Chapter 4: Summary

Tin(IV) compounds have gained particular interest due to their intriguing topologies, industrial applications and appreciable chemotherapeutic features. These compounds have been investigated for their diverse biological activities including anti-cancer, anti-inflammatory, anti-tuberculosis, anti-leishmaniasis and antibacterial activities. Modern chemists are actively engaged in designing new tin(IV) compounds and utilizing them as reagents and intermediates in popular synthetic reactions. Among these, especially bicyclic and tricyclic complexes of tin are of much interest because coordination numbers greater than four are frequently encountered in such structures. Some important structural features of tin(IV) compounds account for their application in a variety of chemical transformations including Stille reactions. However, association of tin(IV) compounds to form dimers or trimers in the solid state as well as in solution phase is well known. These compounds generally associate in solid state due to the presence of reactive moieties in the ligating system and form lower oligomeric moieties (dimeric or trimeric units). This property of oligomerization may be the reason for their limited use in organic synthesis. Hence, our main aim was their segregation to monomeric forms to make them applicable in synthetic chemistry.

In context of our goal, synthesis and characterization of some new stannanes/pseudo-stannatranes/quasi-stannatranes based on trialkanolamines, Mannich and Schiff bases with bicyclic and tricyclic ring systems have been done. The choice of such ligands offers the possibility of a wide variation in donor-acceptor interaction and molecular flexibility. The overall work is divided into two parts; 1) tin(IV) compounds derived from Mannich bases and other tripodal systems; 2) tin(IV) compounds derived form Schiff bases. The first part involves insertion of rigid functionalities into the tripodal motifs to prevent the formation of polymeric tin(IV) products (Fig. 4.1). In this part, a semi-rigid bisphenol, rigid trisphenol and nitrilotriacetic acid was utilized to study the affect of rigid ligating frameworks on self-association of tin(IV) compounds.
Fig. 4.1 Illustration for the usage of tripodal ligating systems to obtain pseudo-stannatranes/stannatranes

In the second part, Schiff bases have been utilized to achieve polycyclic tin compounds. The Schiff bases were selected for obtaining tin(IV) compounds on the basis of their biological applications like antitumour, antimicrobial, antinematicidal, anti-insecticidal and anti-inflammatory activities. Furthermore, tin(IV) compounds of Schiff bases present a wide variety of interesting structural possibilities. Therefore, in this part cyclic (bicyclic, tricyclic or polycyclic) organotin Schiff base compounds have been synthesized by modifying ligand sphere and coordination geometries as shown below (Fig. 4.2).

Fig. 4.2 Illustration for the modification of Schiff base ligating systems used to obtain organotin compounds
The Schiff base ligands were derived from various amines (like flexible diethylenetriamine/ethanol amine, semi-rigid aminoacids and rigid anthranilic acid) and carbonyl compounds (like flexible 2-hydroxyacetophenone and rigid 2-hydroxy-4-methoxybenzophenone/2-hydroxynapthaldehyde). Overall, thesis work attempted to develop tin(IV) compounds with polydentate ligating systems such as Mannich bases (aminobisphenolate and aminotrisphenolate), nitrilotriacetic acid and Schiff bases. This thesis is organized in three chapters (Chapter 1-3) and each chapter is summarized below.

The first chapter ‘Introduction’ is divided in two sections; first section describes the background and literature available on stannatranes and their counterparts. It discusses the structural aspects and general synthetic strategies to develop stannatranes from triethanolamine and its derivatives. The structural features of known stannatranes like transannular Sn-N bond, degree of self-assembly and spectroscopic aspects have been compared and summarized in this section. Moreover, the applications of carbastannatranes in cross coupling reactions (Stille coupling) are discussed with special reference to the mechanistic aspects and intermediate species formed during the reaction course. In the second section, Schiff base tin(IV) compounds are covered. This section involves general synthetic strategies for the formation of tin(IV) Schiff base compounds, various ligating donor systems like ONNNO and ONO systems have been discussed in detail. A special emphasis has been given to the ligating systems derived from diethylenetriamine, simple β-amino alcohol, amino acids and anthranilic acids and their organotin compounds known till date.

In second chapter, brief description of all the chemicals and reagents, general features and specifications of instrumentation, characterization techniques employed to accomplish the research work are described. This chapter discusses detailed experimental procedures used for the synthesis of tricyclic tin(IV) cages [4.4.3.0\textsuperscript{1,6}], [4.4.4.0\textsuperscript{1,6}] and [3.3.3.0\textsuperscript{1,5}] utilizing aminobisphenolate (2-5), aminotrisphenolate (7-10) and nitrilotriacetic acid (11-13), respectively. In addition, cyclic tin(IV) Schiff base compounds with Schiff base ligands comprising ONNNO donor set and their dithiocarbamate derivatives (15-18, 20-25), and ONO donor set with derivatives (27-29, 31-44) are discussed in detail. It also provides the characterization details such as yields, melting points, elemental analysis, UV/Vis spectroscopy, IR spectroscopy,
multinuclear ($^1$H, $^{13}$C and $^{119}$Sn) NMR spectroscopy, and mass spectroscopy of all the synthesized compounds and the data is supported by the corresponding spectra attached as appendices at the end.

The third chapter discusses the synthetic, spectroscopic, structural aspects and brief applications of tin(IV) compounds synthesized from heteropolydentate ligating systems (with NO$_3$, N$_2$O$_2$ and NO$_2$ donor sets). On the basis of work phases, it is divided in two sections; 1) tin(IV) compounds derived from tripodal ligating systems; 2) tin(IV) compounds derived from Schiff base systems. In the first phase, tripodal ligating systems with NO$_3$ donor system having rigid (non-flexible) or semi-rigid skeletons (or substituted skeletons) were utilized to prevent the oligomerization at the initial stage of synthesis. The ligating frameworks were tuned from semi-rigid to rigid to afford extra stability to the heteroatomic fused molecule by the formation of additional donor-acceptor interactions via N-M bond. It was hypothesized that such ligands would stabilize the metal centre and facilitate their isolation as discrete molecules.

Further, it consisted of three sub-sections. In the first part of work, Mannich base derived from the condensation of ethanolamine and 2,4-dimethylphenol (1) have been explored. This unsymmetrical aminobisphenolate ligand usually binds to an element in a tetradentate manner to form “atrane like” [4.4.3.0] tridecane cages (2-5) and provides a range of sterically and electronically stable environments (Scheme 4.1). However, in our case, the binding mode was different depending upon the substituents attached to the tin.

Interestingly, compound 2, 4 and 5 were isolated as dinuclear species whereas 3 as tetranuclear compound due to self-association (Scheme 4.1). The spectroscopic details and X-ray crystal structure revealed the compound 2 as a non-centrosymmetric dimer whereas. However, compound 3 constituted a “ladder” like architecture bearing two types of Sn coordination spheres arranged in centrosymmetric fashion, thus indicating a broad diversity of molecular architectures accessible with this tripodal ligand 1. The X-ray crystal structure of compound 2 and 3 was also compared with the silatrane analogue of the same ligand prepared in our lab, which was isolated as a discrete monomeric molecule and explains the higher degree of oligomerization property of stannatrananyl cages through the flexible aminoethanol arm. Herein, self-
assembly of pseudo-atrane cages was found dependent upon coordination capability of the central metal ion and steric constraints of the exocyclic substituent.

**Scheme 4.1** General procedure for the utilization of aminobisphenolate ligating molecule for the formation of pseudo-stannatrane [4.4.3.0\(^{1,6}\)]

In the second part, we used aminotrisphenolate ligand to introduce structural rigidity by phenolic arms. This modification was done to achieve favourable topological control in order to stabilize stannatrane moieties as monomeric units. Here, the flexibility was (offered by ethanolamine group) completely removed as compared to previous ligand by incorporating 2,4-dimethylphenol moiety in all the three tripods.

**Scheme 4.2** General procedure for the utilization of aminotrisphenolate ligating molecule for the formation of pseudo-stannatrane [4.4.4.0\(^{1,6}\)]
Chapter 4

Summary

Exploration of aminotrisphenol ligand 6 to synthesise heterocyclic tin derivatives led to the unexpected formation of a stannatrane-like [4.4.4.0\^{1,6}] heterotricyclic stannate anion [LSnBuCl]\(^-\) (7), [LSnPhCl]\(^-\) (8) and [LSnCl\(_2\)]\(^-\) (9) (Scheme 4.2). Further, metathesis reaction of 9 with ammonium thiocyanate provided access to its thiocyanate derivative [LSn(NCS)\(_2\)]\(^-\) (10), which proved to be a good chromophoric probe.

The characterization methods such as elemental analysis, various spectroscopic methods (FT-IR, \(^1\)H, \(^{13}\)C, \(^{119}\)Sn NMR, UV-Vis, Mass spectrometry) and X-ray crystallography (for 10) were in accord with the formation of ionic compounds. The rhodanide functionalized stannatrane-like compound (10) was isolated as triethylammonium salt with distorted octahedral environment around Sn generated by the tripodal O\(_3\)N donor system and the N atoms of two cis configured thiocyanates. This particular organization of rhodanides imparted chelator and chromophoric character to 10 (Fig. 4.3) and enhanced its colorimetric and optical response towards some metal ions (such as Fe\(^{3+}\), Cu\(^{2+}\) and Co\(^{2+}\) ions) as compared to the free tripodal ligand (6) and ammonium thiocyanate. Overall, we succeeded in the isolation of monomeric species, however tin(IV) achieved the hexacoordinated environment by the incorporation of an extra exocyclic substituent.

**Fig. 4.3** Pictorial representation of chromophoric behaviouir of rhodanide derivative 10 of aminotrisphenolate with transition metal ions

In the third part, rather modular and commercially available tripodal carboxylic system i.e. nitrilotriacetic acid was utilized for the complexation of butyltin trichloride, phenyltin trichloride and tin tetrachloride resulting in the formation of undecane [3.3.3.0\^{1,5}] heterotricycles 11-13 (Scheme 4.3). This C\(^3\)-symmetric ligand
possessed carbonyl groups as side chains, which disfavor the oligomerization of undecane heterotricycle.

**Scheme 4.3** General procedure for the utilization of NTA molecule for the formation of pseudo-stannatrane [3.3.3.0\(^1\)\(^5\)]

All the compounds were characterized using spectroscopic techniques (\(^1\)H, \(^13\)C, \(^{119}\)Sn NMR, FT-IR and Mass spectrometry). It revealed the diastereotopic nature of the methylene protons of the two rings whereas the third ring showed a broad signal due to homotopic nature indicating the loss of \(C_3\) symmetry due to the strong Sn-N coordination. The single resonance for compound 11 (\(\delta\) -382 ppm), 12 (\(\delta\) -434 ppm) and 13 (\(\delta\) -495 ppm) in the \(^{119}\)Sn NMR spectra showed the formation of pure compounds.

In the second phase, tin(IV) compounds with Schiff bases are explored as they present an interesting variety of structural possibilities. Increasing attention has also been devoted to the cyclic organotin(IV) complexes with Schiff base ligands in view of their special intramolecular Sn–N coordinate bond formation. In the first part, ligands with ONNNO donor set capable of forming more than one intramolecular Sn-N bond were tried. The ligands were modified by varying ketonic (2-hydroxyacetophenone and 2-hydroxy-4-methoxybenzophenone) part. In this series, heptacoordinated tin(IV) mononuclear compounds were synthesized by the reaction of pentadentate Schiff base ligands 14 and 19 with tin tetrachloride (15 and 20), butyltin trichloride (16 and 21), dibutyltin dichloride (22) and dimethyltin dichloride (23). These ligands (14 and 19) were further reacted with dimethyltin dichloride and
phenyltin trichloride to obtain their dithiocarbamate derivatives (17, 18, 24 and 25) (Scheme 4.4). All of the compounds were characterized by IR, mass spectrometry, and $^1$H, $^{13}$C, and $^{119}$Sn NMR spectroscopies, and the spectra displayed chemical shifts corresponding to a six and seven-coordinated tin environment.

Scheme 4.4 (A) Synthesis of the hexa- and hepta-coordinated compound 15-18 from the pentadentate ligand derived from 2-hydroxyacetophenone (B) Synthesis of the hexa- and hepta-coordinated compound 20-24 from the pentadentate ligand derived from 2-hydroxy-4-methoxybenzophenone

The spectroscopic data revealed the broadening of signals as the molecules were involved in conformational equilibria that involved the rupture and formation of Sn-N bond along with the inversion at central nitrogen in the solution state. In order to remove the broadening observed in the NMR spectroscopic data (of 15,16,20-23), rigidity was introduced at the free –NH group by adding CS$_2$. This resulted in the
formation of dithiocarbamate and reduced the fluxionality to the large extent. The reduction in the fluxionality was observed as sharpening of NMR signals (of 17, 18, 24 and 25) for the alkyl region and the data became consistent with the structure proposed.

In the next phase, phenol substituted Schiff base with ONO donor set were chosen as ligand as they act as workhorses for coordination chemists. These ligands can be used to prepare metal complexes with different skeletons. These ligands contain both hard and soft electron donors and can be modified very easily to introduce rigid and flexible parts in their structures.

Tridentate ONO donor system derived from ethanolamine resulted in the formation of pentacoordinated diphenyl- and dimethyl- tin(IV) compounds 27-28 and hexacoordinated compound 29 by using diphenyltin oxide, dimethyltin oxide and tin tetrachloride respectively (Scheme 4.5). The spectroscopic data confirmed the structure of the compounds 27-29. Further confirmation of the structures was provided by the crystal structure of the diphenyltin(IV) compound 27, which crystallized as monomeric unit with trigonal bipyramidal geometry where Schiff base ligand acted as dianionic tridentate ligand.

Scheme 4.5 Synthesis of the penta- and hexa-coordinated compound 27-29 from the tridentate ligand derived from 2-hydroxy-4-methoxybenzophenone and ethanolamine
Further, incorporation of amino acids to produce biogenic ligating system via Schiff base condensation represented a challenging area of research. The incorporation of chiral amino acids in the ligating framework was even more difficult. However, these ligands offer advantages to synthesise chiral metal-Schiff base complexes for asymmetric catalysis and chemo-sensing of chiral molecules etc.

Therefore, Schiff base derived from $\alpha$-amino acid (alanine, valine, isoleucine, methionine and tryptophan) and 2-hydroxy-4-methoxybenzophenone was complexed with diphenyltin oxide to produce diphenyltin(IV) compounds 30-34 (Scheme 4.6). These reactions were done in situ, as isolation of Schiff base derived from $\alpha$-amino acid was very difficult and low yields were observed. The characterization methods such as elemental analysis, various spectroscopic methods FT-IR, NMR ($^1$H, $^{13}$C, $^{119}$Sn), UV-Vis and Mass spectrometry were in accord with the formation of organotin(IV) compounds.

Further the rigidity of the previously applied combination was modulated by using 2-hydroxy-1-napthaldehyde, dibutyltin oxide and simple to heteroatom substituted amino acids (tyrosine, isoleucine, serine and glutamine) to produce dibutyltin(IV) compounds 35-38 (Scheme 4.6). These compounds showed the similar structure as discussed previously.

The confirmation to the structure was provided by the X-ray crystallographic studies for compound 36 and 38. X-ray diffraction studies of 36 consisted of pentacoordinated tin atom; where Schiff base coordinated as a tridentate ligand via azomethinic N, the deprotonated phenolic hydroxyl O and the deprotonated carboxylic O. In a similar way, compound 38 was crystallized in which Sn(IV) adopted a distorted trigonal bipyramidal geometry with SnNO$_2$C$_2$ coordination sphere (azomethinic nitrogen, two oxygen donor atoms of the doubly deprotonated ligating framework and two carbon atoms of the butyl chain).
Scheme 4.6 Synthesis of the pentacoordinated compound 30-34 from the tridentate ligand derived from 2-hydroxy-4-methoxybenzophenone and 35-38 from 2-hydroxy-1-napthaldehyde with α-amino acids

Schiff bases of aliphatic aldehydes are relatively unstable and readily polymerizable while those of aromatic aldehydes having effective conjugation are more stable. Hence, at the end fully aromatic and highly rigid system was incorporated for the complexation with tin(IV) to completely remove the flexibility. 2-[(2-hydroxy-naphthalen-1-ylmethylene)-amino]-benzoic acid (39) was used to obtain μ-hydroxo bridged dimethyl, dibutyl and diphenyl derivatives of tin (40-43) (Scheme 4.7). The compounds exhibited μ-hydroxo bridges between R₂Sn units and this preserved the keto-enamine form by forming network of intramolecular hydrogen bonding between μ-OH, C=O (keto) and N-H confirmed by the crystal structure of...
dibutyltin(IV) compound (41). Fascinatingly, the compound 41 helps in the recognition of Cr$^{3+}$ ions. Fluoregenic ‘turn ON’ response of 41 towards chromium species was elaborated which exhibit fluorescent blue colour in methanol.

**Scheme 4.7** Synthesis of the pentacoordinated compound 40–43 from the ligand derived from 2-hydroxy-1-napthaldehyde and anthranilic acid

Overall, the aim of the proposed plan has been successfully achieved by varying the coordinating environment around the tin.