–71] are able to facilitate redox isomerization reactions [45]. It thus came as no surprise that, under some of the rather harsh reaction conditions employed to afford the metathesis products, traces of indanone compounds were detected. In one particular case, where the reaction solvent had evaporated due to prolonged heating of compound **29a** (R^1, $R^2 = H$) we were able to isolate indanone **36a** ($R^1 = H$) in a yield of 51%. Repetition of this reaction under more controlled conditions (toluene, 80 °C) did allow us to isolate the desired **36a** in a good yield of 89%. However the reaction proved to be quite sensitive to steric hindrance as treatment of substrate **29b** ($R^1 = Me$, $R^2 = H$) under essentially solvent-free conditions at high temperature only gave the methyl-substituted indanone **36b** ($R^1 = Me$) in a mediocre yield of 18% (Scheme 9 and Table 3). The structure of compounds **36a** and **36b** were confirmed by the characteristic methylene signals in the ^1H NMR spectra. In addition the methylene groups were also evident in the aliphatic region of the ^{13}C NMR spectra of both the compounds. However, attempts at forming the aryl substituted system **36c**

Table 2
The synthesis of indenone **35**

	Indenones **35**	Solvent	Conditions	mol% Catalyst **19**	Yield (%)
a	$R^1 = R^2 = H$	Toluene	2 h, 80 °C	8	66
b	$R^1 = Me$, $R^2 = H$	Toluene	16 h, 80 °C	5	47[a]
c	$R^1 = Ph$, $R^2 = H$	Toluene	20 h, 110 °C	5+8	82
c′		Xylene	18 h, 110–120 °C[b]	8	89
d	$R^1 = H$, $R^2 = Me$	Toluene	48 h, 60 °C	10	23[c]
e	$R^1 = Me$, $R^2 = Me$	Toluene	16 h, 80 °C	10	45[d]
f	$R^1 = Ph$, $R^2 = Me$	Toluene	15 h, 80 °C	5+10	82

[a] Also isolated indenol **32 b** (30%).
[b] Reaction done on 40 mg scale.
[c] Also isolated indenol **32c** (15%) and diene **29c** (35%).
[d] Also isolated indenol **32e** (43%).

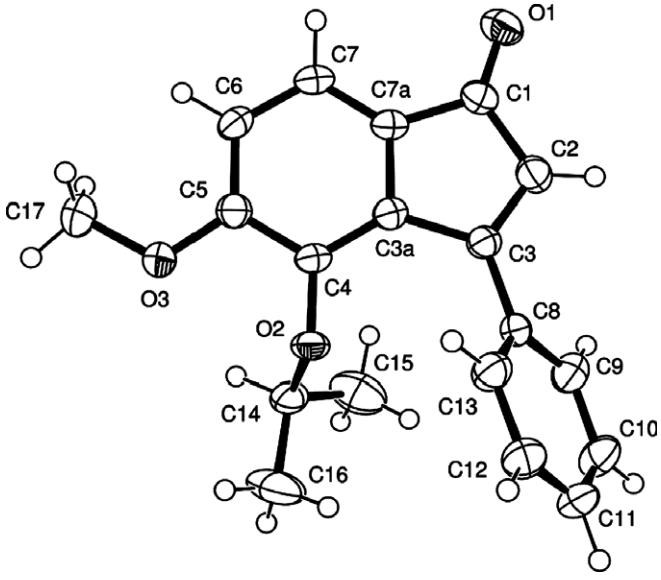
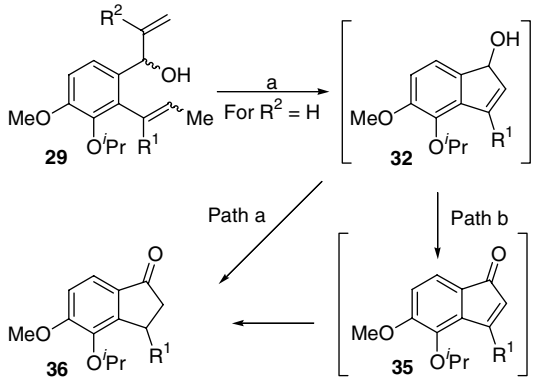


Fig. 5. Single crystal X-ray structure of indenone **35c** (thermal ellipsoids at 50% probability).



Scheme 9. Reagents and conditions: (c) 5% catalyst **19**, toluene (see Table 3 for yields and conditions).

($R^1 = Ph$) by employing high temperature conditions on substrate **29c** ($R^1 = Ph$, $R^2 = H$) met with complete failure. Originally we were satisfied that the transformation of diene **29** to indanone **36** was going by way of mechanism involving direct redox isomerization (path a). However it was brought to our attention that the only significant difference in the reaction conditions leading to indanones **36**, rather than indenones **35** was a much longer reaction time (e.g. for **35a** 2 h and for **36a** 22 h, same solvent and same temperature). There is thus a distinct possibility that the initial transformation involves a dehydrogenative oxidation of **32** to compound **35**, followed by a reduction of the alkene to afford indanone **36** (path b) [72]. To the best of our knowledge the two examples involving the formation of indanones **36a** and **36b** constitutes one of the first reports of a tandem RCM-formal redox isomerization reaction.

One of the resultant indanones, compound **36a**, was found to be crystalline and a structural determination of a suitable single crystal of the compound by X-ray crystallographic methods confirmed its structure (Fig. 6) [73].

2.5. Synthesis of indenes

The indenes are also an important class of compounds and we decided to modify our indenol methodology to afford the corresponding indenes. In our hands the conversion of aldehydes **27** to the corresponding styrene compounds proved surprisingly uncooperative with the Wittig reagent, Ph_3MePBr. Fortunately, however, precursor **27** was facilely converted to the unsaturated esters **37a** (R = H) and **37b** (R = Me) using the activated phosphorous ylide, $Ph_3PCH{=}CHCO_2Et$, in excellent yields (Scheme 10). Subsequent RCM of substrates **37a** and **37b**, under our standard conditions, then afforded indenes **38a** (R = H) and **38b** (R = Me), respectively, in acceptable yields. The spectra of compounds **38a** and **38b** provided clear evidence for the formation of the new cyclopentene ring. This pair of examples thus confirms that this method is a viable route to the synthesis of substituted indenes [40].

2.6. Dehydrogenative oxidation and formal redox isomerization studies

At a similar time to when we published the preliminary report on this work a thought-provoking article by Quayle and co-workers [74] commented on mechanistic issues

Table 3
The synthesis of indanone **36**

	Indanones **36** ($R^2 = H$)	Solvent	Conditions	mol% Catalyst 19	Yield (%)
a	$R^1 = H$	Toluene[a]	18 h, 80 °C[b]	5	51
a′	$R^1 = H$	Toluene	22 h, 80 °C	8	88[c]
b	$R^1 = Me$	Toluene[d]	18 h, 110–170 °C	5	18[e]
c	$R^1 = Ph$	Toluene	20 h, 110 °C[f]	8	0

[a] Solvent evaporated overnight so reaction temperature was ~100 °C (temperature of oil bath) for part of the time.
[b] Initially at rt for 24 h.
[c] Also isolated indenone **35a** (12%).
[d] Solvent evaporated overnight.
[e] Also isolated indenone **35b** (7%).
[f] Reaction also attempted at 80 °C for 18 h and 110 °C for 45 h but no product formation observed.

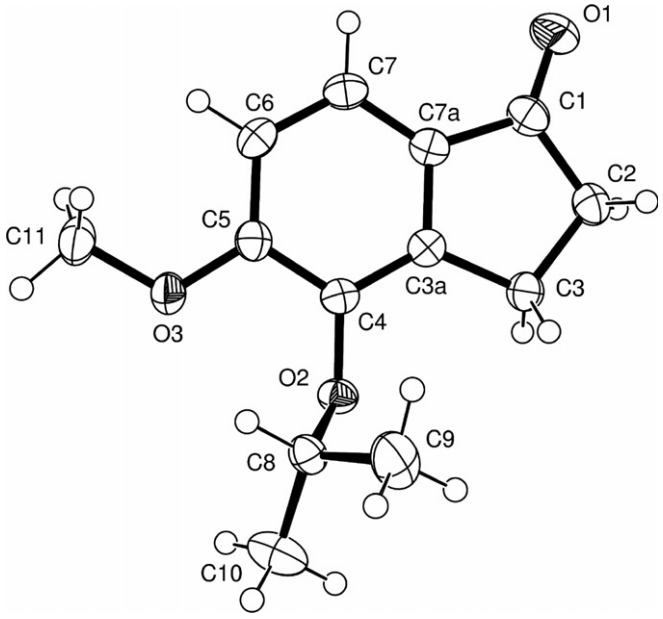
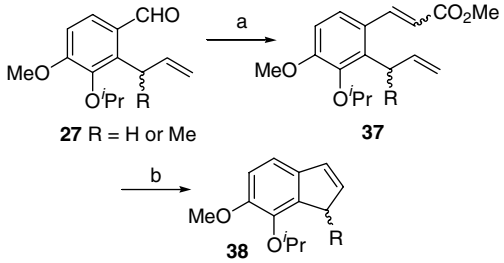
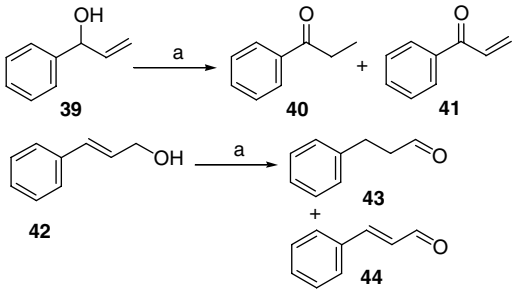


Fig. 6. Single crystal X-ray structure of indanone **36a** (thermal ellipsoids at 50% probability).



Scheme 10. Reagents and conditions: (a) $Ph_3PCH{=}CHCO_2Et$, THF, 0 °C **37a** R = H (97%); **37b** R = Me (95%); (b) 5% catalyst **19**, CH_2Cl_2, rt, **38a** R = H (68%); **38b** R = Me (71%).

regarding alkene isomerization by ruthenium metathesis catalysts. This paper postulated a mechanism for the specific isomerization of allylic alcohols with the ruthenium catalysts, at odds with another mechanism proposed by Gurjar and Yakambram [67]. Quayle proved experimentally that the Grubbs first generation catalyst **18** was able



Scheme 11. Reagents and conditions: (a) Presumably 5% catalyst **18**, toluene, Ar, reflux (see Edlin et al. [74]).

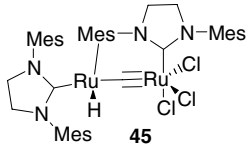


Fig. 7. Grubb's ruthenium hydride complex.

to convert the allylic alcohols **39**, in toluene at reflux, into the isomerized compounds **40** (85%) and **41** (5%) and **42**–**43** (33%) and **44** (33%), respectively (Scheme 11). In the same paper it was proposed that the catalyst for this transformation is probably a ruthenium hydride complex resulting from the thermolysis of the initial Grubbs catalysts used in the experiments [46,47].

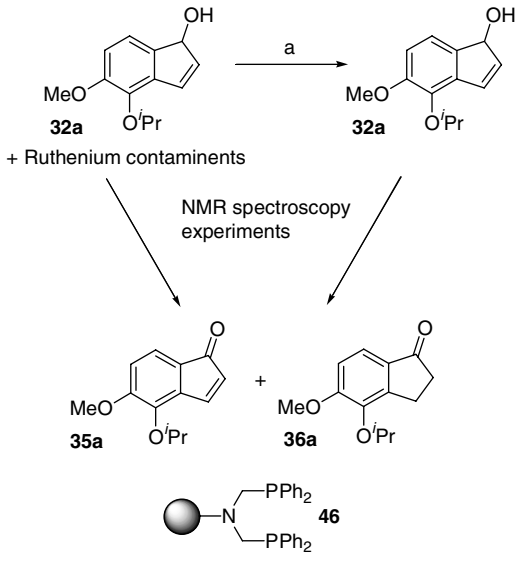
Also of interest is that Grubbs and co-workers have recently isolated a ruthenium hydride complex **45** (Fig. 7), obtained from the decomposition of the *N*-heterocyclic-based ruthenium compound **19**, that was able to perform allyl aryl isomerizations [75]. It is thus a distinct possibility that it is this compound which is responsible for the observed dehydrogenative oxidation of the indenols to the indenone compounds in our study.

A pertinent point from our work is that the metathesis reactions appear to be occurring prior to any competing isomerization processes. We thus decided to investigate the conversions of acyclic precursor **29** to the corresponding indenones **35** and indanones **36**, both presumably by way of the intermediate indenol **32**, to see if we could glean any further useful information. To this end we synthesized

a supply of indenol **32a** with the aim of testing its ability to undergo further transformations. Initial experiments proved that the isolated indenol compounds were relatively sensitive to oxidation in our hands [76–79]. We required samples of indenol **32a** without potentially catalytic ruthenium metal contamination and our initial attempts to remove the residual ruthenium from the indenol product **32a** using established methods involving activated carbon [80] or DMSO [81] afforded only the corresponding indenone **35a**. Fortunately we were able to remove the ruthenium trace contaminants from indenol **32a** [82] by the use of a polymer-bound scavenger **46**, recently described by Breinbauer and co-workers [83,84], without any undesired oxidation (Scheme 12). Samples of ruthenium-depleted **32a** were then dissolved in d_8-toluene and were then monitored by way of NMR spectroscopy [82].

The first experiment involved the addition of Grubbs second generation catalyst **19** to a sample of indenol **32a**, dissolved in d_8-toluene, from which the ruthenium had been scavenged. The NMR spectroscopy tube was then heated at 60 °C and the oxidation progress was monitored by ^{1}H NMR spectroscopy to confirm that indenol **32a** was converting into indenone **35a**.

We were also able to show that for samples of **32a** with depleted ruthenium concentrations, i.e. those that had been treated with the Breinbauer scavenger **46**, that no conversion to the indenone compounds **35a** occurred, even after extended heating (1180 min at 60 °C or 1680 min at 100 °C). In contrast, for samples of **32a** containing residual ruthenium species (i.e. unscavenged) the formation of indenone **35a** became apparent by ^{1}H NMR spectroscopy when heated to 100 °C. Of interest was that at 60 °C this conversion was not observed for similar samples containing residual ruthenium. The addition of Grubbs catalyst **19** to samples of **32a** that had been depleted of ruthenium species showed that the catalyst (or its degradation products) were definitely responsible for the conversion of indenol **32a** to indenone **35a** as after 80 min at 60 °C the first traces of indenone **35a** were observable in the ^{1}H NMR spectra. Furthermore, prolonged heating at this temperature showed that even these mild conditions were resulting in indanone **36a** formation as after 1180 min the sample contained indenol **32a**, indenone **35a** and indanone **36a** in a ratio of 3:5:1. At higher temperatures (100 °C) this conversion was even more facile resulting in a ratio of 1:5:21 of indenol **32a**, indenone **35a** and indanone **36a** after 1680 min. Whether the formation of indanone **36a** occurs by way of a direct redox-isomerization process or by way of a reductive oxidation–reduction process is still open to debate [72].



Scheme 12. Schematic description of NMR spectroscopy experiments. (a) Breinbauer scavenger resin **46**, (5 equiv relative to catalyst **19** in original sample); (b) d_8-toluene, (i) samples of untreated **32a**, (ii) Ru-depleted **32a**, (iii) Ru-depleted **32a**, 5% catalyst **19**; samples heated at rt, 60 °C and 100 °C, product formation monitored by NMR ^{1}H spectroscopy.

Our results thus show that the presence of the Grubbs II catalyst **19** (or its degradation products) is facilitating the transformation of indenol **32a** to indenone **35a** by way of a dehydrogenative oxidation without the addition of a hydrogen acceptor. In addition, it is now also known that under harsher reaction conditions a formal redox isomerization, which converts indenol **32a** into indanone **36a**, possibly by way of intermediate **35a**, successfully competes with this dehydrogenative oxidation.

Examples of alcohol-to-ketone redox isomerization by ruthenium catalysts, including the Grubbs first and second generation catalysts, **18** and **19** respectively, are well documented [66–68]. It must also be noted that there have been other recent reports in the literature describing the ruthenium-mediated dehydrogenation of alcohols without hydrogen acceptors. Recent examples of ruthenium catalysts that have proved capable at performing this transformation include the Shvo complex $\{[(\eta^5\text{-}Ph_4C_4CO)]_2H\}\text{-}Ru_2(CO)_4(\mu\text{-}H)$ [85], $Ru(OCOCF_3)_2(CO)(PPh_3)_2$ [86] and $Ru_3(CO)_{12}/PPh_3$ [87] amongst others [88,89]. However, to the best of our knowledge, our results demonstrate one of the first oxidative dehydrogenations, without additional hydrogen acceptor, mediated by the Grubbs catalyst **19** [90,91].

3. Conclusion

In conclusion, we can thus report that we have developed a general methodology towards substituted indenol and indenone skeletons using the Grubbs second generation catalyst-mediated RCM and a tandem RCM-dehydrogenative oxidation without additional hydrogen scavenger, respectively. These synthetic approaches have been found to be reliable and have the advantage that they are readily adaptable for the synthesis of a wide range of substituted indenols and indenones. In addition it was found that a limited number of indanones could be synthesized by way of a tandem RCM-formal redox isomerization procedure. Finally this paper described how we were able to make a pair of substituted indenes thus demonstrating

that we were able to access the full range of indane skeletons using our RCM approach. Our work in this area will now focus on the application of this approach to the total synthesis of natural products and their analogues for pharmacological evaluation.

4. Experimental

4.1. General information

^{1}H NMR and ^{13}C NMR spectra were recorded either on a Bruker AC-200, Bruker Advance-300 or Bruker DRX 400 spectrometer at the frequency indicated. DEPT, CH-correlated and HMBC spectra were run on some samples to enable complete assignments of all the signals. NMR spectroscopic assignments with the same superscript may be interchanged. Infra-red spectra were recorded on either a Bruker IFS 25 Fourier Transform spectrometer or on a Bruker Vector 22 Fourier Transform spectrometer. Mass spectra were recorded on a Kratos MS 9/50, VG 70E MS or a VG 70 SEQ mass spectrometer. Macherey-Nagel kieselgel 60 (particle size 0.063–0.200 mm) was used for conventional silica gel chromatography and Macherey-Nagel kieselgel 60 (particle size 0.040–0.063 mm) was used for preparative flash chromatography. All solvents used for reactions and chromatography were distilled prior to use.

4.1.1. Preparation of substituted benzaldehydes

The following substituted benzaldehydes were synthesised according to an established procedure [59]: 2-allyl-3-isopropoxy-4-methoxybenzaldehyde **27a** (R^1, R^2 = H) and 3-isopropoxy-4-methoxy-2-(1-methyl-2-propenyl)benzaldehyde **27b** (R^1 = Me, R^2 = H).

3-Isopropoxy-4-methoxy-2-(1-propenyl)benzaldehyde **28a** (*R^1 = H*). Aldehyde **27a** (R^1 = H) (1.65 g, 7.0 mmol) was dissolved in toluene (20 cm^3) and [RuClH(CO)(PPh_3)$_3$] (0.13 g, 0.14 mol) was added. The reaction solution was stirred at 80–90 °C for 4 h under N_2 after which the toluene was removed by evaporation. Purification by silica gel column chromatography (15% EtOAc–hexane) of the residue afforded product **28a** as an amber-coloured oil (1.65 g, quantitative, *E* > 95%). Compound **28a** (0.28 g, 44%) was also successfully synthesised from **27a** (0.63 g, 2.6 mmol) using $PdCl_2$ (5%) in MeOH at rt for 30 h. ^{1}H NMR (200 MHz, $CDCl_3$): δ = 10.05 (s, 1H, C*H*O), 7.70 (d, 1H, *J* = 8.6 Hz, H-5), 6.90 (d, 1H, *J* = 8.6 Hz, H-6), 6.73 (br d, 1H, *J* = 15.8 Hz, C*H*CHCH$_3$), 5.79 (dq, 1H, *J* = 15.8 Hz and 6.6 Hz, CHC*H*CH$_3$), 4.41 [sept, 1H, *J* = 6.2 Hz, OC*H*(CH$_3$)$_2$], 3.91 (s, 3H, OCH$_3$), 1.98 (dd, 3H, *J* = 6.6 Hz and 1.6 Hz, CHCHC*H*$_3$), 1.27 [d, 6H, *J* = 6.2 Hz, OCH(C*H*$_3$)$_2$]; ^{13}C NMR (50 MHz, $CDCl_3$, one quaternary carbon signal obscured in spectrum): δ = 191.7 (C=O), 157.1 (C), 137.8 (C), 136.2 (CH), 128.3 (C), 125.2 (CH), 123.0 (CH), 110.3 (CH), 75.4 [O*C*H(CH$_3$)$_2$], 55.8 (OCH$_3$), 22.5 [OCH(*C*H$_3$)$_2$], 19.1 (CH$_3$); IR (thin film, cm^{-1}): 1681, 1583, 1481, 1439, 1381; HRMS (EI): Calculated mass for $C_{14}H_{18}O_3$: 234.1256, found: 234.1255; *m/z*: 235 (M^++1, 16), 234 (72), 192 (33), 191 (44), 178 (29), 177 (100), 175 (16), 149 (17), 103 (22), 91 (23), 77 (19), 65 (15), 43 (18), 41 (18).

3-Isopropoxy-4-methoxy-2-(1-methyl-1-propenyl)benzaldehyde **28b** (*R^1 = Me*). Precursor **27b** (R^1 = Me) (0.50 g, 2.0 mmol) was dissolved in DMF (25 cm^3) and then KOBu^t (0.25 g, 2.2 mmol) was added. The solution was then heated to 60 °C and allowed to stir under an Ar atmosphere for 1 h. Distilled water (20 cm^3) was then added and the reaction mixture was stirred for 5 min. The pH was then neutralised using 1 M aqueous HCl and saturated $NaHCO_3$ solutions. The solvent was removed on the rotary evaporator and the remaining aqueous layer was extracted with EtOAc (3 × 50 cm^3). The combined organics were then dried over anhydrous $MgSO_4$, filtered and the solvent was removed *in vacuo*. The crude mixture was purified by column chromatography (5–10% EtOAc–hexane) to yield the desired product **28b** as an orange oil (0.038 g, 8%, *E*/*Z* ratio 4.3:1). In addition, a second, more predominant product (orange-brown oil) was recovered and this was found to be 5-isopropoxy-6-methoxy-4-methyl-1-naphthol **30** [59] (0.060 g, 12% relative to starting material). This reaction was originally done on a much smaller scale (0.10 g, 0.40 mmol of **27b**) with KOBu^t (0.049 g, 0.40 mmol) at 60 °C and resulted in desired product **28b** in 44% yield (0.044 g). ^{1}H NMR (300 MHz, $CDCl_3$, only *E* isomer listed): δ = 9.91 (s, 1H, CHO), 7.72 (d, 1H, *J* = 8.6 Hz, H-5), 6.92 (d, 1H, *J* = 8.6 Hz, H-6), 5.41–5.38 [m, 1H, C(CH$_3$)C*H*CH$_3$], 4.45–4.36 [m, 1H, OC*H*(CH$_3$)$_3$], 3.91 (s, 3H, OCH$_3$), 2.04 [s, 3H, C(C*H*$_3$)CHCH$_2$], 1.81 [d, 3H, *J* = 6.8 Hz, C(CH$_3$)CHC*H*$_3$], 1.20 [br s, 6H, OCH(C*H*$_3$)$_2$]; ^{13}C NMR (50 MHz, $CDCl_3$, assignments with superscripts may be interchanged, only *E* isomer listed): δ = 191.8 (C=O), 157.6 (C), 144.8 (C), 143.8 (C), 130.4 (C), 128.3 (CH), 125.3 (C), 123.9 (CH), 110.4 (CH), 75.3 [O*C*H(CH$_3$)$_2$], 55.7 (OCH$_3$), 22.4 [OCH(*C*H$_3$)$_2$], 17.9 [C(*C*H$_3$)CHCH$_3$],[a] 13.6 [C(CH$_3$)CH*C*H$_3$];[a] HRMS (EI): Calculated mass for $C_{15}H_{10}O_3$: 248.1412, found: 248.1417; *m/z*: 248 (M^+, 24), 233 (12), 220 (12), 206 (27), 205 (28), 204 (24), 193 (33), 192 (17), 191 (100), 189 (24), 177 (33), 163 (11), 91 (14), 77 (14), 43 (21), 41 (19), 27 (15).

3-Isopropoxy-4-methoxy-2-(1-phenyl-1-propenyl)benzaldehyde **28c** (*R^1 = Ph*) was synthesized according to a published procedure [59].

General description of Grignard reactions to 2-(1-propenyl)benzaldehydes (i.e. isomerized substrates): In a typical reaction, the Grignard reagent (1.2–10 mol equiv depending on the age and condition of the bottled reagent) was slowly added to cooled (0 or −60 °C) solution of benzaldehyde **28** in THF (the −60 °C solutions were allowed to warm slowly to rt). After reaction completion (1–3 h) the mixture was diluted with water, neutralized with HCl (0.1 M) and extracted with EtOAc. The combined organic extracts were washed with water and dried ($MgSO_4$). Filtration and evaporation of the solvent under reduced pressure afforded a dark yellow residue which was subjected to silica gel column chromatography (20% EtOAc–hexane) to

yield the desired alcohols **29** as clear yellow oils as described below.

1-[3-Isopropoxy-4-methoxy-2-(1-propenyl)phenyl]-2-propen-1-ol **29a** (R^1, $R^2 = H$). Benzaldehyde **28a** ($R^1 = H$) (0.18 g, 0.78 mmol) was treated with vinylmagnesium bromide (1.2 mmol, 1.5 mmol equiv), as described above, to afford **29a** as a yellow oil (0.20 g, 99%, $E/Z = 5{:}1$). ^{1}H NMR (200 MHz, $CDCl_3$, only E isomer listed): $\delta = 7.00$ (d, 1H, $J = 8.6$ Hz, H-6), 6.64 (d, 1H, $J = 8.6$ Hz, H-5), 6.30 (br d, 1H, $J = 16$ Hz, C*H*CHCH$_3$), 5.95–5.80 (m, 2H, CHCH_2), 5.26–4.99 (m, 3H, C*H*OH, CHC*H*CH$_3$ and C*H*CH$_2$), 4.19 [sept, 1H, $J = 6.1$ Hz, C*H*(CH$_3$)$_2$], 3.67 (s, 3H, OCH$_3$), 2.77 (br s, 1H, OH), 1.78 (d, 3H, $J = 5.9$ Hz, CHCHCH_3), 1.09–1.12 (m, 6H, CH(CH_3)$_2$); ^{13}C NMR (50 MHz, $CDCl_3$, only E isomer listed, assignments with superscripts may be interchanged): $\delta = 152.0$ (C), 144.0 (C), 140.3 (CH), 133.6 (C), 133.0 (C), 132.3 (CH), 124.4 (CH), 121.9 (CH), 113.8 (CH), 110.3 (CH), 74.8 [*C*H(CH$_3$)$_2$],[a] 70.6 (COH),[a] 55.3 (OCH$_3$), 22.2 [CH(*C*H$_3$)$_2$], 18.7 (CH$_3$); IR (thin film, cm^{-1}): 3440 br, 1638, 1594, 1573, 1480, 1436, 1380; HRMS (EI): Calculated mass for $C_{16}H_{22}O_3$: 262.1569, found: 262.1560; *m/z*: 262 (M^+, 17), 201 (9), 177 (8), 159 (11), 131 (13), 128 (9), 115 (22), 103 (16), 91 (21), 77 (15), 65 (10), 55 (8), 43 (100), 41 (45), 39 (13), 27 (33).

1-[3-Isopropoxy-4-methoxy-2-(1-phenyl-1-propenyl)phenyl]-2-propen-1-ol **29c** ($R^1 = Ph$, $R^2 = H$). Benzaldehyde **28c** ($R^1 = Ph$) (0.20 g, 0.65 mmol) was treated with vinylmagnesium bromide (1.3 mmol) at 0 °C, as described above, to afford **29c** as a yellow oil (0.12 g, 54%, >90% E isomer). The reaction was also repeated on a larger scale, **28c** (0.20 g, 0.65 mmol) and vinylmagnesium bromide (1.3 mmol) at −60 °C to afford **29c** in a yield of 46% (0.31 g). ^{1}H NMR (200 MHz, $CDCl_3$): $\delta = 7.27$–7.05 (m, 6H, 5 × ArH and H-5), 6.86 (d, 1H, $J = 8.6$ Hz, H-6), 6.38 (q, 1H, $J = 6.9$ Hz, CC*H*CH$_3$), 5.79–5.68 [m, 1H, CH(OH)C*H*CH$_2$], 5.02–4.86 [m, 3H, CH(OH)CHCH_2 and C*H*OH], 4.20 [sept, 1H, $J = 6.2$ Hz, C*H*(CH$_3$)$_2$], 3.74 (s, 3H, OCH$_3$), 1.78 (br s, OH), 1.63 (d, 3H, $J = 6.9$ Hz, CCHCH_3), 1.03 [d, 3H, $J = 6.2$ Hz, CH(CH_3)CH$_3$], 0.92 [d, 3H, $J = 6.2$ Hz, CH(CH$_3$)CH_3]; ^{13}C NMR (50 MHz, $CDCl_3$, assignments with superscripts may be interchanged): $\delta = 152.7$ (C), 144.2 (C), 141.4 (C), 140.2 (CH), 135.9 (C), 134.2 (C), 132.8 (C), 128.4 (2 × CH), 126.8 (CH), 126.1 (CH), 125.8 (2 × CH), 122.0 (CH), 113.8 (CH), 111.5 (CH), 74.7 (CHOH),[a] 71.1 [C*H*(CH$_3$)$_2$],[a] 55.5 (OCH$_3$), 22.6, 22.4 [CH(*C*H$_3$)$_2$], 16.3 (CH$_3$), IR (thin film, cm^{-1}): 1488, 1430, 1375, 1261; HRMS (EI): Calculated mass for $C_{22}H_{26}O_3$: 338.1882, found: 338.1883; *m/z*: 339 (M^++1, 16), 338 (60), 309 (22), 296 (23), 295 (24), 277 (25), 268 (38), 267 (100), 254 (15), 253 (25), 251 (20), 237 (15), 235 (51), 219 (28), 205 (20), 191 (17), 178 (18), 165 (24), 115 (19), 105 (25), 91 (36), 55 (16), 43 (23).

1-[3-Isopropoxy-4-methoxy-2-(1-propenyl)phenyl]-2-methyl-2-propen-1-ol **29d** ($R^1 = H$, $R^2 = Me$). Benzaldehyde **28a** ($R^1 = H$) (0.50 g, 2.0 mmol) was treated with isopropenylmagnesium bromide (3.0 mmol), as described above (−60 °C), to afford **29d** as a yellow oil (0.47 g, 85%, >95% E isomer). ^{1}H NMR (200 MHz, $CDCl_3$, only E isomer characterised): $\delta = 7.09$ (d, 1H, $J = 8.6$ Hz, H-5), 6.78 (d, 1H, $J = 8.6$ Hz, H-6), 6.45 (br d, 1H, $J = 16.0$ Hz, ArC*H*CH), 6.03 (dq, 1H, $J = 16.0$ Hz and 6.5 Hz, ArCHC*H*), 5.28–4.91 (m, 3H, ArC*H*OH and CH=CH_2), 4.32 [sept, 1H, $J = 6.2$ Hz, C*H*(CH$_3$)$_2$], 3.81 (s, 3H, OCH$_3$), 1.96 (br s, 1H, OH), 1.89 (dd, 3H, $J = 6.5$ Hz and 1.5 Hz, CHCH_3), 1.59 [s, 3H, C(OH)CH(CH_3)CH$_2$], 1.23 [d, 6H, $J = 6.2$ Hz, CH(CH_3)$_2$]; ^{13}C NMR (50 MHz, $CDCl_3$, assignments with superscripts may be interchanged): $\delta = 152.5$ (C), 147.1 (C), 137.7 (C), 133.5 (C), 132.2 (C), 132.1 (CH), 124.6 (CH), 122.0 (CH), 110.6 (CH), 110.4 (CH), 75.1 (CHOH),[a] 73.6 [O*C*H(CH$_3$)$_2$],[a] 55.7 (OCH$_3$), 22.5, 22.5 [OCH(*C*H$_3$)$_2$], 19.8 (CH$_3$), 19.1 (CH$_3$); IR (thin film, cm^{-1}): 3400 br, 1596, 1572, 1482, 1437, 1370; HRMS (EI): Calculated mass for $C_{17}H_{24}O_3$: 276.1725, found: 276.1727; *m/z*: 276 (M^+, 60), 247 (79), 234 (21), 233 (20), 216 (28), 206 (25), 205 (100), 201 (49), 193 (78), 192 (45), 191 (84), 190 (22), 189 (32), 187 (24), 177 (52), 176 (29), 175 (33), 174 (21), 173 (84), 171 (31), 161 (24), 159 (32), 157 (72), 145 (29), 143 (25), 131 (21), 115 (28), 103 (21), 91 (29), 77 (24), 43 (37), 41 (45).

1-[3-Isopropoxy-4-methoxy-2-(1-phenyl-1-propenyl)-phenyl]-2-methyl-2- propen-1-ol **29f** ($R^1 = Ph$, $R^2 = Me$). Benzaldehyde **28c** ($R^1 = Ph$) (0.14 g, 0.44 mmol) was treated with isopropenylmagnesium bromide (0.66 mmol), as described above, to afford **29f** as a yellow oil (0.089 g, 57%, >95% E isomer). ^{1}H NMR (200 MHz, $CDCl_3$, only E isomer characterised): $\delta = 7.31$–7.13 (m, 6H, 5 × ArH and H-5), 6.89 (d, 1H, $J = 8.6$ Hz, H-6), 6.45 (q, 1H, $J = 7.0$ Hz, CC*H*CH$_3$), 5.05 (br s, 1H, C*H*OH), 4.81 [br s, 2H, C(OH)CH(CH$_3$)CH_2], 4.20 [sept, 1H, $J = 6.1$ Hz, *C*H(CH$_3$)$_2$], 3.81 (s, 3H, OCH$_3$), 1.59 (d, 3H, $J = 7.0$ Hz, CCHCH_3), 1.48 (s, 3H, CH$_3$), 124 (br s, 1H, OH), 1.12 [d, 3H, $J = 6.1$ Hz, CH(CH_3)CH$_3$], 1.02 [d, 3H, $J = 6.1$ Hz, CH(CH$_3$)CH_3]; ^{13}C NMR (50 MHz, $CDCl_3$, assignments with superscripts may be interchanged): $\delta = 152.7$ (C), 146.1 (C), 144.4 (C), 141.6 (C), 135.5 (C), 133.4 (C), 133.3 (C), 128.4 (2 × CH), 126.8 (CH), 126.1 (CH), 125.8 (2 × CH), 122.1 (CH), 111.2 (CH), 110.2 (CH), 74.8 (CHOH),[a] 73.8 [O*C*H(CH$_3$)$_2$],[a] 55.5 (OCH$_3$), 22.8, 22.2 [CH(*C*H$_3$)$_2$], 19.3 (CH$_3$), 16.3 (CH$_3$); IR (thin film, cm^{-1}): 3458 br, 1651, 1594, 1573, 1478, 1435, 1371, 1347; HRMS (EI): Calculated mass for $C_{23}H_{28}O_3$: 352.2038, found: 352.2033; *m/z*: 352 (M^+, 37), 323 (20), 310 (58), 281 (90), 268 (100), 267 (35), 249 (47), 233 (34), 165 (25), 115 (21), 105 (34), 91 (29), 57 (25), 43 (73), 41 (43).

General description of Grignard reactions to 2-allylbenzaldehydes: The Grignard additions were done as described in the previous set of experiments to afford the desired alcohols listed below.

1-(2-Allyl-3-isopropoxy-4-methoxyphenyl)-2-propen-1-ol **31a** (R^1, $R^2 = H$). Benzaldehyde **27a** ($R^1 = H$) (1.62 g, 6.92 mmol) was treated with vinylmagnesium bromide (27.6 mmol) at −20 to 0 °C, as described above, to afford

31a as a yellow oil (0.89 g, 49%) as well as unreacted **27a** (0.40 g, 25%). ^{1}H NMR (200 MHz, $CDCl_3$): $\delta = 7.11$ (d, 1H, $J = 8.5$ Hz, H-6), 6.78 (d, 1H, $J = 8.5$ Hz, H-5), 6.07–5.90 (m, 2H, CH_2CHCH_2 and $CH(OH)CHCH_2$), 5.34 (br s, 1H, $CHOH$), 5.25–4.86 (m, 4H, CH_2CHCH_2 and $CH(OH)CHCH_2$), 4.45 [sept, 1H, $J = 6.2$ Hz, $CH(CH_3)_2$], 3.80 (s, 3H, OCH_3), 3.61–3.52 (m, 2H, CH_2CHCH_2), 2.32 (br s, 1H, OH), 1.26 [d, 3H, $J = 6.1$ Hz, $CH(CH_3)CH_3$], 1.23 [d, 3H, $J = 6.1$ Hz, $CH(CH_3)CH_3$]; ^{13}C NMR (50 MHz, $CDCl_3$, assignments with superscripts may be interchanged): $\delta = 152.1$ (C), 144.8 (C), 140.0 (CH), 137.5 (CH), 134.0 (C), 131.7 (C), 121.9 (CH), 115.1 (CH), 114.3 (CH), 110.3 (CH), 74.6 (CHOH),[a] 70.8 [$OCH(CH_3)_2$],[a] 55.5 (OCH_3), 30.1 (CH_2), 22.6, 22.5 [$OCH(CH_3)_2$]; IR (thin film, cm^{-1}): 3405 (br), 1637, 1598, 1487, 1437, 1381; HRMS (EI): Calculated mass for $C_{16}H_{22}O_3$: 262.1569, found: 262.1568; *m/z*: 262 (M^+, 35), 235 (20), 233 (32), 193 (100), 191 (67), 177 (50), 175 (30), 174 (24), 165 (20), 161 (23), 159 (32), 143 (45), 131 (21), 115 (23), 103 (20), 91 (21), 55 (18), 43 (24), 41 (25).

1-[3-Isopropoxy-4-methoxy-2-(1-methyl-2-propenyl)-phenyl]-2-propen-1-ol **31b** ($R^1 = Me$, $R^2 = H$). Benzaldehyde **27b** (R^1 = Me) (1.06 g, 4.21 mmol) was treated with vinylmagnesium bromide (8.4 mmol) at −60 °C, as described above, to afford **31b** as a yellow oil (1.05 g, 95%) as a mixture of isomers. ^{1}H NMR (200 MHz, $CDCl_3$, assignments in brackets are for the minor isomer): $\delta = 7.17$ (7.08) (d, 1H, $J = 8.7$ Hz, H-6), 6.82 (6.80) (d. 1H, $J = 8.6$ Hz, H-5), 6.32–5.92 (m, 2H, $2 \times CH{=}CH_2$), 5.56 (br s, 1H, $CHOH$), 5.40–4.92 (m, 4H, $2 \times CH{=}CH_2$), 4.57–4.40 [m, 2H, $CH(CH_3)_2$ and $CH(CH_3)CHCH_2$], 3.82 (s, 3H, OCH_3), 2.02 (1.88) (s, 1H, OH), 1.48 (1.37) (d, 3H, $J = 7.3$ Hz, $CHCH_3$), 1.29 [d, 3H, $J = 6.2$ Hz, $CH(CH_3)CH_3$], 1.24 [d, 3H, $J = 6.2$ Hz, $CH(CH_3)CH_3$]; ^{13}C NMR (75 MHz, $CDCl_3$, assignments in brackets are for the minor isomer, assignments with superscripts may be interchanged): $\delta = 152.2$ (152.0) (C), 143.9 (143.6) (CH), 140.4 (140.3) (CH), 137.6 (137.3) (C), 134.5 (134.4) (C), 123.8 (123.5) (CH), 113.9 (113.4) (CH), 112.9 (112.8) (CH), 110.7 (110.6) (CH), 74.4 [$CH(CH_3)_2$],[a] 69.9 (69.7) (CHOH),[a] 55.5 (OCH_3), 33.6 (33.5) ($CHCH_3$), 22.6 (22.6), 22.4 [$CH(CH_3)_2$], 19.9 (19.3) (CH_3); IR (thin film, cm^{-1}): 3426 br, 1633, 1595, 1485, 1429, 1371; HRMS (EI): Calculated mass for $C_{17}H_{24}O_3$: 276.1725, found: 276.1726; *m/z*: 276 (M^+, 83), 259 (41), 217 (56), 207 (77), 201 (59), 191 (56), 189 (50), 177 (40), 175 (81), 173 (46), 163 (40), 157 (100), 143 (35), 131 (32), 115 (37), 55 (67), 43 (35).

1-[3-isopropoxy-4-methoxy-2-(1-methyl-2-propenyl)-phenyl]-2-methyl-2- propen-1-ol **31e** (R^1, $R^2 = Me$). Benzaldehyde **27b** (R^1 = Me) (1.14 g, 4.59 mmol) was treated with vinylmagnesium bromide (13.5 mmol) at −60 °C, as described above, to afford **31b** as a yellow oil (1.11 g, 83%). This compound was not characterized by spectroscopy but was immediately subjected to isomerization with KOBu^t to afford compound **29e** as described below.

4.1.2. Isomerizations of the 1-(2-allylphenyl)-2-propen-1-ol compounds

1-[3-Isopropoxy-4-methoxy-2-(1-propenyl)phenyl]-2-propen-1-ol **29a** (R^1, $R^2 = H$). Alcohol **31a** (R^1, R^2 = H) (0.299 g, 1.14 mmols) was treated with KOBu^t (0.13 g, 0.12 mmol) in DMF (10 cm^3) for 15 min at rt, as described in the experimental description below, to afford **29a** (0.242 g, 81%). The spectroscopic description of this compound has been described previously in this section.

1-[3-Isopropoxy-4-methoxy-2-(1-methyl-1-propenyl)-phenyl]-2-propen-1-ol **29b** ($R^1 = Me$, $R^2 = H$). Alcohol **31b** (R^1 = Me, R^2 = H) (0.80 g, 4.7 mmol) was dissolved in DMF (15 cm^3). To this was added sublimed KOBu^t (0.45 g, 4.0 mmol) and the reaction mixture was stirred at rt under an Ar atmosphere for 15 min. After this time distilled water (15 cm^3) was added and the pH was neutralised using 1 M aqueous HCl. The solvent was removed *in vacuo* and then the remaining aqueous layer was extracted with EtOAc (3×15 cm^3). The combined organics were then extracted with distilled water (3×100 cm^3) and a small amount of brine. This was then dried over anhydrous $MgSO_4$ and the solvent was removed *in vacuo* to yield a bright yellow oil. This was purified by column chromatography (5% EtOAc–hexane) with the desired product **29b** being obtained as a yellow oil (0.76 g, 94%) which proved to be a complex mixture of isomers by NMR spectroscopy. ^{1}H NMR (300 MHz, $CDCl_3$): $\delta = 7.20$–7.08 (1H, m, H-5), 6.88–6.79 (m, 1H, H-6), 6.06–5.83 (m, 1H, $CH{=}CH_2$), 5.59–4.96 (m, 4H, CH-OH, $CH{=}CH_2$ and $C{=}CHCH_3$), 4.36–4.24 [m, 1H, $OCH(CH_3)_2$], 3.82 (s, 3H, OCH_3), 2.47 (br s, 1H, OH), 1.90–1.77 (multiple s, 3H, CH_3), 1.49–1.15 [multiple d, 9H, CH_3 and $OCH(CH_3)_2$]; ^{13}C NMR (50 MHz, $CDCl_3$): $\delta = 152.7$, 152.5, 152.3 (C), 144.0, 143.7 and 143.7 (C), 141.0, 141.0, 140.7 (CH), 136.1, 135.3 (C), 133.5, 133.3, 133.1, 133.0, 133.0, 132.8, 132.5 ($2 \times$ C), 125.4, 124.5, 123.5, 122.7, 122.1, 121.9, 121.8, 121.4 ($2 \times$ CH), 114.0, 113.9, 113.7 (CH), 110.9, 110.8, 110.7, 110.6 (CH), 75.4, 75.0 [$OCH(CH_3)_2$], 71.5, 71.4, 71.3, 71.0 (CHOH), 55.5 (OCH_3), 24.9, 24.4 (CH_3), 22.7, 22.6 [$OCH(CH_3)_2$], 17.8, 15.7, 15.5, 13.4 (CH_3); IR (thin film, cm^{-1}): 3607 br, 1667, 1593, 1479, 1380; HRMS (EI): Calculated for $C_{17}H_{24}O_3$: 276.1725, found: 276.1723; *m/z*: 276 (M^+, 65), 246 (25), 234 (30), 233 (24), 219 (25), 216 (25), 215 (23), 207 (26), 206 (26), 205 (100), 201 (37), 191 (37), 187 (30), 177 (20), 175 (27), 174 (26), 173 (91), 159 (20), 157 (28), 145 (21), 131 (22), 115 (23), 55 (22).

1-[3-Isopropoxy-4-methoxy-2-(1-methyl-1-propenyl)-phenyl]-2-methyl-2- propen-1-ol **29e** (R^1, $R^2 = Me$). Alcohol **31e** (R^1, R^2 = Me) (1.11 g, 3.8 mmol) was treated with KOBu^t (0.50 g, 4.5 mmol) in DMF (15 cm^3) for 15 min at rt, as described in the previous experiment, to afford **29e** as a yellow oil (0.93 g, 84%) which proved to be a complex mixture of isomers by NMR spectroscopy. ^{1}H NMR (200 MHz, $CDCl_3$): $\delta = 7.15$–7.06 (m, 1H, H-5), 6.88–6.80 (m, 1H, H-6), 5.67–5.43 (m, 1H, $CHOH$), 5.26–5.14 [m, 2H, $C(CH_3)CH_2$], 5.04–4.92 [m, 1H, $C(CH_3)CHCH_3$], 4.39 [sept, 1H, $J = 6.2$ Hz, $CH(CH_3)_2$], 3.84 (s, 3H,

OCH_3), 2.18–1.60 (multiple s, 6H, $2\times CH_3$), 1.55–1.41 (multiple s, 4H, OH and CH_3), 1.28–1.17 (m, 6H, $2\times CH_3$); ^{13}C NMR (50 MHz, $CDCl_3$, assignments with the same superscript may be interchanged): $\delta = 152.7$, 152.4, 152.3, 152.1 (C), 147.4, 147.0, 146.8, 146.6 (C), 143.9, 143.8, 143.6 (C), 142.0, 142.0, 137.0, 136.0 (C), 133.5, 132.9, 132.8 (C), 132.2, 132.1, 131.9, 131.8 (C), 125.2, 124.3, 123.3, 122.8, 121.7, 121.6, 121.4 ($2\times CH$), 110.5, 110.4, 110.4, 110.3, 110.2, 109.8 ($2\times CH$) 75.3, 74.9, 74.9 [$OCH(CH_3)_2$],[a] 73.5, 73.3 (CHOH),[a] 55.4 br (OCH_3), 25.1, 24.3 (CH_3), 22.6, 22.5, 22.5 [$OCH(CH_3)_2$], 19.9, 19.8, 19.4, 19.1, 17.9, 17.6, 15.7, 15.6, 13.4 ($2\times CH_3$); IR (thin film, cm^{-1}): 3398 br, 1652, 1596, 1573, 1480, 1429, 1379, 1347; HRMS (EI): Calculated for $C_{18}H_{26}O_3$: 290.1882, found: 290.1882; *m/z*: 291 (M^++1, 15), 290 (76), 273 (44), 261 (25), 248 (36), 247 (24), 219 (77), 207 (30), 206 (41), 205 (52), 191 (41), 187 (100), 177 (20), 171 (28), 157 (19), 145 (16), 91 (15), 43 (29), 41 (25).

Synthesis of indenols – general description: Grubbs catalyst **19** was added to a degassed solution (N_2) of the diene **29** in CH_2Cl_2 or toluene. The solution was then stirred under N_2 at room temperature (or else at the specified temperature) for an appropriate time until all starting material had been consumed (confirmed by tlc). After evaporation of the solvent and column chromatographic purification of the residue (20% EtOAc–hexane) the indenols were obtained as listed below.

4-Isopropoxy-5-methoxy-1H-inden-1-ol **32a** (R^1, $R^2 = H$). Diene **29a** (R^1, R^2 = H) (0.26 g, 1.00 mmol) was treated with catalyst **19** (0.043 g, 5%) in CH_2Cl_2 (25 cm^3) for 3 h at rt, as described above, to afford **32a** as a pale yellow oil (0.191 g, 87%). On a smaller scale (**29a**, 0.16 g) indenol **32a** (0.088 g, 64%) was isolated in a lower yield. ^1H NMR (200 MHz, $CDCl_3$, assignments with superscripts may be interchanged): $\delta = 7.12$ (d, 1H, $J = 7.9$ Hz, H-7), 6.73 (d, 1H, $J = 5.6$ Hz, H-3),[a] 6.66 (d, 1H, $J = 7.9$ Hz, H-6),[a] 6.27 (dd, 1H, $J = 5.6$ and 2.0 Hz, H-2), 5.04 (br s, 1H, H-1), 4.33 [br sept, 1H, $J = 6.2$ Hz, $CH(CH_3)_2$], 3.80 (s, 3H, OCH_3), 2.08 (br s, 1H, OH), 1.28 [d, 3H, $J = 6.4$ Hz, $CH(CH_3)CH_3$], 1.25 (d, 3H, $J = 6.5$ Hz, $CH(CH_3)CH_3$); ^{13}C NMR (50 MHz, $CDCl_3$, assignments with superscripts may be interchanged): $\delta = 153.3$ (C), 140.1 (C), 138.4 (C), 137.8 (CH), 136.7 (C), 129.2 (CH), 118.9 (CH), 109.4 (CH), 77.1 (C-1),[b] 75.6 [$CH(CH_3)_2$],[b] 55.9 (OCH_3), 22.5, 22.4 [$CH(CH_3)_2$]; IR (thin film, cm^{-1}): 3400 br, 1674, 1617, 1596, 1556, 1482, 1440; HRMS (EI): Calculated for $C_{13}H_{16}O_3$: 220.1099, found: 220.1099; *m/z*: 220 (M^+, 69), 179 (18), 178 (100), 177 (28), 176 (16), 163 (41), 161 (12), 149 (16), 147 (18), 146 (18), 135 (10), 118 (10), 77 (10), 57 (14), 55 (12), 43 (28), 41 (19).

4-Isopropoxy-5-methoxy-3-methyl-1H-inden-1-ol **32b** ($R^1 = Me$, $R^2 = H$). Diene **29b** (R^1 = Me, R^2 = H) (0.060 g, 0.22 mmol) was treated with catalyst **19** (0.011 g, 5%) in CH_2Cl_2 (15 cm^3) for 2 h at rt, as described above, to afford **32b** as a pale yellow oil (0.035 g, 64%). ^1H NMR (200 MHz, $CDCl_3$): $\delta = 7.10$ (d, 1H, $J = 6.9$ Hz, H-7), 6.68 (d, 1H, $J = 7.9$ Hz, H-6), 5.93 (br s, 1H, H-2), 4.99 (br s, 1H, H-1), 4.63 [sept, 1H, $J = 6.2$ Hz, $CH(CH_3)_2$], 3.82 (s, 3H, OCH_3), 2.22 (s, 3H, CH_3), 1.86 (br s, 1H, OH), 1.28 [d, 3H, $J = 6.2$ Hz, $CH(CH_3)CH_3$], 1.22 [d, 3H, $J = 6.2$ Hz, $CH(CH_3)CH_3$]; ^{13}C NMR (50 MHz, $CDCl_3$, assignments with superscripts may be interchanged): $\delta = 153.6$ (C), 141.6 (C), 141.2 (C), 140.1 (C), 136.5 (C), 133.4 (CH), 116.2 (CH), 109.6 (CH), 75.4 (C-1),[a] 74.2 [$CH(CH_3)_2$],[a] 56.0 (OCH_3), 22.5, 22.3 [$CH(CH_3)_2$], 16.6 (CH_3); IR (thin film, cm^{-1}): 3385 br, 1639, 1596, 1573, 1481, 1429; HRMS (EI): Calculated mass for $C_{14}H_{18}O_3$: 234.1256, found: 234.1259; *m/z*: 234 (M^+, 28%), 194 (52), 193 (33), 192 (35), 191 (46), 190 (49), 179 (91), 177 (35), 175 (23), 167 (20), 163 (22), 162 (20), 151 (72), 149 (53), 147 (25), 135 (23), 131 (20), 103 (21), 91 (35), 83 (23), 81 (23), 79 (22), 77 (38), 73 (45), 71 (30), 69 (57), 57 (100), 56 (21), 55 (54), 51 (20), 43 (86), 41 (99).

4-Isopropoxy-5-methoxy-3-phenyl-1H-inden-1-ol **32c** ($R^1 = Ph$, $R^2 = H$). Diene **29c** (R^1 = Ph, R^2 = H) (0.071 g, 0.21 mmol) was treated with catalyst **19** (0.009 g, 5%) in CH_2Cl_2 (15 cm^3) for 2 h at temp, as described above, to afford **32c** (0.041 g, 67%) as a pale cream-coloured solid (mp = 56–59 °C, recrystallized from EtOAc–hexane). ^1H NMR (200 MHz, $CDCl_3$): $\delta = 7.53$–7.48 (m, 2H, $2\times ArH$), 7.40–7.31 (m, 3H, $3\times ArH$), 7.23 (d, 1H, $J = 7.6$ Hz, H-7), 6.77 (d, 1H, $J = 7.6$ Hz, H-6), 6.23 (d, 1H, $J = 2.0$ Hz, H-2), 5.17 (br s, 1H, H-1), 3.92 [sept, 1H, $J = 6.1$ Hz, $CH(CH_3)_2$], 3.83 (s, 3H, OCH_3), 2.02 (br s, 1H, OH, D_2O exchangeable), 0.73 [d, 3H, $J = 6.1$ Hz, $CH(CH_3)CH_3$], 0.67 [d, 3H, $J = 6.1$ Hz, $CH(CH_3)CH_3$]; ^{13}C NMR (50 MHz, $CDCl_3$, C-1 carbon under chloroform signal): $\delta = 154.5$ (C), 146.0 (C), 141.3 (C), 139.8 (C), 136.2 (CH), 136.1 (C), 135.0 (C), 128.8 ($2\times CH$), 127.5 (CH), 127.3 ($2\times CH$), 116.9 (CH), 109.5 (CH), 75.6 [$CH(CH_3)_2$], 55.9 (OCH_3), 21.4, 21.3 [$CH(CH_3)_2$]; IR (thin film, cm^{-1}): 3375 br, 1690, 1593, 1476, 1442; HRMS (EI): Calculated mass for $C_{19}H_{20}O_3$: 296.1412, found: 296.1413; *m/z*: 296 (M^+, 45), 294 (20), 256 (24), 255 (30), 254 (39), 253 (45), 252 (100), 241 (26), 239 (20), 181 (25), 165 (23), 152 (30), 117 (43), 105 (25), 77 (26), 43 (52), 41 (25).

4-Isopropoxy-5-methoxy-2-methyl-1H-inden-1-ol **32d** ($R^1 = H$, $R^2 = Me$). Diene **29d** (R^1 = H, R^2 = Me) (0.12 g, 0.44 mmol) was treated with catalyst **19** (0.018 g × 2, 10%) in toluene (15 cm^3) for 24 h at 60 °C, as described above, to afford **32d** as a pale yellow oil (0.050 g, 49%) as well as indenone **35d** (0.024 g, 24%). ^1H NMR (200 MHz, $CDCl_3$): $\delta = 7.07$ (d, 1H, $J = 7.8$ Hz, H-7), 6.57 (d, 1H, $J = 7.8$ Hz, H-6), 6.32 (s, 1H, H-3), 4.76 (s, 1H, H-1), 4.23 [sept, 1H, $J = 6.1$ Hz, $CH(CH_3)_2$], 3.80 (s, 3H, OCH_3), 2.22 (br s, 1H, OH), 2.02 (s, 3H, CH_3), 1.28 [d, 3H, $J = 6.4$ Hz, $CH(CH_3)CH_3$], 1.24 (d, 3H, $J = 6.4$ Hz, $CH(CH_3)CH_3$); ^{13}C NMR (50 MHz, $CDCl_3$, assignments with superscripts may be interchanged): $\delta = 153.5$ (C), 148.3 (C), 139.2 (C), 138.3 (C), 137.2 (C), 123.5 (CH), 118.6 (CH), 106.1 (CH), 78.6 (C-1),[a] 75.4 [$CH(CH_3)_2$],[a] 55.8 (OCH_3), 22.5, 22.4 [$CH(CH_3)_2$], 13.9 (CH_3); IR (thin film, cm^{-1}): 3385 br, 1625, 1484, 1439, 1382, 1372; HRMS (EI): Calculated mass for $C_{14}H_{18}O_3$:

234.1256, found: 234.1255; *m/z*: 235 (M^++1, 36%), 234 (93), 217 (25), 193 (31), 192 (95), 191 (40), 178 (29), 177 (100), 175 (41), 161 (49), 160 (49), 159 (19), 149 (30), 132 (27), 131 (46), 115 (19), 103 (59), 91 (46), 77 (32), 65 (18), 43 (28), 41 (28), 39 (20), 27 (27).

4-Isopropoxy-5-methoxy-2,3-dimethyl-1H-inden-1-ol **32e** (R^1, $R^2 = Me$). Diene **29e** (R^1, R^2 = Me) (0.12 g, 0.42 mmol) was treated with catalyst **19** (0.035 g, 10%) in toluene (15 cm^3) for 24 h at 80 °C, as described above, to afford **32e** as a pale yellow oil (0.045 g, 43%) as well as indenone **35e** (0.047 g, 47%). ^{1}H NMR (200 MHz, $CDCl_3$): $\delta = 7.06$ (d, 1H, $J = 7.8$ Hz, H-7), 6.58 (d, 1H, $J = 7.8$ Hz, H-6), 4.66 (br s, 1H, H-1), 4.56 [sept, 1H, $J = 6.2$ Hz, C*H*$(CH_3)_2$], 3.80 (s, 3H, OCH_3), 2.15 (s, 3H, CH_3), 1.90 (s, 3H, CH_3), 1.82 (br s, 1H, OH), 1.27 [d, 3H, $J = 6.2$ Hz, CH(C*H*$_3$)CH_3], 1.20 [d, 3H, $J = 6.2$ Hz, CH(CH_3)C*H*$_3$]; ^{13}C NMR (50 MHz, $CDCl_3$, assignments with superscripts may be interchanged): $\delta = 153.1$ (C), 140.4 (C), 139.6 (C), 137.8 (C), 137.0 (C), 132.4 (C), 117.3 (CH), 107.6 (CH), 75.7 (C-1),[a] 73.6 [*C*H$(CH_3)_2$],[a] 55.2 (OCH_3), 21.8 (CH_3), 21.6 (CH_3), 12.6 (CH_3), 10.3 (CH_3); IR (thin film, cm^{-1}): 3398 br, 1635, 1611, 1587, 1540, 1480, 1439; HRMS (EI): Calculated for $C_{15}H_{20}O_3$: 248.1412, found: 248.1412; *m/z*: 249 (M^++1, 30%), 248 (90), 206 (74), 205 (60), 192 (34), 191 (100), 189 (41), 176 (24), 175 (37), 174 (34), 173 (28), 145 (31), 115 (32), 91 (29), 77 (20), 43 (26), 41 (26).

4-Isopropoxy-5-methoxy-2-methyl-3-phenyl-1H-inden-1-ol **32f** ($R^1 = Ph$, $R^2 = Me$). Diene **29f** (R^1 = Ph, R^2 = Me) (0.089 g, 0.25 mmol) was treated with catalyst **19** (0.017 g, 11%) in CH_2Cl_2 (15 cm^3) for 8 h at 40 °C, as described above, to afford **32f** as a pale yellow oil (0.013 g, 16%) as well as unreacted starting material **29f** (0.076 g, 84%). ^{1}H NMR (200 MHz, $CDCl_3$): $\delta = 7.34$–7.28 (m, 5H, 5 × ArH), 7.20 (d, 1H, $J = 7.9$ Hz, H-7), 6.69 (d, 1H, $J = 7.9$ Hz, H-6), 4.92 (br d, 1H, $J = 6.6$ Hz, H-1), 3.87 [sept, 1H, $J = 6.1$ Hz, C*H*$(CH_3)_2$], 3.81 (s, 3H, OCH_3), 1.95 (s, 3H, CH_3), 1.65 (br d, 1H, $J = 6.6$ Hz, OH), 0.66 [d, 3H, $J = 6.1$ Hz, CH(C*H*$_3$)CH_3], 0.59 (d, 3H, $J = 6.1$ Hz, CH(CH_3)C*H*$_3$); ^{13}C NMR (50 MHz, $CDCl_3$): $\delta = 154.6$ (C), 144.2 (C), 140.4 (C), 138.1 (C), 138.0 (C), 136.6 (C), 135.7 (C), 129.9 (2 × CH), 127.3 (2 × CH), 126.6 (CH), 116.5 (CH), 106.2 (CH), 78.4 (C-1),[a] 75.3 [*C*H$(CH_3)_2$],[a] 55.9 (OCH_3), 21.3, 21.2 [CH(*C*H$_3$)$_2$], 11.9 (CH_3); IR (thin film, cm^{-1}): 3369 br, 1598, 1478, 1440, 1371; HRMS (EI): Calculated mass for $C_{20}H_{22}O_3$: 310.1569, found: 310.1568; *m/z*: 311 (M^++1, 22%), 310 (100), 268 (76), 267 (25), 254 (15), 253 (84), 251 (19), 237 (31), 178 (15), 165 (19), 152 (16), 115 (13), 43 (45), 41 (26), 27 (15).

1-[3-isopropoxy-4-methoxy-2-(1-propenyl)phenyl]-2-methyl-2-propenyl acetate **33.** Alcohol **29d** (R^1 = H, R^2 = Me) (0.073 g, 0.27 mmol) was treated with Ac_2O (0.32 mmol) in pyridine (5 cm^3) and EtOAc (10 cm^3) for 16 h at rt. After evaporation of the pyridine under reduced pressure the mixture was diluted with EtOAc (10 cm^3), neutralized with saturated $NaHCO_3$ and extracted with further EtOAc (3 × 10 cm^3). The combined organic extracts were washed with water (3 × 10 cm^3) and dried ($MgSO_4$). Filtration and evaporation of the solvent under reduced pressure afforded a yellow residue which was subjected to silica gel column chromatography (20% EtOAc–hexane) to yield the desired acetyl ester **33** as yellow oil (0.070 g, 82%). ^{1}H NMR (200 MHz, $CDCl_3$, only *E* isomer characterized): $\delta = 7.00$ (d, 1H, $J = 8.6$ Hz, H-6), 6.71 (d, 1H, $J = 8.6$ Hz, H-5), 6.36–6.28 [m, 2H, ArC*H*CHCH$_3$ and ArCH(OAc)], 5.89–5.78 (m, 1H, ArCHC*H*CH$_3$), 4.84 [br d, 2H, $J = 10.4$ Hz, C(CH$_3$)=C*H*$_2$], 4.26–4.17 [m, 1H, C*H*$(CH_3)_2$], 3.74 (s, 3H, OCH_3), 2.01 (s, 3H, $COCH_3$), 1.80 (dd, 3H, $J = 7.0$ Hz and 1.3 Hz, CHC*H*$_3$), 1.56 (s, 3H, CCH_3), 1.16 [d, 3H, $J = 6.0$ Hz, CH(CH_3)C*H*$_3$], 1.13 [d, 3H, $J = 6.1$ Hz, CH(C*H*$_3$)CH_3]; ^{13}C NMR (50 MHz, $CDCl_3$, only *E* isomer characterized, assignments with superscripts may be interchanged): $\delta = 169.8$ (CO), 152.6 (C), 144.5 (C), 143.5 (C), 133.8 (C), 132.2 (CH), 128.9 (C), 124.5 (CH), 122.8 (CH), 112.0 (CH), 110.2 (CH), 75.7 [ArCH(OAc)],[a] 74.5 [*C*H$(CH_3)_2$],[a] 55.5 (OCH_3), 22.5 [CH(*C*H$_3$)$_2$], 21.1 (CH_3), 19.7 (CH_3), 18.9 (CH_3); IR (thin film, cm^{-1}): 1739, 1653, 1574, 1436; 1371; HRMS (EI): Calculated for $C_{19}H_{26}O_4$: 318.1831, found: 318.1832; *m/z*: 318 (M^+, 33%), 275 (7), 258 (17), 233 (21), 216 (93), 205 (48), 201 (100), 192 (20), 185 (27), 175 (36), 157 (43), 143 (14), 129 (17), 115 (20), 103 (9), 91 (13), 77 (9), 43 (47).

Synthesis of indenones – general description: Grubbs catalyst **1** was added to a degassed solution (N_2) of the diene **29** in toluene. The solution was then heated at 80 °C (or at another specified temperature) under N_2 for an appropriate time until all s.m. had been consumed (confirmed by tlc). After cooling, evaporation of the solvent and column chromatographic purification of the residue (20% EtOAc–hexane) the indenones **35** were obtained as described below.

4-Isopropoxy-5-methoxy-1H-inden-1-one **35a** (R^1, $R^2 = H$). Diene **29a** (R^1, R^2 = H) (0.082 g, 0.31 mmol) was treated with catalyst **19** (0.025 g, 8%) in toluene (15 cm^3) for 2 h at 80 °C, as described above, to afford **35a** as a pale yellow semi-solid (0.045 g, 66%). ^{1}H NMR (200 MHz, $CDCl_3$): $\delta = 7.64$ (d, 1H, $J = 5.8$ Hz, H-3), 7.38 (d, 1H, $J = 7.8$ Hz, H-7), 6.60 (d, 1H, $J = 7.8$ Hz, H-6), 5.86 (d, 1H, $J = 5.8$ Hz, H-2), 4.40 [sept, 1H, $J = 6.1$ Hz, C*H*$(CH_3)_2$], 3.87 (s, 3H, OCH_3), 1.31 [d, 6H, $J = 6.1$ Hz, CH(C*H*$_3$)$_2$]; ^{13}C NMR (50 MHz, $CDCl_3$): $\delta = 197.2$ (C=O), 158.8 (C), 145.5 (CH), 142.0 (C), 137.5 (C), 127.9 (CH), 123.9 (C), 119.7 (CH), 109.8 (CH), 75.9 [*C*H$(CH_3)_2$], 56.1 (OCH_3), 22.4 [CH(*C*H$_3$)$_2$]; IR (thin film, cm^{-1}): 1705, 1604, 1539, 1479, 1438, 1369; HRMS (EI): Calculated for $C_{13}H_{14}O_3$: 218.0943, found: 218.0943; *m/z*: 218 (M^+, 29%), 193 (21), 178 (20), 177 (40), 176 (100), 175 (25), 163 (17), 161 (23), 149 (37), 147 (20), 105 (21), 91 (17), 77 (26), 73 (23), 69 (22), 57 (33), 55 (26), 43 (49), 41 (46).

4-Isopropoxy-5-methoxy-3-methyl-1H-inden-1-one **35b** ($R^1 = Me$, $R^2 = H$). Diene **29b** (R^1 = Me, R^2 = H) (0.11 g, 0.40 mmol) was treated with catalyst **19** (0.017 g, 5%) in toluene (15 cm^3) for 48 h at 80 °C, as described

above, to afford **35b** as a pale yellow oil (0.044 g, 47%) as well as indenol **32b** (0.028 g, 30%). ^{1}H NMR (200 MHz, $CDCl_3$): $\delta = 7.17$ (d, 1H, $J = 7.7$ Hz, H-7), 6.60 (d, 1H, $J = 7.7$ Hz, H-6), 5.60 (s, 1H, H-2), 4.71 [sept, 1H, $J = 6.1$ Hz, C*H*$(CH_3)_2$], 3.85 (s, 3H, OCH_3), 2.38 (s, 1H, CH_3), 1.23 [d, 6H, $J = 6.2$ Hz, CH(C*H*$_3)_2$]; ^{13}C NMR (75 MHz, $CDCl_3$): $\delta = 196.4$ (C=O), 162.1 (C), 158.5 (C), 141.9 (C), 136.6 (C), 125.9 (C), 125.5 (CH), 118.1 (CH), 110.1 (CH), 74.7 [*C*H$(CH_3)_2$], 56.0 (OCH_3), 22.5 [CH(*C*H$_3)_2$], 17.9 (CH_3); IR (thin film, cm^{-1}): 1706, 1609, 1575, 1477, 1437, 1383; HRMS (EI): Calculated mass for $C_{14}H_{16}O_3$: 232.1099, found: 232.1098; *m*/*z*: 232 (M^+, 35%), 191 (21), 190 (84), 83 (16), 71 (13), 69 (25), 57 (27), 55 (16), 45 (10), 43 (45), 41 (37), 32 (18), 28 (100).

4-Isopropoxy-5-methoxy-3-phenyl-1H-inden-1-one **35c** (*R*^{1} = *Ph*, *R*^{2} = *H*). Diene **29c** (R^1 = Ph, R^2 = H) (0.11 g, 0.31 mmol) was treated with catalyst **19** (0.016 g × 2, 5% followed by 5% after 2 h) in toluene (15 cm^3) for 14 h at reflux, as described above, to afford **35c** (0.075 g, 82%) as a yellow semi-solid (mp 63–68 °C, recrystallized from EtOAc–hexane). When the reaction was repeated on a smaller scale, **29c** (0.038 g, 0.11 mmol) in xylene at 110 °C for 18 h, indenone **35c** was isolated in a slightly better yield (0.034 g, 89%).^{1}H NMR (200 MHz, $CDCl_3$): $\delta = 7.62$–7.58 (m, 2H, 2 × ArH), 7.43–7.41 (m, 3H, 3 × ArH), 7.27 (d, 1H, peak partially under $CHCl_3$ solvent signal, H-7), 6.68 (d, 1H, $J = 7.9$ Hz, H-6), 5.88 (s, 1H, H-2), 4.03 [sept, 1H, $J = 6.2$ Hz, C*H*$(CH_3)_2$], 3.88 (s, 3H, OCH_3), 0.76 [d, 6H, $J = 6.1$ Hz, CH(C*H*$_3)_2$]; ^{13}C NMR (50 MHz, $CDCl_3$): $\delta = 195.4$ (C=O), 163.1 (C), 159.7 (C), 142.2 (C), 135.8 (C), 134.5 (C), 129.5 (CH), 128.3 (2 × CH), 127.7 (2 × CH), 126.7 (CH), 126.3 (C), 119.4 (CH), 110.0 (CH), 76.3 [*C*H$(CH_3)_2$], 56.1 (OCH_3), 21.5 [CH(*C*H$_3)_2$]; IR (thin film, cm^{-1}): 1697, 1593, 1557, 1490, 1473, 1439, 1372; HRMS (EI): Calculated mass for $C_{19}H_{18}O_3$: 294.1256, found: 294.1264; *m*/*z*: 294 (M^+, 27%), 275 (12), 268 (12), 265 (12), 259 (16), 255 (17), 254 (18), 253 (22), 252 (100), 251 (19), 247 (22), 245 (12), 237 (10), 233 (15), 217 (18), 189 (11), 185 (11), 181 (15), 171 (18), 152 (17), 43 (13).

4-Isopropoxy-5-methoxy-2-methyl-1H-inden-1-one **35d** (*R*^{1} = *H*, *R*^{2} = *Me*). Diene **29d** (R^1 = H, R^2 = Me) (0.086 g, 0.30 mmol) was treated with catalyst **19** (0.039 g, 15%) in toluene (15 cm^3) for 48 h at 60 °C, as described above, to afford **35d** as a pale yellow oil (0.047 g, 23%) as well as indenol **32d** (0.013 g, 15%) and unreacted **29d** (0.030 g, 35%). ^{1}H NMR (200 MHz, $CDCl_3$): $\delta = 7.13$ (s, 1H, H-3), 7.06 (d, 1H, $J = 7.8$ Hz, H-7), 6.42 (d, 1H, $J = 7.8$ Hz, H-6), 4.27 [sept, 1H, $J = 6.1$ Hz, C*H*$(CH_3)_2$], 3.73 (s, 3H, OCH_3), 1.78 (s, 3H, CH_3), 1.23 [d, 3H, $J = 6.1$ Hz, CH(C*H*$_3$)CH_3], 1.22 [d, 3H, $J = 6.1$ Hz, CH(CH_3)C*H*$_3$]; ^{13}C NMR (50 MHz, $CDCl_3$): $\delta = 197.3$ (C=O), 159.0 (C), 140.2 (C), 138.6 (CH), 137.7 (C), 137.0 (C), 124.2 (C), 119.6 (CH), 108.4 (CH), 75.6 [*C*H$(CH_3)_2$], 55.9 (OCH_3), 22.4 [CH(*C*H$_3)_2$], 10.2 (CH_3); IR (thin film, cm^{-1}): 1705, 1606, 1482, 1435, 1366; HRMS (EI): Calculated mass for $C_{14}H_{16}O_3$: 232.1099, found: 232.1098; *m*/*z*: 232 (M^+, 14%), 191 (20), 190 (93), 189 (27), 175 (100), 161 (25), 147 (56), 131 (23), 119 (44), 118 (29), 115 (35), 105 (21), 103 (37), 102 (28), 91 (63), 90 (56), 89 (62), 77 (43), 75 (21), 65 (39), 64 (22), 63 (55), 51 (27), 43 (82), 41 (78), 39 (45), 27 (49).

4-Isopropoxy-5-methoxy-2,3-dimethyl-1H-inden-1-one **35e** (*R*^{1}, *R*^{2} = *Me*). Diene **29e** (R^1, R^2 = Me) (0.12 g, 0.42 mmol) was treated with catalyst **19** (0.035 g, 10%) in toluene (15 cm^3) for 24 h at 80 °C, as described above, to afford **35e** as a pale yellow oil (0.047 g, 47%) as well as indenol **32e** (0.045 g, 43%). ^{1}H NMR (300 MHz, $CDCl_3$): $\delta = 7.03$ (d, 1H, $J = 7.7$ Hz, H-7), 6.43 (d, 1H, $J = 7.7$ Hz, H-6), 4.65 [sept, 1H, $J = 6.2$ Hz, C*H*$(CH_3)_2$], 3.77 (s, 3H, OCH_3), 2.22 (s, 3H, CH_3), 1.69 (s, 3H, CH_3), 1.22 [d, 6H, $J = 6.2$ Hz, CH(C*H*$_3)_2$]; ^{13}C NMR (75.48 MHz, $CDCl_3$): $\delta = 196.8$ (C=O), 158.8 (C), 153.2 (C), 137.5 (C), 132.1 (C), 122.9 (C), 121.5 (C), 118.1 (CH), 108.7 (CH), 74.6 [*C*H$(CH_3)_2$], 55.9 (OCH_3), 22.4 [CH(*C*H$_3)_2$], 14.8 (CH_3), 7.5 (CH_3); IR (thin film, cm^{-1}): 1700, 1623, 1610, 1591, 1480, 1437, 1383, 1368; HRMS (EI): Calculated for $C_{15}H_{18}O_3$: 246.1256, found: 246.1256; *m*/*z*: 247 (M^++1, 15%), 246 (45), 220 (15), 219 (11), 205 (25), 204 (100), 203 (13), 191 (20), 189 (43), 177 (15), 161 (15), 115 (15), 77 (10), 43 (22), 41 (16).

4-Isopropoxy-5-methoxy-2-methyl-3-phenyl-1H-inden-1-one **35f** (*R*^{1} = *Ph*, *R*^{2} = *Me*). Diene **29f** (R^1 = Ph, R^2 = H) (0.060 g, 0.17 mmol) was treated with catalyst **19** (0.008 g, 5% followed by 0.018 g, 10% after 7.5 h) in toluene (15 cm^3) for 15 h at 80 °C, as described above, to afford **35f** (0.043 g, 82%) as a pale yellow solid (mp 152–154 °C, recrystallized from EtOAc–hexane). ^{1}H NMR (200 MHz, $CDCl_3$): $\delta = 7.45$–7.21 (m, 5H, 5 × ArH), 7.17 (d, 1H, $J = 7.7$ Hz, H-7), 6.49 (d, 1H, $J = 7.7$ Hz, H-6), 3.84 [sept, 1H, $J = 6.1$ Hz, C*H*$(CH_3)_2$], 3.76 (s, 3H, OCH_3), 1.73 (s, 3H, CH_3), 0.59 [d, 6H, $J = 6.2$ Hz, CH(C*H*$_3)_2$]; ^{13}C NMR (50 MHz, $CDCl_3$): $\delta = 196.5$ (C=O), 159.7 (C), 154.1 (C), 141.3 (C), 137.1 (C), 134.2 (C), 133.7 (C), 128.9 (2 × CH), 128.3 (CH), 127.5 (2 × CH), 125.1 (C), 119.2 (CH), 108.5 (CH), 75.8 [*C*H$(CH_3)_2$], 55.9 (OCH_3), 21.3 [CH(*C*H$_3)_2$], 8.6 (CH_3); IR (thin film, cm^{-1}): 1699, 1611, 1593, 1477, 1438, 1371; HRMS (EI): Calculated mass for $C_{20}H_{20}O_3$: 308.1412, found: 308.1413; *m*/*z*: 309 (M^++1, 18%), 308 (69), 267 (29), 266 (100), 265 (36), 251 (59), 235 (11), 205 (15), 165 (35), 152 (13), 139 (10), 115 (10), 43 (24), 41 (14).

4.1.3. Synthesis of indanones

4-Isopropoxy-5-methoxy-indan-1-one **36a** (*R* = *H*). Diene **29a** (R^1, R^2 = H) (0.20 g, 0.76 mmol) was dissolved in distilled toluene (20 cm^3) and the solution was heated to 80 °C. Grubbs II catalyst **19** (0.052 g, 0.060 mmol) was then added and the reaction mixture was allowed to stir at 80 °C under an Ar atmosphere for 22 h. After this time the solvent was removed *in vacuo* to give a brown-black oil that was then purified by column chromatography (5–10% EtOAc–hexane). The desired product **36a** was obtained as a pale orange oil (0.147 g, 88%) that solidified on standing (mp 52–55 °C) as well as a small amount of indenone **35a** (0.020 g, 12%). ^{1}H NMR (200 MHz, $CDCl_3$, assignments

with superscripts may be interchanged): $\delta = 7.48$ (d, 1H, $J = 8.3$ Hz, H-7), 6.94 (d, 1H, $J = 8.3$ Hz, H-6), 4.51 [sept, 1H, $J = 6.1$ Hz, C*H*$(CH_3)_2$], 3.90 (s, 3H, OCH_3), 3.08–3.02 (m, 2H, H-2),[a] 2.66–2.60 (m, 2H, H-3),[a] 1.29 [d, 6H, $J = 6.1$ Hz, CH(C*H*$_3)_2$]; ^{13}C NMR (50 MHz, $CDCl_3$): $\delta = 205.6$ (C=O), 157.9 (C), 149.0 (C), 143.4 (C), 131.0 (C), 119.8 (CH), 112.1 (CH), 74.6 [*C*H$(CH_3)_2$], 56.1 (OCH_3), 36.4 (C-2), 22.9 (C-3), 22.7 [CH(*C*H$_3)_2$]; IR (thin film, cm^{-1}): 1708, 1598, 1492, 1444, 1371, 1333; HRMS (EI): Calculated mass for $C_{13}H_{16}O_3$: 220.1099, found: 220.1099; *m*/*z*: 221 (M^++1, 6%), 220 (33), 179 (12), 178 (100), 177 (9), 163 (10), 149 (6), 135 (15), 107 (11), 71 (7), 43 (6).

4-Isopropoxy-5-methoxy-3-methyl-indan-1-one **36b** (*R* = *Me*). Diene **29b** (R^1 = Me, R^2 = H) (0.080 g, 0.29 mmol) was transferred to the round bottomed flask using CH_2Cl_2 (8 cm^3) and then the solution was degassed using N_2 for 11 min. After this time Grubbs catalyst **19** (0.013 g, 0.014 mmol) was added and the solution was heated to 110 °C (all the CH_2Cl_2 evaporated from flask over time). The solventless reaction mixture was then allowed to stir at 110–170 °C under an Ar atmosphere for 18 h. After this time the residue was purified by column chromatography (5–10% EtOAc–hexane) to yield the desired compound **36b** as a dark yellow oil (0.012 g, 18%) and a trace amount of indenone **35b** (0.005 g, 7% relative to starting material). ^{1}H NMR (300 MHz, $CDCl_3$): $\delta = 7.49$ (d, 1H, $J = 8.4$ Hz, H-7), 6.96 (d, 1H, $J = 8.4$ Hz, H-6), 4.58 [sept, 1H, $J = 6.1$ Hz, OC*H*$(CH_3)_2$], 3.92 (s, 3H, OCH_3), 3.54–3.49 (m, 1H, H-3), 2.91 (dd, 1H, $J = 7.7$ Hz and 19.0 Hz, one of H-2), 2.25 (dd, 1H, $J = 2.6$ Hz and 19.0 Hz, one of H-2), 1.42 and 1.36 (2 × d, 3H, $J = 6.6$ Hz, CH_3), 1.27 [6H, d, $J = 6.1$ Hz, OCH(C*H*$_3)_2$]; ^{13}C NMR (75 MHz, $CDCl_3$): $\delta = 205.2$ (C=O), 158.3 (C), 153.1 (C), 143.7 (C), 130.6 (C), 119.6 (CH), 112.3 (CH), 75.6 [O*C*H$(CH_3)_2$], 56.1 (OCH_3), 45.9 (C-2), 31.5 (C-3), 22.6 and 22.7 [OCH(*C*H$_3)_2$], 20.6 (CH_3); IR (thin film, cm^{-1}): 3019, 2981, 2882, 1699, 1594, 1490, 1437, 1379, 1335; HRMS (EI): Calculated mass for $C_{14}H_{18}O_3$: 234.1256. Found: 234.1213; *m*/*z* 234 (M^+, 21%), 41 (11), 43 (14), 69 (100), 77 (8), 91 (8), 131 (18), 132 (15), 177 (57), 178 (8), 190 (9), 191 (7), 192 (64), 219 (80), 220 (28), 234 (21), 263 (9), 264 (7).

4.1.4. Synthesis of indenes

Ethyl (2E)-3-(2-allyl-3-isopropoxy-4-methoxyphenyl)-2-propenoate **37a** (*R* = *H*). Benzaldehyde **27a** (R = H) (0.11 g, 0.49 mmols) and Ph_3P=$CHCO_2Et$ (0.20 g, 0.57 mmols) were heated neat at 120–140 °C for 2 h. After cooling down to rt, the dark solid mixture was purified by silica gel column chromatography (20% EtOAc–hexane) yielding **37a** (0.15 g, 97%) as an oily semi-solid. ^{1}H NMR (300 MHz, $CDCl_3$): $\delta = 7.92$ (d, 1H, $J = 15.8$ Hz, ArC*H*-$CHCO_2CH_2CH_3$), 7.33 (d, 1H, $J = 8.6$ Hz, H-6), 6.80 (d, 1H, $J = 8.6$ Hz, H-5), 6.25 (d, 1H, $J = 15.8$ Hz, ArCH-C*H*$CO_2CH_2CH_3$), 5.95–5.86 (m, 1H, $ArCH_2CHCH_2$), 5.02 [dd, 1H, $J = 10.2$ Hz and 1.5 Hz, $ArCH_2CHCH$(H)], 4.94 [dd, 1H, $J = 17.1$ Hz and 1.5 Hz, $ArCH_2CHCH$(*H*)], 4.50 [sept, 1H, $J = 6.2$ Hz, OC*H*$(CH_3)_2$], 4.24 (q, 2H, $J = 7.1$ Hz, $CO_2CH_2CH_3$), 3.85 (s, 3H, OCH_3), 3.62 (br d, 2H, $J = 5.8$ Hz, $ArCH_2CHCH_2$), 1.32 (t, 3H, $J = 7.1$ Hz, $CO_2CH_2CH_3$), 1.27 [d, 6H, $J = 6.2$ Hz, CH(C*H*$_3)_2$]; ^{13}C NMR (75 MHz, $CDCl_3$): $\delta = 167.1$ (C=O), 154.2 (C), 144.8 (C), 142.5 (CH), 136.4 (CH), 133.8 (C), 127.1 (C), 122.0 (CH), 117.2 (CH), 115.6 (CH), 110.2 (CH), 74.6 [*C*H$(CH_3)_2$], 60.1 (OCH_2), 55.5 (OCH_3), 30.4 ($ArCH_2$), 22.5 [CH(*C*H$_3)_2$], 14.2 (CH_3); IR (thin film, cm^{-1}): 1711, 1631, 1591, 1486, 1465, 1441, 1368; HRMS (EI): Calculated mass for $C_{18}H_{24}O_4$: 304.1675, found: 304.1678; *m*/*z*: 304 (M^+, 70%), 262 (45), 233 (36), 216 (37), 189 (55), 188 (58), 175 (25), 174 (100), 162 (55), 157 (86), 143 (31), 129 (31), 128 (26), 115 (40), 43 (30), 41 (25), 29 (41).

Ethyl (2E)-3-[3-isopropoxy-4-methoxy-2-(1-methyl-2-propenyl) phenyl]-2-propenoate **37b** (*R* = *Me*). Benzaldehyde **27b** (R = Me) (0.11 g, 0.44 mmol) was treated with Ph_3P=$CHCO_2Et$ (0.214 g, 0.61 mmols) as described in the previous experiment to afford **37b** (0.14 g, 95%) as an oily semi-solid. ^{1}H NMR (300 MHz, $CDCl_3$): $\delta = 8.18$ (d, 1H, $J = 15.7$ Hz, ArC*H*$CHCO_2CH_2CH_3$), 7.29 (d, 1H, $J = 8.7$ Hz, H-6), 6.78 (d, 1H, $J = 8.7$ Hz, H-5), 6.14 (d, 1H, $J = 15.7$ Hz, ArCHC*H*$CO_2CH_2CH_3$), 6.16–6.06 [m, 1H, $ArCH(CH_3)CHCH_2$], 5.15 [br d, 1H, $J = 12.1$ Hz, $ArCH(CH_3)CHCH$(*H*)], 5.10 [br d, 1H, $J = 17.5$ Hz, $ArCH(CH_3)CHCH$(H)], 4.42–4.57 [m, 2H, OC*H*$(CH_3)_2$ and ArC*H*$(CH_3)CHCH_2$], 4.23 (q, 2H, $J = 7.2$ Hz, $CO_2CH_2CH_3$), 3.85 (s, 3H, OCH_3), 1.40 [d, 3H, $J = 7.3$ Hz, $ArCH(CH_3)CHCH_2$], 1.31 (t, 3H, $J = 7.2$ Hz, $CO_2CH_2CH_3$), 1.29 [d, 3H, $J = 6.2$ Hz, CH(C*H*$_3)CH_3$], 1.26 [d, 3H, $J = 6.2$ Hz, CH(C*H*$_3)CH_3$]; ^{13}C NMR (75 MHz, $CDCl_3$): $\delta = 167.1$ (C=O), 154.0 (C), 144.4 (C), 144.1 (CH), 142.2 (CH), 139.0 (C), 127.1 (C), 123.0 (CH), 116.4 (CH), 113.4 (CH), 110.1 (CH), 74.6 [*C*H$(CH_3)_2$], 60.0 (OCH_2), 55.5 (OCH_3), 33.6 (*C*HCH_3), 22.5, 22.4 [CH(*C*H$_3)_2$], 19.1 (CH_3), 14.2 (CH_3); IR (thin film, cm^{-1}): 1712, 1630, 1589, 1483, 1466, 1441, 1369; HRMS (EI): Calculated mass for $C_{19}H_{26}O_4$: 318.1831, found: 318.1832; *m*/*z*: 318 (M^+, 46%), 276 (27), 247 (21), 202 (36), 189 (25), 188 (100), 187 (34), 173 (38), 171 (63), 157 (25), 115 (27), 43 (33), 29 (27).

7-Isopropoxy-6-methoxy-1H-indene **38a** (*R* = *H*). Grubbs catalyst **19** (0.013 g, 5%) was added to a degassed solution (N_2) of the diene **37a** (R = H) (0.092 g, 0.30 mmols) in CH_2Cl_2 (15 cm^3). The solution was then stirred under N_2 at rt for 1 h until all starting material had been consumed (confirmed by tlc). After evaporation of the solvent and silica gel column chromatographic purification of the residue (20% EtOAc–hexane) indene **38a** was afford as a yellow semi-solid (0.042 g, 68%). ^{1}H NMR (300 MHz, $CDCl_3$, assignments with superscripts may be interchanged): $\delta = 7.04$ (d, 1H, $J = 8.0$ Hz, H-4), 6.84 (d, 1H, $J = 8.0$ Hz, H-5), 6.78–6.75 (m, 1H, H-2),[a] 6.41–6.38 (m, 1H, H-3),[a] 4.55 [sept, 1H, $J = 6.2$ Hz, C*H*$(CH_3)_2$], 3.85 (s, 3H, OCH_3), 3.39 (s br, 2H, H-1), 1.31 [d, 6H,

$J = 6.2$ Hz, $CH(CH_3)_2$]; ^{13}C NMR (75 MHz, $CDCl_3$): $\delta = 150.8$ (C), 143.4 (C), 139.3 (C), 137.2 (C), 132.3 (CH), 131.4 (CH), 115.6 (CH), 111.4 (CH), 74.2 [$CH(CH_3)_2$], 56.3 (OCH_3), 37.1 (C-1), 22.8 [$CH(CH_3)_2$]; IR (thin film, cm^{-1}): 1590, 1552, 1481, 1440, 1380; HRMS (EI): Calculated mass for $C_{13}H_{16}O_2$: 204.1150, found: 204.1152; *m/z*: 204 (M^+, 64%), 176 (20), 166 (20), 162 (94), 150 (27), 147 (100), 131 (49), 130 (22), 103 (20), 91 (18), 77 (22), 51 (23), 43 (32), 41 (26).

7-Isopropoxy-6-methoxy-1-methyl-1H-indene **38b** (*R = Me*). Diene **37b** (R = Me) (0.096 g, 0.30 mmol) was treated with catalyst **19** (0.013 g, 5%) in CH_2Cl_2 (15 cm^3) for 1 h at rt, as described in the previous experiment, to afford **38b** as a pale yellow oil (0.047 g, 72%). ^1H NMR (200 MHz, $CDCl_3$): $\delta = 6.96$ (d, 1H, $J = 7.7$ Hz, H-4), 6.79 (d, 1H, $J = 7.7$ Hz, H-5), 6.63–6.59 (m, 1H, H-2), 6.30–6.26 (m, 1H, H-3), 4.57 [sept, 1H, $J = 6.2$ Hz, $CH(CH_3)_2$], 3.82 (s, 3H, OCH_3), 3.69–3.54 (m, 1H, H-1), 1.38–1.25 [multiple d, 9H, $CH(CH_3)_2$ and CH_3]; ^{13}C NMR (50 MHz, $CDCl_3$): $\delta = 151.1$ (C), 143.6 (C), 141.7 (C), 140.0 (CH), 138.3 (C), 129.2 (CH), 115.6 (CH), 111.1 (CH), 74.0 [$CH(CH_3)_2$], 56.1 (OCH_3), 44.7 (1-C), 22.9, 22.7 [$CH(CH_3)_2$], 14.8 (CH_3); IR (thin film, cm^{-1}): 1590, 1556, 1481, 1439, 1380, 1370; HRMS (EI): Calculated mass for $C_{14}H_{18}O_2$: 218.1307, found: 218.1306; *m/z*: 219 (M^++1, 20%), 218 (85), 194 (25), 179 (47), 177 (53), 176 (100), 175 (25), 164 (45), 161 (91), 151 (40), 144 (63), 143 (30), 131 (24), 116 (26), 115 (68), 103 (32), 91 (20), 77 (26), 43 (37), 41 (32), 39 (22), 27 (24).

Representative example describing the scavenging of ruthenium from an indenol sample using Breinbauer's scavenger resin 46. The indenol **32a** (0.485 mmol, 0.107 g) was dissolved in distilled CH_2Cl_2 (10 cm^3) and the solution was then degassed for 30 min using N_2. The Ru-scavenger **46** (0.77 mmol/g, 5 equiv relative to Grubbs II catalyst **11** present in the indenol sample, 0.0162 g) was added and the reaction mixture was left to stir for 17 h at rt under an Ar atmosphere. After this time the white "beads" of the Ru-scavenger had changed colour from bright white to grey-brown. The Ru-scavenger was then removed by filteration through a celite pad, which was subsequently rinsed with CH_2Cl_2 (50 cm^3). The solvent was then removed *in vacuo* to yield purified indenol **32a** as a bright yellow semi-solid (0.104 g, 99%).

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Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at doi:10.1016/j.jorganchem.2006.08.074.

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