Synthesis and catalytic application of ferrocene substituted camphane-based aminoalcohols and S-containing heterocyclic analogues

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ABSTRACT: A facile and practical approach was developed for the synthesis of chiral α -, β - and δ -aminoalcohols and S-containing heterocyclic analogues by using of readily available sources of chirality. The synthetic strategy involves utilization of camphor-derived ferrocene-containing starting compounds allowing, by means of nucleophilic additions of functionalized organolithiums, for the preparation of a small library of structurally diverse multifunctional derivatives possessing the bicyclic camphane skeleton as the central core. The new diastereoisomeric pure aminoalcohols and S-containing heterocyclic analogues have been evaluated as precatalysts for the addition of diethyl zinc to benzaldehyde providing in some cases very high enantioselectivity (up to 96%).

1. Introduction

The enantioselective addition of organozinc reagents to carbonyl compounds observed by Oguni and Omi,¹ first demonstrated with the reaction of Et_2Zn and benzaldehyde catalyzed by (*S*)-leucinol, still attracts considerable interest due to the opportunity of generating important pharmaceutically relevant intermediates with high enantioselectivity.²⁻⁵ The methods developed in recent years for the synthesis of structurally diverse organozinc reagents⁶⁻⁸ and a wide variety of chiral aminoalcohols^{9,10} prepared with the purpose to catalyze enantioselectively the additions of organozinc reagents, led the motivation to design the synthesis of new important chiral compounds. Since Noyori et al.¹¹⁻¹⁶ showed the efficiency of 3-dimethylamino-isoborneol as a chiral aminoalcohol able to serve as a ligand, there has been considerable interest for the preparation of structurally diverse aminoalcohols incorporating the camphane skeleton.

For the synthesis of camphane-based derivatives containing different functionalities camphor and fenchone are very convenient chiral pool sources which are readily available in enantiomerically pure form. The realization of diverse substitutions at the 1-, 2-, 3- and 7-positions of the camphane skeleton has been achieved by introducing mainly hydroxy and/or heteroatom-containing groups (Fig.1; the methyl groups in the product representing the different substitutions are omitted for clarity). Several synthetic strategies have been developed for the introduction of functionalities at 1- and 2-position of the bicyclic skeleton,¹⁷⁻³² some of which include skeleton rearrangements.³³⁻³⁷ The most simple way to introduce simultaneously hydroxyl- and heteroatom-containing groups at the 2-position is the nucleophilic addition of functionalized organometallic reagents to camphor and fenchone leading directly³⁸⁻⁴⁷ or after subsequent transformations⁴⁸⁻⁵¹ to aminoalcohols or analogues. The simultaneous occupation of the 2- and 3-position is limited to the synthesis of 3-dimethylaminoisoborneol and analogues.^{52,53} Interesting approaches have been demonstrated to introduce functionalities at the 2- and 7-position of the camphane scaffold^{54,55} and to realize the rare example of 1-, 2- and 3-substitution.⁵⁶

Figure 1. Substitution pattern within the camphane skeleton realized by synthetic transformations from camphor and fenchone (regardless the positions of remaining methyl groups).

In recent years we have demonstrated the synthesis of 2,3-⁵⁷ and 1,2,3-substituted⁵⁸ camphane-based aminoalcohols and analogues. The ability of these derivatives to act as precatalysts for enantioselective additions of

Et_2Zn to aldehydes has been evaluated as promising. Herein we report a synthetic approach to obtain aminoalcohols and analogues starting from (+)-camphor **1** and (+)-camphor-10-sulfonamide **3** by shielding the C-3 position with ferrocene-containing a fragment and then by using the nucleophilic addition approach to realize C-2 substitution.

2. Results and discussion

The synthesis of the starting compounds **7** and **9** for the planned addition reactions was performed by the initial generation of chiral enolates **2** and **4** (Scheme 1) from (+)-camphor **1** and (+)-10-camphor-sulfonamide **3** and subsequent Claisen-Schmidt condensation with ferrocene carbaldehyde. The enolates generation (**2** and **4**) was realized by deprotonation of **1** and **3** with lithium bis(trimethylsilyl)amide (LiHMDS)⁵⁸ or LDA (Method A), or alternatively by reaction with KOH under phase-transfer conditions catalyzed by 18-crown-6 (Method B) following an analogously published procedure.⁵⁹ The condensation using Method A is faster, however the yields of **7** and **9** do not exceed 70%.⁵⁸ Method B provides **7** and **9** in excellent yields (up to 91%) but requires longer reaction times. In all cases, the *Z*-isomers **6** and **8** are formed (up to 6%), which can be easily separated by column chromatography. Method B is suitable to perform the synthesis of **7** and **9** on a multi-gram scale.

Scheme 1. Synthesis of the starting compounds **7** and **9**.

Method A: LiHMDS or LDA for **2** and **4**, respectively; Method B: KOH/18-crown-6.

The selection of the functionalized organolithium reagents for the additions to **7** and **9** was performed in accordance with previously published results.^{39,42,44,60} Reagents **10-12**^{61,62} and **14**⁶² were generated *in situ* and used in hexane, hexane/ether or THF solvent mixtures (Scheme 2). Reagent **13** was isolated⁶³ and applied in pure form (colorless crystals). The addition of reagents **10-14** to ketone **7** provided products **15-19** in low to moderate yields (Scheme 2). The reaction of reagent **10** with **7** produced compound **15** in 17% yield together with a significant amount of 1,4-addition product **20** (20%). The addition of **11** consumed **7** completely, however significant decomposition occurred (recognized by TLC through the presence of several not identified by-products) thus lowering the yield of **16** (19% yield). With the analogous reagent **12**, the formation of product **17** was significantly higher (33%). The addition of reagents **13** and **14** in hexane was very low yielding (5% of **18** and 8% of **19**) as a result of a considerable 1,4-addition reaction (40% of **21** and 28% of **22** were isolated). In the case of products **15** and **17**, considerable amounts of the starting ketone **7** were isolated (37% and 53%, respectively) as result of its low conversion. The activation of **7** with anhydrous CeCl_3 in THF⁶⁴ improved only the addition of reagents **13** and **14** resulting in the isolation of the desired products **18** and **19** in higher yields (53% and 50%, respectively). Despite the CeCl_3 activation of ketone **7**, significant amounts of 1,4-addition product **21** were isolated after the reaction of reagent **13**. The competing 1,4-addition reaction is the main reason for the low yields of the desired products.

Isolated products of 1,4-addition:

Scheme 2. Synthesis of the compounds **15-19** by addition of organolithium reagents **10-14** to **7**.

The direct synthesis of ferrocene-substituted aminoalcohols and sulfur-containing analogues by using the addition approach of organolithium reagents was also applied in the case of ketone **9** (Scheme 3). The addition of reagents **10-12** to the ferrocenylmethylidene-camphor-10-sulfonamide **9** was not practical; reagent **10** did not react with **9** and the addition of **12** provided only the 1,4-addition product (mixture of two diastereoisomers in 65% yield). The latter observation was the reason for not performing reactions with reagent **11** since a similar result was expected. The addition of reagents **13** and **23-28**^{62,65-68} (generated *in situ*) to ketone **9** was performed in THF or hexane/THF solvent mixtures (in case of **13** toluene was used). The yields of the isolated 1,2-addition products were moderate (up to 48%). In the case of reagents **13**, **23** and **26**, considerable amounts of 1,4-addition products **36-38** were isolated in form of inseparable mixtures of diastereoisomers. The reaction of reagents **24**, **27** and **28** with **9** provided moderate yields of products **31**, **34** and **35** (in 48%, 47% and 25% yields of isolated pure compounds, respectively). Significant amounts of unreacted ketone **9** could be observed in most cases. The difficult separation of the products from mixtures containing **9** was an additional reason for reduced yields.

Some aspects of the 1,4-addition are noteworthy. In most cases, we observed the formation of two diastereoisomers. Compound **20** was isolated as a single diastereoisomer while in the case of **21** (procedure A; see Experimental) three isomers were observed in the ratio 5:10:12 contrary to procedure B, which provided only two isomers (ratio 2:5). In general, the formation of the 1,4-addition products depended strongly on the lithium reagent applied. The use of anhydrous CeCl_3 could shift some of the reactions towards the 1,2-addition, but not completely. The isolation of pure isomers was possible for **37** and **38** by column chromatography after significant efforts. The

experimental data with respect to the isolation, purification and determination of the ratio observed are reported in the Experimental. It was not possible to collect enough data for assigning the isomers either as originating from *endo*- or *exo*-positioned side chain, and/or as a result of the stereogenic center formation next to the ferrocene moiety.

R-Li	R (% yield)
13	29 (37)
23	30 (52)
24	31 (48)
25	32 (65)
26	33 (25)
27	34 (47)
28	35 (25)

Isolated products of 1,4-addition:

Scheme 3. Synthesis of compounds **29-30** by the addition of organolithium reagents **13** and **23-28** to **9**.

A further reaction sequence leading to aminoalcohols was the addition of reagent **39** (LiCH_2CN generated *in situ* from *n*-BuLi and dry CH_3CN)^{69,70} to ketones **7** and **9** (Scheme 4). The addition was performed at -78°C in THF to give compounds **40** and **41**, respectively, in good yields, which were then reduced to the corresponding aminoalcohols **42** and **43**. The latter were transformed easily into the alkylated cyclic derivatives **45** and **46** by using a simple procedure (addition of compound **44** and excess of K_2CO_3 in refluxing acetonitrile).⁷¹

Scheme 4. Synthesis of compounds **45** and **46** by the addition of cyanomethyl lithium **39** to **7** and **9** and subsequent transformations.

The structures of the new chiral compounds were proved by NMR experiments and mass spectra. The unambiguous assignment of the ¹H and ¹³C NMR spectra was made on the basis of DEPT, COSY, HSQC, HMBC and NOESY experiments. In all cases, the observed *endo*-diastereoselectivities of the addition reactions to the carbonyl C-atom of ketones **7** and **9** were excellent due to the exclusive *endo*-attack of the organolithium reagents. The decisive arguments for the course of the additions and thus for the determination of configurations were the NOESY experiments.

For compounds **15-17** and **19**, characteristic NOESY signals confirmed the proximity between *ortho*-aromatic protons of the substituents and 5-H_{endo}/6-H_{endo} protons were observed (Fig. 2). In the case of **45** strong interaction between both protons of the CH₂-group and 5-H_{endo}/6-H_{endo} protons was observed. Compound **18** was isolated as a single diastereoisomer, but due to signals overlap for CH₂-protons (from the side chain) and 5-H_{endo}/6-H_{endo} protons, no essential interactions could be observed. However, according to previously published results⁴⁴ for similar camphor-derived compounds, an *exo*-position for the OH-group in **18** was presumed. The observed proximity between OH-protons and 10-H/11-H in **15-17** and **19** confirmed the *exo*-position of the OH-groups in these compounds.

To confirm the *endo*-position of the substituents in compounds **30-34** and **46**, the same approach was applied (Fig. 2). In all cases characteristic protons from the substituents were determined to have close proximities to at least one of the *endo*-protons of the bicyclic moiety. In the case of compound **35** there is no suitable proton within the introduced substituent to demonstrate characteristic proximity to *endo*-positioned protons. However, there is an interaction observed in the NOESY spectra, between the protons of the OH-group and the protons of the methyl group (C-8) attached to the C-bridge of the bicyclic moiety. The same proton proximities are observed in the case of compounds **32-34**. For compound **29**, no characteristic signals could be observed due to overlapping resonances of the CH₂-protons from the substituent chain and the 5-H_{endo}/6-H_{endo} protons of the bicyclic core. The *endo*-position of the dimethylaminopropyl group could also be deduced in this case from previous results.⁴⁴

Figure 2. The observed proton proximities of specified substituent protons and the *endo*-H within the bicyclic core of compounds **15-17**, **19**, **30-34**, **45** and **46**, obtained by means of NOESY spectra.

Compounds **15-19**, **29-35**, **45** and **46** were applied as ligands for the enantioselective addition of Et_2Zn to benzaldehyde (Table 1) according to the literature.⁵⁸ The reaction times were between 3 and 168 hours. The yields of the isolated 1-phenyl-1-propanol were excellent in all cases, except for the reaction catalyzed by ligand **30** (entry 7, Tab. 1). The enantioselectivities obtained were in the range of low to excellent (up to 96%). The best enantioselectivities were realized with ligands **15** and **16**. When comparing ligands **16** and **17** there is a clear influence of the Me_3Si -group for obtaining better enantioselectivity. The same trend has been reported.⁴² The moderate enantioselectivity obtained with ligands **18** and **29** is in the range of those observed for the analogous ligand prepared through the reaction of reagent **13** and (+)-camphor.⁴⁴ It is interesting to note that ligands **47** and **48**, whose synthesis and application has been published earlier,⁵⁸ provide better enantioselectivities than ligands **19** and **32**. The latter are sulfur-containing structural analogues of **47** and **48**. By comparing the thiophene-substituted ligands **19** and **49**,⁵⁸ it seems that there is a positive influence of the sulfonamide group leading to an improvement of the enantioselectivity.

Scheme 5. Addition of Et_2Zn to benzaldehyde catalyzed by chiral ligands **15-19**, **29-35** and **45-49**.

Table 1. Addition of Et_2Zn to benzaldehyde catalyzed by ligands **15-19**, **29-35** and **45-49**.

Entry	Ligand	Ligand (% mol)	Yield (%) ^a	ee (%), conf ^b
1	15	1.5	99	96 (<i>R</i>)
2	16	1.5	97	96 (<i>S</i>)
3	17	3.0	99	89 (<i>S</i>)
4	18	1.5	96	35 (<i>R</i>)
5	19	3.0	96	22 (<i>R</i>)
6	29	3.0	82	68 (<i>S</i>)
7	30	3.0	62	14 (<i>R</i>)
8	31	3.0	97	20 (<i>S</i>)
9	32	3.0	90	62 (<i>R</i>)
10	33	3.0	73	6 (<i>S</i>)
11	34	3.0	92	56 (<i>R</i>)
12	35	3.0	90	18 (<i>S</i>)
13	45	3.0	99	38 (<i>R</i>)

14	46	3.0	88	25 (<i>R</i>)
15	47^c	3.0	59	76 (<i>R</i>)
16	48^c	3.0	83	76 (<i>R</i>)
17	49^c	3.0	48	56 (<i>R</i>)

^aYields of isolated 1-phenyl-1-propanol after column chromatography.

^bDetermined by GC (see Experimental).

^c Structure of compounds **47-49** (synthesis and application has been published earlier⁵⁸).

3. Conclusion

In conclusion, we have demonstrated a practicable application of functionalized organolithium reagents for the synthesis of chiral β -, γ - and δ - aminoalcohols as well as *S*-containing analogues possessing the bicyclo-heptane skeleton as the central core and ferrocene moiety as the bulky substituent attached to the 3-position of the bicyclic core. The use of inexpensive and readily available sources of chirality makes the presented synthetic strategies very useful for the preparation of a structurally diverse series of multifunctional chiral derivatives. The series of compounds synthesized were isolated in diastereoisomerically pure form and were characterized by spectroscopic methods. The configurations, with respect of the newly formed stereogenic centers within the compounds synthesized, were determined by applying advanced NMR methods. The evaluation of the synthesized compounds as ligands in the addition of Et_2Zn to benzaldehyde provided moderate to excellent enantioselectivities (up to 96%). The synthesized small library of compounds was evaluated for the biological activity and showed promising results (these results will be published elsewhere).

4. Experimental

4.1. General

The reactions were carried out in flame-dried Schlenk flasks under an argon atmosphere. Tetrahydrofuran (THF) and diethyl ether (Et_2O) were distilled over sodium/benzophenone. Hexane, benzene and toluene were distilled over $\text{Na}[\text{Et}_4\text{Al}]$. Acetonitrile was dried over molecular sieve (3 Å). Thin layer chromatography (TLC): aluminum sheets pre-coated with silica gel 60 F₂₅₄ (Merck). Column chromatography was carried out at normal pressure, using silica gel 60 (0.040–0.063 mm, 230–400 mesh ASTM Merck). Methyl *tert*-butyl ether (MTBE) and other solvents for crystallization, TLC and column chromatography were of high purity (>99.8 %) and were used without distillation. Melting points were determined in capillary tubes on Electrothermal MEL-TEMP 1102D–230 VAC apparatus without corrections. Optical rotation $[\alpha]$ measurements were obtained using Perkin–Elmer 241 polarimeter. Enantiomeric excess was measured on gas chromatograph Shimadzu GC-17A equipped with flame ionization detector (FID) and two chiral capillary columns: Cyclosil-B (permethylated- β -cyclodextrin) (30 m, $\varnothing = 0.25$ mm, film thickness 0.25 μm ; ee-determination of 1-phenyl-1-propanol: 0.7 ml/min He flow; thermal gradient 10 min at 80°C, 2°C/min to 100°C, 10 min at 100, 3°C/min to 150°C; retention time $t_{(R)} = 41.4$ min, $t_{(S)} = 42.2$ min) and Hydrodex- β -TBDAC (heptakis-(2,3-di-O-acetyl-6-O-*t*-butyldimethyl-silyl)- β -cyclodextrin) (25 m, $\varnothing = 0.25$ mm; ee-determination of 1-phenyl-1-propanol: 0.7 ml/min He flow; isothermal 122°C; retention time $t_{(R)} = 9.4$ min, $t_{(S)} = 9.8$ min). Mass spectra (MS) were recorded on a Thermo Scientific HRDFS (High Resolution Double Focusing Magnetic Sector) mass spectrometer (Bremen, Germany) and on a Hewlett Packard Mass Selective Detector 5973. MS spectra were reported as fragmentation in m/z with relative intensities (%) in parentheses. NMR spectra were recorded on a Bruker Avance DRX-250 (^1H at 250.13 MHz; ^{13}C at 62.90 MHz) and Bruker Avance II+ 600 (^1H at 600.13 MHz; ^{13}C at 150.92 MHz) spectrometers with TMS as internal standard for chemical shifts (δ , ppm). For the numbering of the C-atoms see Schemes 1–4. ^1H and ^{13}C NMR data are reported as follows: chemical shift, multiplicity (s = singlet, d = doublet, t = triplet, q = quartet, m = multiplet; br = broad signal), integration, identification and coupling constants (Hz). The chemical shifts of the ambiguously assigned signals in NMR data are marked with an asterisk (Cp stands for cyclopentadienyl, Fc marks the ferrocene moiety). The assignment of the ^1H and ^{13}C NMR spectra was made on the basis of DEPT, COSY, HSQC, HMBC and NOESY experiments. Samples for NOE difference experiments were prepared by blowing argon through the CDCl_3 solution. Elemental analyses were performed by the Microanalytical Laboratory for Elemental Analysis at the Institute of Organic Chemistry, Bulgarian Academy of Sciences. The following starting materials were used (commercially available or prepared according to the literature): ferrocenecarbaldehyde (Acros), *n*-butyllithium (*n*-BuLi, Fluka), (+)-camphor

(Fluka), diethylzinc (1 M solution in hexane, Fluka), *N,N*-dimethyl(2-(trimethylsilyl)phenyl)methanamine,⁴² (3-(dimethylamino)propyl)lithium,⁶³ thiophene (Fluka), *N,N*-dimethylbenzylamine (Fluka), *N,N*-dimethylaniline (Fluka), lithium aluminium hydride (Fluka), lithium diisopropylamide (LDA, Fluka), lithium hexamethyldisilazide (LiHMDS, Fluka), tetramethylethylenediamine (TMED), anhydrous cerium (III) chloride,⁴⁶ 1-isopropyl-1*H*-imidazole,⁶⁸ 2,6-lutidine (Fluka), benzothiophene (Fluka), dibenzothiophene (Fluka), trimethy-2-thienylsilane (Acros), benzothiazole (Fluka), 18-crown-6 (Fluka), α,α' -dichloro-*o*-xylene (Aldrich).

4.2. (1*R*,4*S*,*Z*)-3-Ferrocenylmethylidene-1,7,7-trimethylbicyclo[2.2.1]heptan-2-one **6** and (1*R*,4*S*,*E*)-3-ferrocenylmethylidene-1,7,7-trimethylbicyclo[2.2.1]heptan-2-one **7**

Method A:

To a solution of **1** (2.30 g, 15.00 mmol) in 100 ml of dry toluene was added LDA (7.50 ml, 15.12 mmol of 2 M solution in THF/ethylbenzene). After stirring for 15 min, **5** (2.10 g, 10.00 mmol) was added and the deep red mixture refluxed for 1 h. The reaction was monitored by TLC (petroleum ether/Et₂O = 5:1). The mixture was cooled and quenched with saturated aq. NH₄Cl, extracted with Et₂O and the organic phase was dried over anhydrous Na₂SO₄. The solvent was evaporated *in vacuo* and the crude product was chromatographed (37 g silica gel, petroleum ether/Et₂O = 25:1) to give **6** (0.170 g, 6%) as dark red crystals and **7** (2.05 g, 60%) as deep red crystals.

Method B:

A mixture of **1** (0.50 g, 3.28 mmol), KOH (0.28 g, 4.92 mmol) and 18-crown-6 (0.087 g, 0.33 mmol) in 10 ml dry benzene was stirred under argon for 30 min and **5** (0.70 g, 3.28 mmol) was added. The mixture was heated for 7 h at 80°C and then cooled, quenched with water and extracted with CH₂Cl₂ (3x30 ml). The organic phase was washed with water and dried over anhydrous Na₂SO₄. The solvent was evaporated *in vacuo* and the crude product was chromatographed (130 g silica gel, hexane/MTBE = 5:1) to give **6** (0.049 g, 4%) as dark red crystals and **7** (1.005 g, 88%) as deep red crystals.

Data of **6**: ¹H NMR (250 MHz, CDCl₃, 300 K): δ = 6.32 (s, 1H, 11-H), 5.12 (m, 1H, 13-H), 4.91 (m, 1H, 16-H), 4.34 (m, 2H, 14-H, 15-H), 4.10 (s, 5H, Cp), 2.49 (d, 1H, 4-H, *J* = 3.9 Hz), 1.97-2.11 (m, 1H, 5-H_{exo}), 1.63-1.72 (m, 1H, 6-H_{exo}), 1.39-1.50 (m, 2H, 5-H_{endo}, 6-H_{endo}), 0.99 (s, 3H, 10-H), 0.94 (s, 3H, 9-H), 0.88 (s, 3H, 8-H). ¹³C NMR (62.90 MHz, CDCl₃, 300 K): δ = 206.57 (1C, 2-C), 138.17 (1C, 3-C), 132.47 (1C, 11-C), 78.77 (1C, 12-C), 72.21 (1C, 16-C), 71.60 (1C, 13-C), 70.56* (1C, 14-C), 70.38* (1C, 15-C), 69.13 (5C, Cp), 59.47 (1C, 1-C), 54.77 (1C, 4-C), 46.00 (1C, 7-C), 29.83 (1C, 6-C), 27.51 (1C, 5-C), 20.63 (1C, 8-C), 18.66 (1C, 9-C), 9.65 (1C, 10-C). MS (EI) *m/z* (rel. int.): 348 (M⁺, 100), 283 (36).

Data of **7**: ¹H NMR (250 MHz, CDCl₃, 300 K): δ = 7.04 (s, 1H, 11-H), 4.48-4.53 (m, 2H, 13-H, 16-H), 4.36-4.41 (m, 2H, 14-H, 15-H), 4.13 (s, 5H, Cp), 2.93 (d, 1H, 4-H, *J* = 4.2 Hz), 2.04-2.15 (m, 1H, 5-H_{exo}), 1.66-1.80 (m, 1H, 6-H_{exo}), 1.41-1.54 (m, 2H, 5-H_{endo}, 6-H_{endo}), 1.01 (s, 3H, 10-H), 0.99 (s, 3H, 9-H), 0.82 (s, 3H, 8-H). ¹³C NMR (62.90 MHz, CDCl₃, 300 K): δ = 207.56 (1C, 2-C), 138.51 (1C, 3-C), 127.79 (1C, 11-C), 78.86 (1C, 12-C), 71.29 (1C, 16-C), 70.43* (1C, 14-C), 69.31 (5C, Cp), 69.01* (1C, 15-C), 68.39 (1C, 13-C), 57.11 (1C, 1-C), 49.30 (1C, 4-C), 46.34 (1C, 7-C), 30.80 (1C, 6-C), 25.72 (1C, 5-C), 20.70 (1C, 8-C), 18.42 (1C, 9-C), 9.32 (1C, 10-C).

4.3. 1-((1*S*,4*S*,*Z*)-3-Ferrocenylmethylidene-7,7-dimethyl-2-oxobicyclo[2.2.1]heptan-1-yl)-*N,N*-dimethylmethanesulfonamide **8** and 1-((1*S*,4*S*,*E*)-3-ferrocenylmethylidene-7,7-dimethyl-2-oxobicyclo[2.2.1]heptan-1-yl)-*N,N*-dimethylmethanesulfonamide **9**

A mixture of **3** (0.50 g, 1.93 mmol), KOH (0.16 g, 2.89 mmol) and 18-crown-6 (0.050 g, 0.19 mmol) in 12 ml dry toluene was stirred for 30 min and **5** (0.41 g, 1.93 mmol) was added. The mixture was heated for 5 h at 80°C (oil bath) and then cooled, quenched with water and extracted with CH₂Cl₂ (3x30 ml). The combined organic layers were washed with water and dried over anhydrous Na₂SO₄. The solvent was evaporated *in vacuo* and the crude product was chromatographed (170 g silica gel, hexane/MTBE = 5:1) to give **8** (0.021 g, 2%) as dark red crystals and **9** (0.799 g, 91%) as deep red crystals. Compounds **8** and **9** have identical physical and spectroscopic data as described in the literature.⁵⁸

4.4. (1*R*,2*R*,4*S*,*E*)-3-(Ferrocenylmethylidene)-2-(2-(dimethylamino)phenyl)-1,7,7-trimethylbicyclo[2.2.1]heptan-2-ol **15**

To a solution of *n*-BuLi (0.83 ml, 1.32 mmol of 1.6 M solution in hexane) in 3 ml of hexane were added TMED (0.20 ml, 1.32 mmol) and *N,N*-dimethylaniline (0.20 ml, 1.58 mmol). The mixture was refluxed for 4 h and after cooling to 0°C was added **7** (0.23 g, 0.66 mmol) as a solid. The reaction mixture was stirred for 18 h (monitoring by TLC, petroleum ether/Et₂O = 10:1), quenched with water, extracted with Et₂O and the organic phase dried over anhydrous Na₂SO₄. The solvent was evaporated *in vacuo* and the crude product was chromatographed (70 g silica gel,

petroleum ether/Et₂O = 40:1), to give unreacted **7** (0.085 g, 37%), **20** (0.062 g, 20%) as a yellow oil and **15** (0.053 g, 17%) as a yellow solid.

Data of **15**: Mp 171-173°C (with decomp.). [α]_D²⁰ = -136.9 (*c* 0.41, CHCl₃). ¹H NMR (250 MHz, CDCl₃, 300 K): δ = 9.30 (s, 1H, OH), 7.40 (dd, 1H, 3'-H, *J* = 8.0, 1.4 Hz), 7.30-7.36 (m, 1H, 6'-H), 7.23-7.30 (m, 1H, 4'-H), 7.08-7.16 (m, 1H, 5'-H), 6.10 (s, 1H, 11-H), 4.44 (m, 1H, 16-H), 4.28 (m, 1H, 13-H), 4.22 (m, 1H, 15-H), 4.16 (m, 1H, 14-H), 4.15 (s, 5H, Cp), 2.88 (d, 1H, 4-H, *J* = 4.3 Hz), 2.79* (s, 3H, NMe_a), 2.71* (s, 3H, NMe_b), 1.98 (m, 1H, H-5_{exo}), 1.58 (m, 1H, H-5_{endo}), 1.38 (m, 1H, H-6_{exo}), 1.11 (m, 1H, H-6_{endo}), 1.17 (s, 3H, 8-H), 0.96 (s, 3H, 10-H), 0.94 (s, 3H, 9-H). ¹³C NMR (62.90 MHz, CDCl₃, 300 K): δ = 154.29 (1C, 2'-C), 152.03 (1C, 3-C), 140.23 (1C, 1'-C), 131.62 (1C, 6'-C), 127.76 (1C, 4'-C), 124.34 (1C, 5'-C), 123.53 (1C, 3'-C), 122.78 (1C, 11-C), 89.13* (1C, 2-C), 83.78* (1C, 12-C), 69.61 (1C, 13-C), 68.55 (6C, 14-C, Cp), 68.22 (1C, 15-C), 67.62 (1C, 16C), 54.64 (1C, 1-C), 51.62 (1C, 4-C), 49.51 (1C, 7-C), 46.33* (1C, NMe_a), 49.03* (1C, NMe_b), 31.15 (1C, 6-C), 24.53 (1C, 5-C), 22.87 (1C, 8-C), 21.11 (1C, 10-C), 11.10 (1C, 9-C). MS (EI) *m/z* (rel. int.): 469 (M⁺, 100), 199 (22), 167 (23), 149 (88). Anal. calcd. for C₂₉H₃₅FeNO (469.44) C, 74.20; H, 7.51; Fe, 11.90; N, 2.98. Found: C, 74.16; H, 7.59; Fe, 11.76; N, 2.89 %.

Data of **20**: ¹H NMR (250 MHz, CDCl₃, 300 K): δ = 7.08-7.27 (m, 4H, 3'-H, 4'-H, 5'-H, 6'-H), 4.69 (d, 1H, 3-H, *J* = 11.8 Hz), 4.11 (m, 1H, Fc), 4.07 (m, 3H, Fc), 3.77 (s, 5H, Cp), 2.69 (s, 6H, NMe₂), 2.23 (d, 1H, 11-H, *J* = 11.8 Hz), 2.09 (d, 1H, 4-H, *J* = 4.1 Hz), 1.93 (m, 1H), 1.53 (m, 1H), 1.22-1.36 (m, 1H), 1.16 (s, 3H, Me), 0.89 (s, 3H, Me), 0.85 (m, 1H), 0.78 (s, 3H, Me). ¹³C NMR (CDCl₃, 300K): δ = 217.22 (1C, C=O), 151.76 (1C, quaternary Ar), 142.80 (1C, quaternary Ar), 128.04 (1C, CH Ar), 126.54 (1C, CH Ar), 124.06 (1C, CH Ar), 120.12 (1C, CH Ar), 94.87 (1C, quaternary), 70.27 (1C, Fc), 68.59 (5C, Cp), 67.84 (1C, Fc), 66.87 (1C, Fc), 65.33 (1C, Fc), 61.60 (1C, CH), 57.99 (1C, quaternary), 47.13 (1C, CH), 45.95 (1C, quaternary), 45.41 (2C, NMe₂), 38.45 (1C, CH), 29.79 (1C, CH₂), 29.26 (1C, CH₂), 20.83 (1C, Me), 20.67 (1C, Me), 9.47 (1C, Me).

4.5. (1*R*,2*R*,4*S*,*E*)-3-(Ferrocenylmethylidene)-2-(2-((dimethylamino)methyl)-3-(trimethylsilyl)phenyl)-1,7,7-trimethylbicyclo[2.2.1]heptan-2-ol **16**

To a solution of *n*-BuLi (2.14 ml, 3.42 mmol of 1.6 M solution in hexane) in 6 ml of hexane were added 1 ml of Et₂O and *N,N*-dimethyl(2-(trimethylsilyl)phenyl)methanamine (0.71 g, 3.42 mmol) at room temperature. The solution was refluxed for 3 h and its color changed from colorless to a clear deep red. The mixture was then cooled to 0°C and **7** was added (0.30 g, 0.86 mmol) as a solid (reaction progress was monitored by TLC, petroleum ether/Et₂O = 5:1). After stirring for 1 h at 0°C, it was quenched with water, extracted with Et₂O and the organic phase was dried over anhydrous Na₂SO₄. The solvent was evaporated *in vacuo* and the crude product was chromatographed (70 g silica gel, petroleum ether/Et₂O = 20:1 to 3:1) to give **16** (0.09 g, 19%) as an orange-yellow solid. Mp 81-83°C. [α]_D²⁰ = -381.8 (*c* 0.40, CHCl₃). ¹H NMR (250 MHz, CDCl₃, 300 K): δ = 10.07 (br s, 1H, OH), 7.69 (dd, 1H, 6'-H, *J* = 8.0, 2.4 Hz), 7.41 (dd, 1H, 4'-H, *J* = 7.3, 1.5 Hz), 7.18 (t, 1H, 5'-H, *J* = 7.6 Hz), 6.18 (s, 1H, 11-H), 4.55 (d, 1H, 7'-H_a, *J* = 12.1 Hz), 4.48 (m, 1H, 16-H), 4.31 (m, 1H, 13-H), 4.24 (m, 1H, 15-H), 4.17-4.21 (m, 1H, 14-H), 4.19 (s, 5H, Cp), 3.38 (d, 1H, 7'-H_b, *J* = 12.1 Hz), 2.86 (d, 1H, 4-H, *J* = 4.4 Hz), 2.18 (s, 6H, NMe₂), 1.81 (tt, 1H, 6-H_{exo}, *J* = 12.1, 4.1 Hz), 1.43 (ddd, 1H, 6-H_{endo}, *J* = 13.1, 9.2, 4.6 Hz), 1.10-1.26 (m, 1H, 5-H_{exo}), 1.17 (s, 3H, 8-H), 1.02 (s, 3H, 10-H), 0.89 (s, 3H, 9-H), 0.43 (ddd, 1H, 5-H_{endo}, *J* = 13.1, 8.8, 4.0 Hz), 0.37 (s, 9H, SiMe₃). ¹³C NMR (62.90 MHz, CDCl₃, 300 K): δ = 155.28 (1C, 3-C), 145.05 (1C, 2'-C), 143.15 (1C, 1'-C), 142.22 (1C, 3'-C), 133.19 (1C, 4'-C), 133.09 (1C, 6'-C), 124.96 (1C, 5'-C), 121.21 (1C, 11-C), 88.28* (1C, 2-C), 84.35* (1C, 12-C), 69.44 (1C, 13-C), 68.51 (5C, Cp), 68.12 (1C, 14-C), 68.09 (1C, 15-C), 67.69 (1C, 16-C), 62.95 (1C, 7'-C), 55.87 (1C, 1-C), 51.82 (1C, 4-C), 49.42 (1C, 7-C), 43.03 (2C, NMe₂), 30.77 (1C, 5-C), 23.26 (1C, 6-C), 22.59 (1C, 8-C), 21.29 (1C, 9-C), 12.51 (1C, 10-C), 2.19 (3C, SiMe₃). MS (EI) *m/z* (rel. int.): 555 (M⁺, 5), 167 (21), 149 (100), 129 (29). Anal. calcd. for C₃₃H₄₅FeNOSi (555.65): C, 71.33; H, 8.16; Fe, 10.05; N, 2.52. Found: C, 71.45; H, 8.24; Fe, 10.16; N, 2.63 %.

4.6. (1*R*,2*R*,4*S*,*E*)-3-(Ferrocenylmethylidene)-2-(2-((dimethylamino)methyl)phenyl)-1,7,7-trimethylbicyclo[2.2.1]heptan-2-ol **17**

To a solution of *N,N*-dimethylbenzylamine (0.31 g, 2.25 mmol) in 4 ml of Et₂O was added *n*-BuLi (1.70 ml, 2.70 mmol of 1.6 M solution in hexane) at room temperature and stirred for 48 h; next 5 ml of Et₂O and **7** (0.50 g, 1.44 mmol) were added at room temperature. The reaction mixture was monitored by TLC (petroleum ether/Et₂O/Et₃N = 100:20:1) and after 1 h was quenched at 0°C with 8% aqueous H₃PO₄ (pH 4), and extracted with Et₂O to remove **7**. The aqueous phase was alkalized with solid K₂CO₃ to pH 11, extracted with Et₂O and the organic phase was dried over anhydrous Na₂SO₄. The solvent was evaporated *in vacuo* and the crude product was chromatographed (87 g silica gel, Et₂O) to give **17** (0.23 g, 33%) as an orange solid. Mp 66-68°C. [α]_D²⁰ = -389.7 (*c* 1.00, CHCl₃). ¹H NMR (250 MHz, CDCl₃, 300 K): δ = 9.03 (br s, 1H, OH), 7.57 (dd, 1H, 6'-H, *J* = 16.9, 1.5 Hz), 7.12-7.25 (m, 3H, 3'-H, 4'-H, 5'-H), 6.09 (s, 1H, 11-H), 4.54 (d, 1H, 7'-H_a, *J* = 11.7 Hz), 4.46 (m, 1H, 16-H), 4.29 (m, 1H, 13-H), 4.23 (m, 1H, 15-H), 4.18 (s, 5H, Cp), 4.15-4.20 (m, 1H, 14-H), 2.87 (d, 1H, H-4, *J* = 4.4 Hz), 2.87 (d, 1H, 7'-H_b, *J* = 11.7 Hz), 2.24 (s, 6H, NMe₂),

2.20 (m, 1H, 4-H), 1.89 (m, 1H, 6-H_{exo}), 1.52 (ddd, 1H, 6-H_{endo}, $J = 12.0, 8.1, 4.7$ Hz), 1.29 (ddd, 1H, 5-H_{exo}, $J = 12.0, 4.7, 1.3$ Hz), 1.16 (s, 3H, 9-H), 1.07 (s, 3H, 10-H), 0.91 (s, 3H, 8-H), 0.78-0.90 (m, 1H, H-5_{endo}). ¹³C NMR (62.90 MHz, CDCl₃, 300 K): $\delta = 154.91$ (1C, 3-C), 145.99^* (1C, 2'-C), 136.74^* (1C, 1'-C), 133.37 (1C, 5'-C), 132.07 (1C, 6'-C), 126.39 (1C, 3'-C), 126.22 (1C, 4'-C), 121.60 (1C, 11-C), 88.64^* (1C, 2-C), 84.21^* (1C, 12-C), 69.45 (1C, 13-C), 68.51 (5C, Cp), 68.11^* (1C, 15-C), 67.64 (1C, 16-C), 67.64^* (1C, 14-C), 65.13 (1C, 7'-C), 55.38 (1C, 1-C), 51.72 (1C, 4-C), 49.60 (1C, 7-C), 44.10 (2C, NMe₂), 31.04 (1C, 5-C), 23.57 (1C, 6-C), 22.52 (1C, 9-C), 21.22 (1C, 8-C), 12.86 (1C, 10-C). MS (EI) m/z (rel. int.): 483 (M^+ , 5), 149 (100), 129 (19). Anal. calcd. for C₃₀H₃₇FeNO (483.47): C, 74.53; H, 7.71; Fe, 11.55; N, 2.90. Found: C, 74.67; H, 7.80; Fe, 11.41; N, 2.79 %.

4.7. (1R,2R,4S,E)-3-(Ferrocenylmethylidene)-2-(3-(dimethylamino)propyl)-1,7,7-trimethylbicyclo[2.2.1]heptan-2-ol **18**

Method A:

To a solution of **7** (0.36 g, 1.03 mmol) in 20 ml of hexane was added **13** as a solid (0.14 g, 1.55 mmol) at room temperature. The reaction was monitored by TLC (petroleum ether/Et₂O = 1:1) and after stirring for 1 h at room temperature, was quenched with water, extracted with Et₂O, and the organic phase was dried over anhydrous Na₂SO₄. The solvent was evaporated *in vacuo* and the crude product was chromatographed (79 g silica gel, Et₂O/Et₃N = 50:1) to give **21** (0.18 g, 40%) as an orange oil (diastereomeric mixture of 3 isomers in ratio 5:10:12) and pure **18** (0.02 g, 5%) as an orange-yellow solid.

Method B:

A mixture of CeCl₃ (0.14 g, 0.57 mmol) and 5 ml of THF was stirred at room temperature under an argon atmosphere for 15 min. Ketone **7** (0.20 g, 0.57 mmol) was added as a solid and the mixture was stirred for an additional 1 h. To this mixture was added **13** as a solid (0.11 g, 1.15 mmol). The reaction was monitored by TLC (Et₂O/Et₃N = 200:1) and after 1 h it was quenched with diluted aqueous NH₄Cl, and extracted with Et₂O. The organic phase was dried over anhydrous Na₂SO₄, the solvent was evaporated *in vacuo* and the crude product was chromatographed (115 g silica gel, petroleum ether/Et₂O = 1:1 then Et₂O/Et₃N = 200:1) to give **21** (0.06 g, 22%, diastereomeric mixture of two isomers in a ratio 2:5, major and minor respectively) as an orange oil, and pure **18** (0.13 g, 53%) as an orange-yellow solid.

Data of **18**: Mp 102-103°C. $[\alpha]_D^{20} = -31.0$ (c 0.58, CHCl₃). ¹H NMR (250 MHz, CDCl₃, 300 K): $\delta = 6.09$ (s, 1H, 11-H), 4.31 (m, 1H, 16-H), 4.28 (m, 1H, 13-H), 4.12-4.19 (m, 2H, 14-H, 15-H), 4.10 (s, 5H, Cp), 2.73 (d, 1H, 4-H, $J = 4.9$ Hz), 2.28 (s, 6H, NMe₂), 2.20-2.40 (m, 2H, 3'-H), 1.84-1.97 (m, 1H, 5-H_{exo}), 1.60-1.90 (m, 2H, 1'-H), 1.60-1.84 (m, 2H, 2'-H), 1.50-1.62 (m, 2H, 6-H_{exo}, 6-H_{endo}), 1.20-1.31 (m, 1H, 5-H_{endo}), 1.01 (s, 3H, 8-H), 0.99 (s, 3H, 10-H), 0.88 (s, 3H, 9-H). ¹³C NMR (62.90 MHz, CDCl₃, 300 K): $\delta = 154.62$ (1C, 3-C), 116.28 (1C, 11-C), 83.68^* (1C, 2-C), 80.18^* (1C, 12-C), 69.02 (1C, 13-C), 68.85 (5C, Cp), 68.12 (1C, 14-C), 68.12 (1C, 15-C), 68.05 (1C, 16-C), 60.85 (1C, 3'-C), 52.54 (1C, 1-C), 50.97 (1C, 4-C), 49.17 (1C, 7-C), 45.62 (2C, NMe₂), 40.62 (1C, 1'-C), 30.79 (1C, 6-C), 25.37 (1C, 5-C), 23.26 (1C, 2'-C), 22.39 (1C, 8-C), 20.10 (1C, 9-C), 12.11 (1C, 10-C). MS (EI) m/z (rel. int.): 435 (M^+ , 100), 364 (21), 283 (23), 199 (16), 149 (22). Anal. calcd. for C₂₆H₃₇FeNO (435.42): C, 71.72; H, 8.56; Fe, 12.83; N, 3.22. Found: C, 71.77; H, 8.67; Fe, 13.00; N, 3.31 %.

Data of **21** (data extracted from a mixture of two isomers, obtained according Method B): ¹H NMR (250 MHz, CDCl₃, 300 K): $\delta = 4.13$ (s, Cp minor isomer), 4.11 (s, Cp major isomer), 4.06-4.11 (m), 4.02-4.05 (m), 3.93-3.98 (m), 2.56-2.69 (m), 2.20-2.35 (m), 2.24 (s, NMe₂), 2.10-2.18 (m), 1.15-1.98 (m), 0.97 (s, Me major isomer), 0.89 (s, Me major isomer), 0.86 (s, Me minor isomer), 0.85 (s, Me minor isomer), 0.84 (s, Me minor isomer), 0.83 (s, Me major isomer). MS (EI) m/z (rel. int.): 435 (M^+ , 100), 362 (15), 336 (16), 237 (18), 171 (9), 121 (15), 58 (42).

4.8. (1R,2R,4S,E)-3-(Ferrocenylmethylidene)-1,7,7-trimethyl-2-(thiophen-2-yl)bicyclo[2.2.1]heptan-2-ol (**19**)

Method A:

To a mixture of *n*-BuLi (0.77 ml, 0.92 mmol of 1.6 M solution in hexane) and 1.0 ml THF was added thiophene (0.07 ml, 0.92 mmol) at 0°C. The light yellow solution was allowed to warm to room temperature and stirred for 1 h, then cooled down to -50°C and **7** (0.16 g, 0.46 mmol) was added as a solid. The mixture was stirred and allowed to warm slowly to room temperature; the reaction progress was monitored by TLC (petroleum ether/Et₂O = 5:1). After 1.5 h **7** was consumed completely and the mixture was quenched with water, extracted with Et₂O, and the organic phase was dried over anhydrous Na₂SO₄. The solvent was evaporated *in vacuo* and the crude product was chromatographed (110 g silica gel, petroleum ether/toluene/Et₂O = 50:1:1 then petroleum ether/toluene = 15:1) to give pure **19** (0.021 g, 8%) as an orange solid and 0.071 g (28%) mixture of **19** and **22** (**22** as a mixture of two isomers).

Method B:

To a mixture of *n*-BuLi (1.00 ml, 1.2 mmol of 1.2 M solution in hexane) and 1.0 ml THF was added thiophene (0.077 g, 0.07 ml, 0.92 mmol) at 0°C. The formed light yellow solution of 2-lithiothiophene was allowed to warm to room temperature and stirred for 1h. Separately prepared was a suspension of CeCl₃ (0.11 g, 0.46 mmol) in 2 ml THF and **7** (0.16 g, 0.46 mmol), and it was stirred at room temperature under argon within 1.5. The mixture was then cooled to -40°C and the solution of 2-lithiothiophene was added. The mixture was allowed to warm slowly to room temperature. The reaction progress was monitored by TLC (petroleum ether/Et₂O = 5:1). After stirring for 20 h at room temperature, **7** was converted completely and the mixture was quenched with saturated aqueous NH₄Cl, extracted with Et₂O and the organic phase was dried over anhydrous Na₂SO₄. The solvent was evaporated *in vacuo* and the crude product was chromatographed (37 g silica gel, petroleum ether/Et₂O = 30:1) to give pure **19** (0.10 g, 50%) as orange solid.

Data of **19**: Mp 113-114°C. [α]_D²⁰ = -261.0 (c 1.29, hexane). ¹H NMR (250 MHz, CDCl₃, 300 K): δ = 7.26 (dd, 1H, 2'-H, *J* = 4.9, 1.5 Hz), 6.97 (d, 1H, 4'-H, *J* = 7.0 Hz), 6.97-7.03 (m, 1H, 3'-H), 6.30 (s, 1H, 11-H), 4.42 (m, 1H, 16-H), 4.34 (m, 1H, 15-H), 4.26 (m, 1H, 14-H), 4.23 (m, 1H, 13-H), 4.20 (s, 5H, Cp), 2.92 (d, 1H, 4-H, *J* = 4.4 Hz), 2.26 (s, 1H, OH), 1.92 (m, 1H, 5-H_{exo}), 1.35-1.46 (m, 2H, 5-H_{endo}, 6-H_{exo}), 1.00-1.08 (m, 1H, 6-H_{endo}), 1.15 (s, 3H, 8-H), 1.10 (s, 3H, 10-H), 0.98 (s, 3H, 9-H). ¹³C NMR (62.90 MHz, CDCl₃, 300 K): δ = 151.71 (1C, 3-C), 151.00 (1C, 1'-C), 125.86 (1C, 4'-C), 125.49 (1C, 3'-C), 124.65 (1C, 2'-C), 121.85 (1C, 11-C), 83.74* (1C, 2-C), 82.67* (1C, 12-C), 68.79 (5C, Cp), 68.55 (2C, 13-C, 14-C), 69.26 (1C, 15-C), 68.05 (1C, 16-C), 54.40 (1C, 1-C), 51.24 (1C, 4-C), 48.77 (1C, 7-C), 31.54 (1C, 6-C), 24.59 (1C, 5-C), 22.42 (1C, 8-C), 20.90 (1C, 9-C), 9.64 (1C, 10-C). MS (EI) *m/z* (rel. int.): 432 (M⁺, 100), 416 (13), 149 (71). Anal. calcd. for C₂₅H₂₈FeOS (432.40): C, 69.44; H, 6.53; Fe, 12.92; S, 7.42. Found: C, 69.60; H, 6.79; Fe, 13.09; S, 7.32 %.

Data of **22** (data extracted from a mixture of **19** and **22**, obtained according Method A): ¹H NMR (250 MHz, CDCl₃, 300 K): δ = 7.72-7.71 (m, **22**-Ar), 7.56-7.50 (m, **22**-Ar), 7.26-7.23 (m, **19**-Ar), 7.22-7.20 (m, **22**-Ar), 7.01-6.92 (m, **19**-Ar, **22**-Ar), 6.28 (s, **19**), 4.40-4.39 (m, **19**-Fc), 4.33-4.31 (m, **19**-Fc), 4.24-4.20 (m, **19**-Fc, **22**), 4.18 (s, **22**-Fc), 4.16-4.10 (m, **22**-Fc), 3.97 (d, **22**), 2.89 (d, **19**), 2.80-2.42 (m, **22**), 1.96-1.84 (m, **19**), 1.71-1.64 (m, **22**), 1.45-1.27 (m, **19**, **22**), 1.13 (s, **19**), 1.09 (s, **19**), 0.97-0.82 (m, **19**, **22**).

4.9. 1-((1*S*,2*R*,4*S*,*E*)-3-(Ferrocenylmethylidene)-2-(3-(dimethylamino)propyl)-2-hydroxy-7,7-dimethylbicyclo[2.2.1]heptan-1-yl)-*N,N*-dimethylmethanesulfonamide **29**

To a solution of 3-(dimethylamino)propyllithium (0.43 g, 4.62 mmol) in 5 ml toluene was added **9** (0.70 g, 1.54 mmol) at -50°C. After stirring at this temperature for 3 h, the mixture was allowed to warm to 5°C. The reaction progress was monitored by TLC (EtOAc/MeOH/CH₂Cl₂/Et₃N = 5.8:0.05:0.05:0.1) until **9** was consumed. The mixture was quenched with water (10 ml), extracted with Et₂O (3×20 ml) and the organic phase was dried over anhydrous Na₂SO₄. The solvent was evaporated *in vacuo* and the crude product was chromatographed (90 g silica gel, EtOAc/MeOH/CH₂Cl₂/Et₃N = 5.8:0.05:0.05:0.001) to give **36** (0.413 g, 48%; diastereomeric mixture of two isomers in ratio 1:1) as an orange-yellow oil and pure **29** (0.306 g, 37%) as an orange-yellow solid.

Data of **29**: Mp 137-139°C. [α]_D²⁰ = -68.3 (c 0.38, CHCl₃). ¹H NMR (600 MHz, CDCl₃, 293 K): δ = 6.17 (s, 1H, 11-H), 4.30-4.29 (m, 1H, 16-H), 4.28-4.27 (m, 1H, 13-H), 4.19-4.18* (m, 1H, 14-H), 4.17-4.16* (m, 1H, 15-H), 4.10 (s, 5H, Cp), 3.47 (d, 1H, 10-H_a, *J* = 14.3 Hz), 2.90 (s, 6H, SO₂NMe₂), 2.74 (d, 1H, 4-H, *J* = 4.9 Hz), 2.68 (d, 1H, 10-H_b, *J* = 14.3 Hz), 2.42-2.36 (m, 2H, 3'-H), 2.33 (s, 6H, NMe₂), 2.29-2.25 (m, 1H, 2'-H_a), 2.09-1.94 (m, 4H, 1'-H, 6-H_{exo}, 5-H_{exo}), 1.80-1.73 (m, 2H, 2'-H_b, 5-H_{endo}), 1.40-1.35 (m, 1H, 6-H_{endo}), 1.01 (s, 3H, 8-H), 0.96 (s, 3H, 9-H). ¹³C NMR (150.92 MHz, CDCl₃, 293 K): δ = 152.56 (1C, 3-C), 116.72 (1C, 11-C), 83.44 (1C, 2-C), 78.84 (1C, 12-C), 69.01 (1C, 13-C), 68.83 (5C, Cp), 68.21 (1C, 16-C), 68.13 (2C, 14-C, 15-C), 60.63 (1C, 3'-C), 53.98 (1C, 1-C), 50.69 (1C, 7-C), 50.45 (1C, 4-C), 45.43 (2C, NMe₂), 44.39 (1C, 10-C), 38.47 (1C, 2'-C), 37.69 (2C, SO₂NMe₂), 26.65 (1C, 1'-C), 25.09 (1C, 6-C), 22.04 (1C, 8-C), 21.55 (1C, 5-C), 20.39 (1C, 9-C). MS (EI) *m/z* (rel. int.): 542 (M⁺, 29), 434 (100), 389 (55). Anal. calcd. for C₂₈H₄₂FeN₂O₃S (542.55): C, 61.98; H, 7.80; Fe, 10.29; N, 5.16; S, 5.91. Found: C, 62.07; H, 7.91; Fe, 10.48; N, 5.22; S 5.75 %.

Data of **36** (data for a diastereomeric mixture of two isomers in ratio 1:1): ¹H NMR (250 MHz, CDCl₃, 300 K): δ = 4.16-4.11 (m, Fc), 4.12 (s, Cp), 4.10 (s, Cp), 4.10 (s, Cp), 4.09-4.00 (m, Fc), 3.96-3.92 (m, Fc), 3.32 (d, *J* = 14.5 Hz), 3.29 (d, *J* = 14.5 Hz), 2.89 (s, SO₂NMe₂), 2.88 (s, SO₂NMe₂), 2.80-2.76 (m), 2.70 (d, *J* = 14.6 Hz), 2.69 (d, *J* = 14.6 Hz), 2.67-2.53 (m), 2.49-2.35 (m), 2.32-2.27 (m), 2.24 (s, NMe₂), 2.23 (s, NMe₂), 2.16-2.81 (m), 1.74-1.49 (m), 1.46-1.22 (m), 1.09 (s, Me), 1.01 (s, Me), 1.89 (m, Me), 1.85 (s, Me). ¹³C NMR (62.90 MHz, CDCl₃, 300 K): δ = 216.08 (1C, C=O), 215.85 (1C, C=O), 94.75 (1C, quaternary Fc), 93.80 (1C, quaternary Fc), 69.03 (1C, Fc), 68.54 (5C, Cp), 68.45 (5C, Cp), 68.40 (1C, Fc), 67.72 (1C, Fc), 67.68 (1C, Fc), 67.27 (1C, Fc), 66.82 (1C, Fc), 66.45 (1C, Fc), 66.22 (1C, Fc), 60.29 (1C, CH₂), 59.93 (1C, CH₂), 59.70 (1C, quaternary), 58.52 (1C, quaternary), 57.94 (1C, CH), 53.85 (1C, CH), 47.31 (1C, quaternary), 46.60 (2C, quaternary, CH), 46.60 (1C, CH), 45.57 (2C, NMe₂), 45.54 (2C, NMe₂), 44.04 (1C,

CH₂), 43.84 (1C, CH₂), 40.51 (1C, CH), 37.48 (2C, SO₂NMe₂), 37.46 (2C, SO₂NMe₂), 36.79 (1C, CH), 33.10 (1C, CH₂), 30.86 (1C, CH₂), 29.35 (1C, CH₂), 26.23 (1C, CH₂), 25.38 (1C, CH₂), 25.26 (1C, CH₂), 25.01 (1C, CH₂), 21.68 (1C, Me), 21.32 (1C, Me), 20.73 (1C, CH₂), 19.86 (1C, Me), 19.55 (1C, Me).

4.10. 1-((1*S*,2*R*,4*S*,*E*)-3-(Ferrocenylmethylidene)-2-hydroxy-7,7-dimethyl-2-((6-methylpyridin-2-yl)methyl)bicyclo[2.2.1]heptan-1-yl)-*N,N*-dimethylmethanesulfonamide 30

To a solution of 2,6-lutidine (0.54 ml, 4.62 mmol) in 12 ml of THF was added dropwise *n*-BuLi (2.03 ml, 5.08 mmol of 2.5 M solution in hexane) at -60°C. The mixture was stirred for 1 h at -40°C and after cooling to -60°C, **9** (0.70 g, 1.54 mmol) was added. The reaction progress was monitored by TLC (hexane/ethyl acetate = 2:1). After stirring for 1 h the mixture was quenched with water (20 ml), extracted with Et₂O (3x30 ml) and the organic phase was dried over anhydrous Na₂SO₄. The solvent was evaporated *in vacuo* and the crude product was chromatographed (160 g silica gel, hexane/ethyl acetate = 5:1) to give pure **30** (0.450 g, 52 %) as a deep orange solid and **37** (0.187 g, 22%) as an orange oil in form of diastereomeric mixture of two isomers (major **37a** and minor **37b**) in ratio 10:1.

Data of **30**: Mp 162-164°C. $[\alpha]_D^{20} = 0$ (the measurement failed because no light penetrates through the deep colored solution even at *c* 0.02, CHCl₃). ¹H NMR (600 MHz, CDCl₃, 293 K): δ = 8.16 (br s, 1H, OH), 7.59 (t, 1H, 4'-H, *J* = 7.5 Hz), 7.10 (d, 1H, 5'-H, *J* = 7.7 Hz), 7.06 (d, 1H, 3'-H, *J* = 7.5 Hz), 5.50 (s, 1H, 11-H), 4.18 (br s 1H, 16-H), 4.14* (br s 1H, 14-H), 4.12 (br s 1H, 13-H), 4.11* (br s, 1H, 15-H), 3.99 (s, 5H, Cp), 3.49 (d, 1H, 1'-H_b, *J* = 14.7 Hz), 3.31 (d, 1H, 10-H_a, *J* = 14.6 Hz), 2.93 (d, 1H, 1'-H_a, *J* = 14.7 Hz), 2.78 (s, 6H, SO₂NMe₂), 2.77 (d, 1H, 10-H_b, *J* = 14.6 Hz), 2.73 (d, 1H, 4-H, *J* = 5.4 Hz), 2.59 (s, 3H, 7'-H), 2.39-2.34 (m, 1H, 6-H_{exo}), 2.09-2.00 (m, 2H, 5-H_{exo}, 6-H_{endo}), 1.44-1.39 (m, 1H, 5-H_{endo}), 1.05 (s, 3H, 8-H), 1.04 (s, 3H, 9-H). ¹³C NMR (150.92 MHz, CDCl₃, 293 K): δ = 159.18 (1C, 2'-C), 156.52 (1C, 6'-C), 151.33 (1C, 3-C), 137.55 (1C, 4'-C), 122.50 (1C, 3'-C), 121.24 (1C, 5'-C), 117.82 (1C, 11-C), 83.05 (1C, 12-C), 81.67 (1C, 2-C), 69.05 (1C, 13-C), 68.82 (5C, Cp), 68.22* (1C, 15-C), 68.14* (1C, 14-C), 67.91 (1C, 16-C), 53.62 (1C, 1-C), 50.33 (1C, 4-C), 50.25 (1C, 7-C), 43.59 (1C, 10-C), 43.43 (1C, 1'-C), 37.64 (2C, SO₂NMe₂), 26.09 (1C, 6-C), 25.17 (1C, 5-C), 24.27 (1C, 7'-C), 22.00 (1C, 8-C), 20.95 (1C, 9-C). MS (EI) *m/z* (rel. int.): 562 (M⁺, 35), 455 (100), 347 (33), 281 (26), 107 (40). Anal. calcd. for C₃₀H₃₈FeN₂O₃S (562.54): C, 64.05; H, 6.81; Fe, 9.93; N, 4.98; S, 5.70. Found: C, 64.20; H, 6.76; Fe, 9.77; N, 5.03; S, 5.80 %.

Data for **37a**: (the major diastereoisomer **37a** was isolated in 43 mg quantity as orange-yellow solid by crystallization of mixture **37a/37b** from heptane/CH₂Cl₂ = 90:10). ¹H NMR (250 MHz, CDCl₃, 300 K): δ = 7.51 (t, 1H, 4'-H, *J* = 7.6 Hz), 7.06 (d, 1H, 5'-H, *J* = 7.6 Hz), 7.00 (d, 1H, 3'-H, *J* = 7.8 Hz), 4.13-4.08 (m, 4H, Fe), 4.10 (s, 5H, Cp), 3.68-3.61 (m, 1H, 1'-H_a), 3.33-3.26 (m, 1H, 4-H), 3.19 (d, 1H, 10-H_a, *J* = 14.7 Hz), 3.07 (dd, 1H, 1'-H_b, *J* = 13.7, 5.5 Hz), 2.80 (s, 6H, SO₂NMe₂), 2.63-2.58 (m, 2H, 10-H_b, 11), 2.55 (s, 3H, 7'-H), 2.43-2.31* (m, 1H, 5-H_{exo}), 1.67-1.64 (m, 1H, 3-H), 1.59-1.53 (m, 2H, 6-H_{endo}, 6-H_{exo}), 1.42-1.31* (m, 1H, 5-H_{endo}), 1.06* (s, 3H, 8-H), 0.77* (s, 3H, 9-H). ¹³C NMR (62.90 MHz, CDCl₃, 300 K): δ = 214.65 (1C, 2-C), 160.05 (1C, 2'-C), 157.75 (1C, 6'-C), 136.38 (1C, 4'-C), 120.64 (1C, 3'-C), 120.36 (1C, 5'-C), 92.69 (1C, 12-C), 69.64 (1C, Fe), 68.50 (5C, Cp), 67.22 (1C, Fe), 67.04 (1C, Fe), 66.27 (1C, Fe), 59.18 (1C, 1-C), 55.33 (1C, 11-C), 47.62 (1C, 3-C), 46.65 (1C, 7-C), 44.74 (1C, 1'-C), 43.92 (1C, 10-C), 37.39 (2C, SO₂NMe₂), 37.35 (1C, 4-C), 25.01* (1C, 5-C), 24.50 (1C, 7'-C), 20.82* (1C, 6-C), 20.06* (1C, 8-C), 19.36* (1C, 9-C).

4.11. 1-((1*S*,2*R*,4*S*,*E*)-3-Ferrocenylmethylidene-2-hydroxy-2-(1-isopropyl-1*H*-imidazol-2-yl)-7,7-dimethylbicyclo[2.2.1]heptan-1-yl)-*N,N*-dimethylmethanesulfonamide 31

To a solution of 1-isopropyl-1*H*-imidazole (0.22 g, 1.98 mmol) in 4 ml of hexane and 4 ml of THF was added dropwise *n*-BuLi (1.20 ml, 2.97 mmol of 2.5 M solution in hexane) at -90°C. The mixture was stirring for 1 h at this temperature, after which **9** (0.30 g, 0.66 mmol) was added. The reaction progress was monitored by TLC (Et₂O/NH₃ = 6:0.01). After stirring for additional 1.5 h at -40°C, the mixture was quenched with water (5 ml), extracted with Et₂O (3x20 ml) and the organic phase was dried over anhydrous Na₂SO₄. The solvent was evaporated *in vacuo* and the crude product was chromatographed (90 g silica gel, Et₂O/NH₃ = 6:0.01), to give **31** (0.178 g, 48%) as a yellow solid. Mp 86-87°C. $[\alpha]_D^{20} = -339.0$ (*c* 0.64, CHCl₃). ¹H NMR (250 MHz, CDCl₃, 300 K): δ = 7.01 (d, 1H, 2'-H, *J* = 1.3 Hz), 6.95 (d, 1H, 3'-H, *J* = 1.3 Hz), 6.33 (br s, 1H, OH), 4.76 (quint, 1H, 4'-H), 4.48-4.47 (m, 1H, 16-H), 4.28-4.26* (m, 1H, 14-H), 4.22-4.20* (m, 1H, 15-H), 4.18-4.16 (m, 1H, 13-H), 4.16 (s, 5H, Cp), 3.79 (d, 1H, 10-H_a, *J* = 14.9 Hz), 3.11 (d, 1H, 10-H_b, *J* = 14.9 Hz), 3.06 (d, 1H, 4-H, *J* = 4.3 Hz), 2.85 (s, 6H, SO₂NMe₂), 2.42 (ddd, 1H, 6-H_{exo}, *J* = 13.8, 12.2, 3.6 Hz), 2.09-1.95 (m, 1H, 5-H_{exo}), 1.57-1.42 (m, 1H, 5-H_{endo}), 1.39 (d, 3H, 5'-H_a, *J* = 6.8 Hz), 1.32 (s, 3H, 8-H), 1.22 (s, 3H, 9-H), 1.20 (d, 3H, 5'-H_b, *J* = 6.8 Hz), 1.18-1.05 (m, 1H, 6-H_{endo}). ¹³C NMR (62.90 MHz, CDCl₃, 300 K): δ = 149.31 (1C, 1'-C), 144.32 (1C, 3-C), 126.74 (1C, 2'-C), 124.60 (1C, 11-C), 117.02 (1C, 3'-C), 83.30 (1C, 12-C), 81.15 (1C, 2-C), 70.23 (1C, 13-C), 69.02* (1C, 14-C), 69.00 (5C, Cp), 68.28* (1C, 15-C), 67.58 (1C, 16-C), 55.38 (1C, 1-C), 51.14 (1C, 4-C), 49.44 (1C, 7-C), 47.84 (1C, 4'-C), 42.79 (1C, 10-C), 37.67 (2C, SO₂NMe₂), 25.62 (1C, 6-C), 24.32 (1C, 5-C), 24.27 (2C, 5'-C), 22.34 (1C, 8-C), 21.68 (1C, 9-C). MS (EI) *m/z* (rel. int.): 565 (M⁺, 5), 455 (100), 281 (30), 227 (30).

Anal. calcd. for $C_{29}H_{39}FeN_3O_3S$ (565.55): C, 61.59; H, 6.95; Fe, 9.87; N, 7.43; S, 5.67. Found: C, 61.70; H, 6.88; Fe, 9.94; N, 7.57; S, 5.59 %.

4.12. 1-((1*S*,2*R*,4*S*,*E*)-2-(Benzo[*b*]thiophen-2-yl)-3-ferrocenylmethylidene-2-hydroxy-7,7-dimethylbicyclo[2.2.1]heptan-1-yl)-*N,N*-dimethylmethanesulfonamide 32

To a solution of benzothiophene (0.27 g, 1.98 mmol) in 20 ml of THF was added dropwise *n*-BuLi (1.36 ml, 2.18 mmol of 1.6 M solution in hexane) at -50°C . The mixture was stirred for 30 min. at -10°C , then cooled to -60°C and **9** (0.30 g, 0.66 mmol) was added at this temperature. After slowly warming to room temperature and stirring for 40 min, the mixture was quenched with water (5 ml), extracted with Et_2O (3×20 ml) and the organic phase was dried over anhydrous Na_2SO_4 . The solvent was evaporated *in vacuo* and the crude product was chromatographed (180 g silica gel, toluene/ Et_2O = 20:1), to give **32** (0.263 g, 65%) as a yellow solid. Mp $113\text{--}115^{\circ}\text{C}$. $[\alpha]_{\text{D}}^{20} = -256.3$ (c 1.00, CHCl_3). ^1H NMR (600 MHz, CDCl_3 , 293 K): δ = 7.72* (dd, 1H, 7'-H, J = 6.1, 2.8 Hz), 7.33* (dd, 1H, 4'-H, J = 6.1, 2.8 Hz), 7.35-7.32 (m, 2H, 5'-H, 6'-H), 7.23 (s, 1H, 2'-H), 6.27 (s, 1H, 11-H), 4.44-4.43 (m, 1H, 16-H), 4.33-4.32* (m, 1H, 14-H), 4.31-4.30 (m, 1H, 13-H), 4.27-4.26* (m, 1H, 15-H), 4.21 (s, 5H, Cp), 3.51 (d, 1H, 10- H_a , J = 14.9 Hz), 3.34 (d, 1H, 10- H_b , J = 14.9 Hz), 2.94 (d, 1H, 4-H, J = 4.6), 2.92 (s, 6H, SO_2NMe_2), 2.75 (s, 1H, OH), 2.35 (ddd, 1H, 6- H_{exo} , J = 13.2, 12.3, 4.6 Hz), 2.13-2.07 (m, 1H, 5- H_{exo}), 1.59-1.55 (m, 1H, 5- H_{endo}), 1.51-1.47 (m, 1H, 6- H_{endo}), 1.27 (s, 3H, 8-H), 1.26 (s, 3H, 9-H). ^{13}C NMR (150.92 MHz, CDCl_3 , 293 K): δ = 150.15 (1C, 1'-C), 144.32 (1C, 3-C), 139.77 (1C, 8'-C), 138.90 (1C, 3'-C), 124.40 (2C, 5'-C, 6'-C), 123.56 (1C, 4'-C), 123.29 (1C, 2'-C), 122.73 (1C, 11-C), 122.16 (1C, 7'-C), 85.35 (1C, 12-C), 81.15 (1C, 2-C), 69.45* (1C, 15-C), 68.90* (1C, 14-C), 68.88 (1C, 13-C), 68.82 (5C, Cp), 67.97 (1C, 16-C), 55.02 (1C, 1-C), 51.47 (1C, 4-C), 49.98 (1C, 7-C), 43.49 (1C, 10-C), 37.76 (2C, SO_2NMe_2), 27.59 (1C, 6-C), 22.44 (1C, 5-C), 22.43 (1C, 8-C), 21.89 (1C, 9-C). MS (EI) m/z (rel. int.): 589 ($\text{M}^{+\bullet}$, 100), 573 (27), 480 (77), 463 (19), 415 (51), 343 (74). Anal. calcd. for $\text{C}_{31}\text{H}_{35}\text{FeNO}_3\text{S}_2$ (589.59): C, 63.15; H, 5.98; Fe, 9.47; N, 2.38; S, 10.88. Found: C, 63.31; H 5.88; Fe, 9.54; N, 2.26; S, 10.69 %.

4.13. 1-((1*S*,2*R*,4*S*,*E*)-3-Ferrocenylmethylidene-2-(dibenzo[*b,d*]thiophen-4-yl)-2-hydroxy-7,7-dimethylbicyclo[2.2.1]heptan-1-yl)-*N,N*-dimethylmethanesulfonamide 33

To a solution of dibenzothiophene (0.37 g, 1.98 mmol) in 20 ml of THF was added dropwise *n*-BuLi (1.36 ml, 2.18 mmol of 1.6 M solution in hexane) at -20°C . The mixture was stirred for 3 h at 0°C and 2 h at room temperature. Next, **9** (0.30 g, 0.66 mmol) was added at 0°C . After stirring for 1 h at room temperature the mixture was quenched with water (5 ml), extracted with Et_2O (3×20 ml) and the organic phase was dried over anhydrous Na_2SO_4 . The solvent was evaporated *in vacuo* and the crude product was chromatographed (40 g silica gel, toluene/ Et_2O = 20:1), to give pure **33** (0.111 g, 25%) as orange solid and **38** (0.186 g, 44%) as a diastereomeric mixture of two isomers (major **38a** and minor **38b**) in ratio 10:1 as orange-yellow solid.

Data of **33**: Mp $158\text{--}160^{\circ}\text{C}$ with decomp. $[\alpha]_{\text{D}}^{20} = -216.2$ (c 0.63, CHCl_3). ^1H NMR (600 MHz, CDCl_3 , 293 K): δ = 8.17-8.15 (m, 2H, 4'-H, 7'-H), 7.83-7.80 (m, 1H, 10'-H), 7.46-7.43 (m, 3H, 3'-H, 8'-H, 9'-H), 7.38-7.37 (br d, 1H, 2'-H), 6.13 (s, 1H, 11-H), 4.45 (br s, 1H, 16-H), 4.30* (br s, 1H, 14-H), 4.27 (br s, 1H, 13-H), 4.27* (br s, 1H, 15-H), 4.17 (s, 5H, Cp), 3.60 (d, 1H, 10- H_a , J = 14.8 Hz), 3.42 (d, 1H, 10- H_b , J = 14.8 Hz), 3.00 (d, 1H, 4-H, J = 4.4 Hz), 2.65 (s, 6H, SO_2NMe_2), 2.45-2.43 (m, 2H, 6- H_{exo} , OH), 2.20-2.14 (m, 1H, 5- H_{exo}), 1.72-1.67 (m, 1H, 5- H_{endo}), 1.55-1.50 (m, 1H, 6- H_{endo}), 1.35 (s, 3H, 8-H), 1.26 (s, 3H, 9-H). ^{13}C NMR (150.92 MHz, CDCl_3 , 293 K): δ = 140.28 (1C, 3-C), 140.28 (1C, 11'-C), 138.71 (1C, 12'-C), 138.54 (1C, 1'-C), 128.40 (1C, 2'-C), 137.11 (1C, 5'-C), 134.77 (1C, 6'-C), 126.80 (1C, 9'-C), 124.21 (1C, 8'-C), 123.17 (1C, 3'-C), 122.86 (1C, 11-C), 121.60 (1C, 10'-C), 121.46 (1C, 7'-C), 121.32 (1C, 4'-C), 88.69 (1C, 2-C), 81.93 (1C, 12-C), 69.60 (1C, 13-C), 68.97* (1C, 15-C), 68.89* (1C, 14-C), 68.72 (5C, Cp), 67.69 (1C, 16-C), 57.09 (1C, 1-C), 51.96 (1C, 4-C), 50.68 (1C, 7-C), 44.95 (1C, 10-C), 37.63 (2C, SO_2NMe_2), 25.88 (1C, 6-C), 24.42 (1C, 5-C), 22.96 (1C, 8-C), 22.01 (1C, 9-C). MS (EI) m/z (rel. int.): 639 ($\text{M}^{+\bullet}$, 100), 530 (100), 465 (53), 393 (20). Anal. calcd. for $\text{C}_{35}\text{H}_{37}\text{FeNO}_3\text{S}_2$ (639.65): C, 65.72; H, 5.83; Fe, 8.73; N, 2.19; S, 10.03. Found: C, 65.62; H 5.69; Fe, 8.83; N, 2.08; S, 10.17 %.

Data for **38a**: (the major diastereoisomer **38a** was isolated in 36 mg quantity as orange-yellow solid by crystallization of mixture **38a/38b** from heptane/ CH_2Cl_2 = 90:10). ^1H NMR (250 MHz, CDCl_3 , 300 K): δ = 8.19-8.09 (m, 2H), 7.90-7.86 (m, 1H), 7.60-7.44 (m, 4H), 4.17-4.14 (m, 4H, Fc), 3.96 (d, 1H, J = 11.4 Hz), 3.57 (s, 5H, Cp), 3.19 (d, 1H, J = 14.5 Hz), 2.76 (s, 6H, SO_2NMe_2), 2.70-2.61 (m, 2H), 2.53-2.44 (m, 1H), 2.09-2.01 (m, 1H), 1.67-1.60 (m, 1H), 1.44-1.25 (m, 2H), 1.21 (s, 3H), 1.11 (s, 3H). ^{13}C NMR (62.90 MHz, CDCl_3 , 300 K): δ = 213.21 (1C, C=O), 139.96 (1C, quaternary), 139.87 (1C, quaternary), 138.73 (1C, quaternary), 136.76 (1C, quaternary), 135.30 (1C, quaternary), 126.57 (1C, CH Ar), 124.78 (1C, CH Ar), 124.36 (1C, CH Ar), 124.29 (1C, CH Ar), 122.66 (1C, CH Ar), 121.84 (1C, CH Ar), 119.62 (1C, CH Ar), 91.95 (1C, quaternary Fc), 70.26 (1C, CH Fc), 68.60 (1C, CH Fc), 68.52 (5C, Cp), 66.25 (1C, CH Fc), 65.70 (1C, CH Fc), 60.42 (1C, CH), 58.54 (1C, quaternary), 47.27 (1C, quaternary), 46.69 (1C, CH), 46.39 (1C, CH), 43.06 (1C, CH_2), 37.44 (2C, Me), 29.44 (1C, CH_2), 24.38 (1C, CH_2), 21.94 (1C, Me), 21.53 (1C, Me).

4.14. 1-((1*S*,2*R*,4*S*,*E*)-3-Ferrocenylmethylidene-2-hydroxy-7,7-dimethyl-2-(5-(trimethylsilyl)thiophen-2-yl)bicyclo[2.2.1]heptan-1-yl)-*N,N*-dimethylmethanesulfonamide 34

To a solution of trimethy-2-thienylsilane (0.31 g, 1.98 mmol) in 15 ml of THF was added dropwise *n*-BuLi (1.09 ml, 2.73 mmol of 2.5 M solution in hexane) at 0°C. The mixture was stirred for 1 h at room temperature and then **9** (0.30 g, 0.66 mmol) was added. The reaction progress was monitored by TLC (petroleum ether/Et₂O = 2:1) until **9** was consumed. After stirring for 30 min. at room temperature, the reaction was quenched with water (5 ml), extracted with Et₂O (3×20 ml) and the organic phase was dried over anhydrous Na₂SO₄. The solvent was evaporated *in vacuo* and the crude product was chromatographed (250 g silica gel, petroleum ether/Et₂O = 5:1), to give **34** (0.197 g, 47%) as a yellow solid. Mp 88-90°C. $[\alpha]_D^{20} = -210.2$ (*c* 1.00, CHCl₃). ¹H NMR (250 MHz, CDCl₃, 300 K): δ = 7.14 (d, 1H, 3'-H), 7.07 (s, 1H, 2'-H), 6.25 (s, 1H, 11-H), 4.41-4.40 (m, 1H, 16-H), 4.29-4.27 (m, 2H, 14-H, 15-H), 4.25-4.23 (m, 1H, 13-H), 4.19 (s, 5H, Cp), 3.49 (d, 1H, 10-H_a, *J* = 14.9 Hz), 3.25 (d, 1H, 10-H_b, *J* = 14.9 Hz), 2.90 (s, 6H, SO₂NMe₂), 2.89 (br d, 1H, 4-H), 2.57 (s, 1H, OH), 2.36-2.24 (m, 1H, 6-H_{exo}), 2.11-1.98 (m, 1H, 5-H_{exo}), 1.57-1.46 (m, 1H, 5-H_{endo}), 1.37-1.31 (m, 1H, 6-H_{endo}), 1.21 (s, 6H, 8-H, 9-H), 0.32 (s, 9H, SiMe₃). ¹³C NMR (62.90 MHz, CDCl₃, 300 K): δ = 154.77 (1C, 4'-C), 150.44 (1C, 1'-C), 140.15 (1C, 3-C), 133.26 (1C, 3'-C), 127.57 (1C, 2'-C), 122.16 (1C, 11-C), 84.84 (1C, 12-C), 82.18 (1C, 2-C), 69.44* (1C, 15-C), 68.80 (5C, Cp), 68.76* (1C, 14-C), 68.69 (1C, 13-C), 67.76 (1C, 16-C), 55.09 (1C, 1-C), 51.24 (1C, 4-C), 49.72 (1C, 7-C), 43.24 (1C, 10-C), 37.66 (2C, SO₂NMe₂), 27.38 (1C, 6-C), 24.46 (1C, 5-C), 22.38 (1C, 8-C), 21.84 (1C, 9-C), -0.07 (3C, SiMe₃). MS (EI) *m/z* (rel. int.): 611 (M⁺, 64), 503 (31), 437 (100). Anal. calcd. for C₃₀H₄₁FeNO₃S₂Si (611.71): C, 58.90; H, 6.76; Fe, 9.13; N, 2.29; S, 10.48. Found: C, 59.02; H, 6.58; Fe, 9.35; N, 2.39; S, 10.27 %.

4.15. 1-((1*S*,2*R*,4*S*,*E*)-2-(Benzo[*d*]thiazol-2-yl)-3-ferrocenylmethylidene-2-hydroxy-7,7-dimethylbicyclo[2.2.1]heptan-1-yl)-*N,N*-dimethylmethanesulfonamide 35

To a solution of benzothiazole (0.45 g, 3.3 mmol) in 10 ml of THF was added dropwise *n*-BuLi (1.40 ml, 3.47 mmol of 2.5 M solution in hexane) at -90°C. The mixture was stirred for 1 h at -90°C and then was added **9** (0.50 g, 1.10 mmol) was added. After stirring for 40 min. at -40°C, the mixture was quenched with water (10 ml), extracted with Et₂O (3×30 ml) and the organic phase was dried (Na₂SO₄). The solvent was evaporated *in vacuo* and the crude product was chromatographed (170 g silica gel, hexane/acetone = 5:1), to give 0.289 g of a mixture of **9** and **35**. The crystallization from hexane/CH₂Cl₂ = 90:10 provided pure **35** (0.167 g, 25%) as a yellow solid. Mp 156-158°C. $[\alpha]_D^{20} = -208.9$ (*c* 0.34, CHCl₃). ¹H NMR (600 MHz, CDCl₃, 293 K): δ = 7.98 (d, 1H, 6'-H, *J* = 8.0 Hz), 7.87 (d, 1H, 3'-H, *J* = 8.0 Hz), 7.49 (dt, 1H, 4'-H, *J* = 7.2, 0.9 Hz), 7.40 (dt, 1H, 5'-H, *J* = 7.2, 0.9 Hz), 6.31 (s, 1H, 11-H), 4.44 (br s, 1H, 16-H), 4.32 (br s, 1H, 13-H), 4.30* (br s, 1H, 14-H), 4.28 (s, 1H, OH), 4.24* (br s, 1H, 15-H), 4.22 (s, 5H, Cp), 3.80 (d, 1H, 10-H_a, *J* = 14.8 Hz), 3.25 (d, 1H, 10-H_b, *J* = 14.8 Hz), 2.93 (d, 1H, 4-H, *J* = 4.6 Hz), 2.87 (s, 6H, SO₂NMe₂), 2.39-2.33 (m, 1H, 6-H_{exo}), 2.16-2.11 (m, 1H, 5-H_{exo}), 1.74-1.69 (m, 1H, 5-H_{endo}), 1.65-1.60 (m, 1H, 6-H_{endo}), 1.22 (s, 3H, 8-H), 1.21 (s, 3H, 9-H). ¹³C NMR (150.92 MHz, CDCl₃, 293 K): δ = 176.57 (1C, 1'-C), 152.43 (1C, 2'-C), 148.47 (1C, 3-C), 135.65 (1C, 7'-C), 126.23 (1C, 4'-C), 125.32 (1C, 5'-C), 124.72 (1C, 11-C), 122.92 (1C, 6'-C), 121.57 (1C, 3'-C), 84.54 (1C, 2-C), 81.72 (1C, 12-C), 69.80 (1C, 13-C), 68.95 (2C, 14-C, 15-C), 68.87 (5C, Cp), 67.86 (1C, 16-C), 55.53 (1C, 1-C), 51.13 (1C, 4-C), 50.41 (1C, 7-C), 43.65 (1C, 10-C), 37.61 (2C, SO₂NMe₂), 27.04 (1C, 6-C), 25.03 (1C, 5-C), 22.06 (1C, 8-C), 21.15 (1C, 9-C). MS (CI) *m/z* (rel. int.): 591 (M+1, 51), 590 (M, 61), 573 (M-H₂O, 100), 136 (benzothiazole+1, 28). Anal. calcd. for C₃₀H₃₄FeN₂O₃S₂ (590.58): C, 61.01; H, 5.80; Fe, 9.46; N, 4.74; S, 10.86. Found: C, 60.96; H 5.70; Fe, 9.62; N, 4.63; S, 10.97 %.

4.16. 2-((1*R*,2*R*,4*S*,*E*)-3-Ferrocenylmethylidene-2-hydroxy-1,7,7-trimethylbicyclo[2.2.1]heptan-2-yl)acetonitrile 40

To a solution of dry acetonitrile (0.177 g, 4.31 mmol) in 20 ml of THF was added *n*-BuLi (1.72 ml, 4.31 mmol of 2.5 M solution in hexane) dropwise at -78°C. After stirring for 45 min at -78°C, compound **7** (1.00 g, 2.87 mmol) was added and the reaction mixture was stirred for 3 h while keeping the temperature between -78°C and -65°C. The reaction progress was monitored by TLC (petroleum ether/MTBE = 7:1). The mixture was quenched at this temperature with saturated aqueous NH₄Cl, after which the mixture warmed to room temperature, extracted with Et₂O and the organic phase washed with water, and dried over anhydrous Na₂SO₄. The solvent was evaporated *in vacuo* and the crude product was chromatographed (190 g silica gel, petroleum ether/MTBE = 7:1), to give **40** (0.711 g, 64%) as an orange solid. Mp 115-117°C. $[\alpha]_D^{20} = -49.0$ (*c* 0.74, CHCl₃). ¹H NMR (600 MHz, CDCl₃, 293 K): δ = 6.46 (s, 1H, 11-H), 4.33-4.32 (m, 2H, 16-H, 13-H), 4.25-4.24* (m, 1H, 15-H), 4.23-4.22* (m, 1H, 14-H), 4.13 (s, 5H, Cp), 2.82 (d, 1H, 4-H, *J* = 4.6 Hz), 2.69 (d, 1H, 1'-H_a, *J* = 16.6 Hz), 2.65 (d, 1H, 1'-H_b, *J* = 16.6 Hz), 1.99-1.94 (m, 2H, 5-H_{exo}, OH), 1.70 (ddd, 1H, 6-H_{exo}, *J* = 14.1, 11.8, 5.4 Hz), 1.44-1.40 (m, 1H, 6-H_{endo}), 1.31-1.26 (m, 1H, 5-H_{endo}), 1.07 (s, 3H, 10-H), 1.02 (s, 3H, 8-H), 0.94 (s, 3H, 9-H). ¹³C NMR (150.92 MHz, CDCl₃, 293 K): δ = 148.94 (1C, 3-C), 119.81 (1C, 11-C), 118.41 (1C, CN), 78.56 (2C, 2-C, 12-C), 69.43* (1C, 16-C), 69.01* (1C, 15-C), 68.82 (5C, Cp), 68.74* (1C, 14-C), 68.09* (1C, 13-C), 53.03 (1C, 7-C), 50.85 (1C, 4-C), 48.53 (1C, 1-C), 31.00 (1C, 6-C), 28.72 (1C, 1'-C), 24.75 (1C, 5-C), 22.23

(1C, 8-C), 19.95 (1C, 9-C), 9.90 (1C, 10-C). MS (ESI) m/z (rel. int.): 390 (M+1, 6), 372 (M-H₂O, 100). Anal. calcd. for C₂₃H₂₇FeNO (389.31): C, 70.96; H, 6.99; Fe, 14.34; N, 3.60. Found: C, 70.89; H 7.07; Fe, 14.42; N, 3.69 %.

4.17. 1-((1S,2R,4S,E)-2-(Cyanomethyl)-3-ferrocenylmethylidene-2-hydroxy-7,7-dimethylbicyclo[2.2.1]heptan-1-yl)-N,N-dimethylmethanesulfonamide 41

To a solution of dry acetonitrile (0.108 g, 2.64 mmol) in 10 ml of THF was added *n*-BuLi (0.88 ml, 2.20 mmol of 2.5 M solution in hexane) dropwise at -78°C. After stirring for 45 min at -78°C, compound **9** (0.500 g, 1.10 mmol) was added and the reaction mixture was stirred for 3 h while keeping the temperature between -78°C and -65°C. The reaction progress was monitored by TLC (hexane/Et₂O = 5:1). The reaction was quenched at this temperature with saturated aq. NH₄Cl, the mixture warmed to room temperature, extracted with Et₂O and the organic phase washed with water, and dried over anhydrous Na₂SO₄. The solvent was evaporated *in vacuo* and the crude product was chromatographed (8 g silica gel, hexane/Et₂O = 5:1), to give **41** (0.502 g, 92%) as an orange solid. Mp 125-128°C. [α]_D²⁰ = -98.7 (*c* 0.54, CHCl₃). ¹H NMR (600 MHz, CDCl₃, 293 K): δ = 6.73 (s, 1H, 11-H), 4.34* (br s, 1H, 13-H), 4.32* (br s, 1H, 16-H), 4.24* (br s, 1H, 14-H), 4.22* (br s, 1H, 15-H), 4.17 (s, 5H, Cp), 3.61 (d, 1H, 1'-H_a, *J* = 16.7 Hz), 3.38 (d, 1H, 10-H_a, *J* = 14.1 Hz), 2.93 (s, 6H, SO₂NMe₂), 2.80 (d, 1H, 4-H, *J* = 4.8 Hz), 2.76 (d, 1H, 1'-H_b, *J* = 16.7 Hz), 2.68 (d, 1H, 10-H_a, *J* = 14.1 Hz), 2.07-2.02 (m, 1H, 5-H_{exo}), 1.97-1.88 (m, 2H, 6-H_{exo}, 6-H_{endo}), 1.49-1.45 (m, 1H, 5-H_{endo}), 1.02 (s, 3H, 8-H), 0.93 (s, 3H, 9-H). ¹³C NMR (150.92 MHz, CDCl₃, 293 K): δ = 146.34 (1C, 3-C), 120.18 (1C, 11-C), 118.38 (1C, CN), 81.73 (1C, 2-C), 77.12 (1C, 12-C), 69.63* (1C, 13-C), 69.09 (5C, Cp), 68.76* (1C, 14-C), 68.65* (1C, 15-C), 67.87* (1C, 16-C), 54.20 (1C, 7-C), 51.20 (1C, 1-C), 50.02 (1C, 4-C), 45.17 (1C, 10-C), 37.60 (2C, SO₂NMe₂), 30.13 (1C, 1'-C), 27.75 (1C, 6-H), 24.95 (1C, 5-H), 21.74 (1C, 8-C), 20.09 (1C, 9-C). MS (ESI) m/z (rel. int.): 497 (M+1, 90), 480 (M-H₂O, 100). Anal. calcd. for C₂₅H₃₂FeN₂O₃S (496.44): C, 60.48; H, 6.50; Fe, 11.25; N, 5.64; S, 6.46. Found: C, 60.36; H 6.58; Fe, 11.39; N, 5.56; S, 6.52 %.

4.18. (1R,2R,4S,E)-2-(2-Aminoethyl)-3-ferrocenylmethylidene-1,7,7-trimethylbicyclo[2.2.1]heptan-2-ol 42

To a suspension of LiAlH₄ (0.486 g, 12.80 mmol) in 25 ml of Et₂O was added dropwise a solution of **40** (0.500 g, 1.28 mmol) in 10 ml of THF at 0°C within 30 min and the resulting mixture was stirred for 1 h. The reaction progress was monitored by TLC (petroleum ether/MTBE = 50:1). The reaction mixture was carefully quenched with H₂O at 0°C and the mixture was stirred for 30 min. The inorganic salts were filtered and washed with Et₂O and CH₂Cl₂. The combined organic phase was washed with water and dried over anhydrous Na₂SO₄. The solvent was evaporated *in vacuo* and the crude product was purified by chromatographic filtration (3 g basic Al₂O₃, petroleum ether/MTBE = 50:1 to MTBE), to give **42** (0.500 g, 99%) as an orange solid. Mp 83-85°C. [α]_D²⁰ = -20.5 (*c* 0.44, CHCl₃). ¹H NMR (600 MHz, CDCl₃, 293 K): δ = 6.15 (s, 1H, 11-H), 4.32-4.31 (m, 2H, 13-H, 16-H), 4.18-4.17* (m, 1H, 14-H), 4.16-4.15* (m, 1H, 15-H), 4.09 (s, 5H, Cp), 3.18-3.14 (m, 1H, 2'-H_b), 3.11-3.06 (m, 1H, 2'-H_a), 2.72 (d, 1H, 4-H, *J* = 4.8 Hz), 1.94-1.88 (m, 1H, 5-H_{exo}), 1.79-1.77 (m, 2H, 1'-H), 1.62-1.57 (m, 1H, 6-H_{exo}), 1.49-1.45 (m, 1H, 6-H_{endo}), 1.26-1.21 (m, 2H, 5-H_{endo}, OH), 1.03 (s, 3H, 10-H), 1.01 (s, 3H, 8-H), 0.89 (s, 3H, 9-H). ¹³C NMR (150.92 MHz, CDCl₃, 293 K): δ = 153.63 (1C, 3-C), 116.90 (1C, 11-C), 83.57 (1C, 12-C), 82.41 (1C, 2-C), 68.97* (1C, 16-C), 68.84 (5C, Cp), 68.16 (2C, 14-C, 15-C), 68.02* (1C, 13-C), 52.52 (1C, 7-C), 50.88 (1C, 4-C), 49.18 (1C, 1-C), 41.16 (1C, 1'-C), 39.18 (1C, 2'-C), 30.61 (1C, 6-C), 25.29 (1C, 5-C), 22.20 (1C, 8-C), 20.02 (1C, 9-C), 11.96 (1C, 10-C). MS (ESI) m/z (rel. int.): 394 (M+1, 5), 377 (M-H₂O, 100). Anal. calcd. for C₂₃H₃₁FeNO (393.34): C, 70.23; H, 7.94; Fe, 14.20; N, 3.56. Found: C, 70.34; H 7.99; Fe, 14.34; N, 3.44 %.

4.19. 1-((1S,2R,4S,E)-2-(2-Aminoethyl)-3-ferrocenylmethylidene-2-hydroxy-7,7-dimethylbicyclo[2.2.1]heptan-1-yl)-N,N-dimethylmethanesulfonamide 43

To a suspension of LiAlH₄ (0.920 g, 24.20 mmol) in 100 ml of Et₂O was added dropwise a solution of **41** (1.200 g, 2.42 mmol) in 30 ml of THF at 0°C within 30 min, and the resulting mixture was stirred for 1 h. The reaction progress was monitored by TLC (Et₂O/MeOH/Et₃N = 100:2:0.1). The reaction mixture was carefully quenched with H₂O at 0°C and the mixture was stirred for 30 min. The inorganic salts were filtered and washed with Et₂O, and CH₂Cl₂. The combined organic phase was washed with water and dried over anhydrous Na₂SO₄. The solvent was evaporated *in vacuo* and the crude product was chromatographed (100 g silica gel, Et₂O/MeOH/Et₃N = 100:2:0.1 to 100:10:0.1), to give **43** (0.736 g, 61%) as orange solid. Mp 88-89°C. [α]_D²⁰ = -28.2 (*c* 0.54, CHCl₃). ¹H NMR (600 MHz, CDCl₃, 293 K): δ = 6.26 (s, 1H, 11-H), 4.30-4.29 (m, 2H, 13-H, 16-H), 4.19-4.18* (m, 1H, 14-H), 4.17-4.16* (m, 1H, 15-H), 4.09 (s, 5H, Cp), 3.59 (d, 1H, 10-H_b, *J* = 14.4 Hz), 3.33-3.24 (m, 2H, 2'-H), 2.90 (s, 6H, SO₂NMe₂), 2.74 (d, 1H, 4-H, *J* = 4.8 Hz), 2.68 (d, 1H, 10-H_a, *J* = 14.4 Hz), 2.39-2.34* (m, 1H, 1'-H_a), 2.16-2.11 (m, 1H, 6-H_{exo}), 1.99-1.92 (m, 2H, 5-H_{exo}, 6-H_{endo}), 1.64-1.60* (m, 1H, 1'-H_b), 1.35-1.30 (m, 1H, 5-H_{endo}), 0.99 (s, 3H, 8-H), 0.96 (s, 3H, 9-H). ¹³C NMR (150.92 MHz, CDCl₃, 293 K): δ = 152.74 (1C, 3-C), 116.88 (1C, 11-C), 83.32 (1C, 12-C), 81.81 (1C, 2-C), 68.94* (1C, 16-C), 68.80 (5C, Cp), 68.26* (1C, 13-C), 68.20* (1C, 15-C), 68.09* (1C, 14-C), 53.68 (1C, 7-C), 50.72 (1C, 1-C), 50.31 (1C, 4-C), 43.80 (1C, 10-C), 38.32 (1C, 2'-C), 37.74 (1C, 1'-C), 37.72 (2C, SO₂NMe₂), 26.13 (1C, 6-C), 24.99 (1C, 5-C),

21.81 (1C, 8-C), 20.33 (1C, 9-C). MS (ESI) m/z (rel. int.): 501 (M+1, 30), 484 (M-H₂O, 48), 455 (M-EtNH₂, 100). Anal. calcd. for C₂₅H₃₆FeN₂O₃S (500.47): C, 60.00; H, 7.25; Fe, 11.16; N, 5.60; S, 6.41. Found: C, 60.09; H 7.35; Fe, 11.08; N, 5.69; S, 6.35 %.

4.20. (1R,2R,4S,E)-3-Ferrocenylmethylidene-2-(2-(isoindolin-2-yl)ethyl)-1,7,7-trimethylbicyclo[2.2.1]heptan-2-ol 45

To a stirred solution of **42** (0.350 g, 0.89 mmol) in CH₃CN (25 ml) were added K₂CO₃ (0.160 g, 1.16 mmol) and α,α' -dichloro-o-xylene (0.187 g, 1.07 mmol) at room temperature. The reaction mixture was refluxed for 17 h. The reaction progress was monitored by TLC (petroleum ether/MTBE = 2:1). The mixture was quenched with H₂O, extracted with CH₂Cl₂ and the organic phase was dried over anhydrous Na₂SO₄. The solvent was evaporated *in vacuo* and the crude product was chromatographed (40 g silica gel, petroleum ether/MTBE = 2:1 to 1:1), to give **45** (0.110 g, 25%) as orange solid. Mp 126-128°C. $[\alpha]_D^{20} = +51.3$ (c 0.39, CHCl₃). ¹H NMR (600 MHz, CDCl₃, 293 K): δ = 7.20 (s, 4H, 5'-H, 6'-H, 7'-H, 8'-H), 6.19 (s, 1H, 11-H), 4.34-4.33 (m, 2H, 13-H, 16-H), 4.19-4.16* (m, 4H, 14-H, 15-H, 10'-H), 4.12 (s, 5H, Cp), 3.99* (d, 2H, 3'-H, J = 11.6 Hz), 3.28-3.23 (m, 1H, 2'-H_a), 3.02-2.99 (m, 1H, 2'-H_b), 2.74 (d, 1H, 4-H, J = 4.7 Hz), 1.99-1.92 (m, 2H, 5-H_{exo}, 1'-H_a), 1.87-1.83 (m, 1H, 1'-H_b), 1.66-1.61 (m, 1H, 6-H_{exo}), 1.53-1.49 (m, 1H, 6-H_{endo}), 1.29-1.25 (m, 1H, 5-H_{endo}), 1.07 (s, 3H, 10-H), 0.99 (s, 3H, 8-H), 0.90 (s, 3H, 9-H). ¹³C NMR (150.92 MHz, CDCl₃, 293 K): δ = 153.39 (1C, 3-C), 139.42 (2C, 4'-C, 9'-C), 126.85* (2C, 5'-C, 8'-C), 122.22* (2C, 6'-C, 7'-C), 116.97 (1C, 11-C), 83.58 (1C, 12-C), 82.58 (1C, 2-C), 69.04* (1C, 15-C), 68.86 (5C, Cp), 68.18 (2C, 13-C, 16-C), 68.01* (1C, 14-C), 59.20 (2C, 3'-C, 10'-C), 53.89 (1C, 2'-C), 52.46 (1C, 7-C), 50.93 (1C, 4-C), 49.26 (1C, 1-C), 37.02 (1C, 1'-C), 30.68 (1C, 6-C), 25.35 (1C, 5-C), 22.11 (1C, 8-C), 20.03 (1C, 9-C), 12.06 (1C, 3-C). MS (ESI) m/z (rel. int.): 496 (M+1, 16), 479 (M-H₂O, 13), 132 (N-methylisoindoline, 100). Anal. calcd. for C₃₁H₃₇FeNO (495.48): C, 75.15; H, 7.53; Fe, 11.27; N, 2.83. Found: C, 75.08; H 7.48; Fe, 11.36; N, 2.91 %.

4.21. 1-((1S,2R,4S,E)-3-Ferrocenylmethylidene-2-hydroxy-2-(2-(isoindolin-2-yl)ethyl)-7,7-dimethylbicyclo[2.2.1]heptan-1-yl)-N,N-dimethylmethanesulfonamide 46

To a stirred solution of **43** (0.300 g, 0.60 mmol) in CH₃CN (15 ml) were added K₂CO₃ (0.133 g, 0.96 mmol) and α,α' -dichloro-o-xylene (0.158 g, 0.90 mmol) at room temperature. The reaction mixture was refluxed for 7 h. The reaction progress was monitored by TLC (cyclohexane/MTBE = 2:1). The reaction was quenched with water, extracted with CH₂Cl₂ and the organic phase was dried over anhydrous Na₂SO₄. The solvent was evaporated *in vacuo* and the crude product was chromatographed (30 g silica gel, cyclohexane/MTBE = 2:1), to give **46** (0.097 g, 27%) as an orange solid. Mp 152-154°C. $[\alpha]_D^{20} = +16.7$ (c 0.18, CHCl₃). ¹H NMR (600 MHz, CDCl₃, 293 K): δ = 7.21 (s, 4H, 5'-H, 6'-H, 7'-H, 8'-H), 6.26 (s, 1H, 11-H), 4.33-4.32 (m, 2H, 13-H, 16-H), 4.22-4.18* (m, 4H, 14-H, 15-H, 10'-H), 4.13 (s, 5H, Cp), 4.06* (br d, 2H, 3'-H, J = 11.8 Hz), 3.63 (d, 1H, 10-H_b, J = 14.9 Hz), 3.55 (dt, 1H, 2'-H_a, J = 12.2, 2.7 Hz), 3.07-3.04 (m, 1H, 2'-H_b), 2.94 (s, 6H, SO₂NMe₂), 2.76 (d, 1H, 4-H, J = 4.7 Hz), 2.70-2.65 (m, 2H, 10-H_a, 1'-H_a), 2.26-2.21 (m, 1H, 6-H_{exo}), 2.02-1.96 (m, 2H, 5-H_{exo}, 6-H_{endo}), 1.62-1.58 (m, 1H, 1'-H_b), 1.38-1.34 (m, 1H, 5-H_{endo}), 0.97 (s, 3H, 9-H), 0.95 (s, 3H, 8-H). ¹³C NMR (150.92 MHz, CDCl₃, 293 K): δ = 152.55 (1C, 3-C), 139.37 (2C, 4'-C, 9'-C), 126.91 (2C, 5'-C, 8'-C), 122.19 (2C, 6'-C, 7'-C), 117.33 (1C, 11-C), 83.31 (1C, 12-C), 81.83 (1C, 2-C), 68.98* (1C, 13-C), 68.85 (5C, Cp), 68.35* (1C, 16-C), 68.33* (1C, 14-C), 68.14* (1C, 15-C), 59.00 (2C, 3'-C, 10'-C), 53.58 (1C, 7-C), 52.55 (1C, 2'-C), 50.70 (1C, 1-C), 50.44 (1C, 4-C), 43.63 (1C, 10-C), 37.76 (2C, SO₂NMe₂), 33.60 (1C, 1'-C), 25.80 (1C, 6-C), 24.90 (1C, 5-C), 21.67 (1C, 8-C), 20.34 (1C, 9-C). MS (ESI) m/z (rel. int.): 603 (M+1, 38), 585 (M-H₂O, 7), 132 (N-methylisoindoline, 100). Anal. calcd. for C₃₃H₄₂FeN₂O₃S (602.61): C, 65.77; H, 7.03; Fe, 9.27; N, 4.65; S, 5.32. Found: C, 65.85; H 6.98; Fe, 9.21; N, 4.62; S, 5.23 %.

4.22. Enantioselective addition of diethylzinc to benzaldehyde in presence of ligands 15-19, 29-35, 45 and 46 (General procedure)

To a solution of the corresponding ligand in 6 ml of hexane or toluene, Et₂Zn (5.6 ml, 5.60 mmol of 1 M solution in hexane) was added dropwise at 0°C. The mixture was stirred for 30 min at 0°C and then benzaldehyde (0.288 ml, 2.83 mmol) was added at 0°C. The reaction was stirred at room temperature and monitored by TLC (petroleum ether/Et₂O = 5:1) until the full consumption of benzaldehyde. The mixture was quenched at 0°C (aq. NH₄Cl), extracted with Et₂O (3×20 ml) and organic phase was dried over anhydrous Na₂SO₄. The solvent was evaporated *in vacuo* and the crude product was chromatographed (15 g silica gel, petroleum ether/Et₂O = 6:1) to obtain pure 1-phenyl-1-propanol as a mixture of both enantiomers. For the ee determination of 1-phenyl-1-propanol, see section 4.1. General.

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