X-Ray Structural Investigations of Gold Compounds

A COMPILATION OF REFERENCE DATA. SUPPLEMENT I

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Parts I and II of this article reviewed X-ray structural analysis of gold compounds up to early 1980. This first supplement covers the period 1980-1982; some publications from early 1983 are also included.

The period 1980-1982 has seen a continued increase in the use of X-ray crystallography to investigate chemical structure; this increase is reflected in the number of contributions to the structural chemistry of gold. An update of the previous two articles in this series (*Gold Bull.*, 1981, 14, 102-118 and 159-166) thus seems worthwhile.

As before, the author would like to thank the curators of various crystallographic data centres and their co-workers for their invaluable help in compiling this supplement: Drs. O. Kennard and S. Bellard, Cambridge; Dr. I.D. Brown, 'BIDICS', Ontario; and Prof. G. Bergerhoff, Bonn. Dr. J.W.A. van der Velden (Univ. of Nijmegen) kindly made unpublished results available.

References, Figures and Tables are numbered to follow on from Parts I and II.

Omissions in Parts I and II

Regrettably but perhaps inevitably, some addenda are necessary. The author would be grateful to be notified of any further errors or omissions; these will be dealt with in a future supplement.

To the early studies of naturally occurring gold tellurides (7,8) should be added related investigations of the mixed gold/silver tellurides, selenides and sulphides, sylvanite AuAgTe_4 (168), petzite Ag_3AuTe_2 (169, 170), Ag_3AuSe_2 (170) and Ag_3AuS_2 (171). Since all these structures are of low accuracy, they will not be discussed further here. Reference (168) discusses the close structural relationship between some Au/Ag/Te minerals.

Recent X-ray powder investigations of double oxides ABO (A = alkali metal, B = coinage metal) (172), including CsAuO , largely repeat the earlier work of Hoppe and co-workers (64).

The following structures were previously reported as preliminary or private communications, but have now been published in full: $\text{HAuCl}_4 \cdot 4\text{H}_2\text{O}$ (111, 173); $\text{Os}_3(\text{CO})_{10}(\text{Ph}_3\text{PAu})\text{X}$ (X = H, SCN; 31a, 174); Au_4Cl_8 (49, 175); ' $\text{C}_6\text{H}_5\text{NAuX}$ ' (X = Cl, I; 37a, 37b, 176); $\text{Na}_6\text{Au}_2\text{O}_6$ (123, 177); $\text{C}_6\text{H}_5\text{NH}^+\text{AuCl}_4^-$, $\text{C}_6\text{H}_5\text{NAuCl}_3$ and $(\text{C}_6\text{H}_5\text{N})_2\text{AuCl}_2 \cdot \text{Cl}^- \cdot \text{H}_2\text{O}$ (37b, 178); $\text{Me}_3\text{AuCH}_2\text{SOMe}_2$ (134, 179); and the cluster compound $[\text{Au}_5(\text{dppm})_3(\text{dppm}^-)](\text{NO}_3)_2$ (17, 180).

The remainder of this supplement is subdivided into the same sections as Parts I and II.

I. Simple Binary and Ternary Compounds

The reaction of gold with selenic acid affords yellow crystals, previously formulated as $\text{Au}_2(\text{SeO}_4)_3$, which are used to colour

Table VIII
Gold Clusters Structurally Characterized by X-ray Methods

Cluster*	References	Special Crystallographic Symmetry	Comments
$[\text{Au}_{13}(\text{P})_{10}\text{Cl}_2]^{3+}$	184	$\bar{1}$	**
$[\text{Au}_{13}(\text{PP})_6]^{\ddagger}$	180	$\bar{3}$ or 32	**, ††
$[\text{Au}_{11}(\text{P})_7\text{X}_3]$	22	m	**, ††
	23	3	**, ††
	24	3	**
	184a		**, ††
$[\text{Au}_{11}(\text{PP})_5]^{3+}$	185, 186		**, ††
$[\text{Au}_9(\text{P})_8]^{3+}$	21, 186a	222	**, ††
$[\text{Au}_9(\text{P})_5(\text{SCN})_3]$	166		**
$[\text{Au}_9(\text{P})_8]^+$	187	32	**, ††
$[\text{Au}_9(\text{P})_8]^{3+}$	188	2	\$
$[\text{Au}_8(\text{P})_8]^{2+}$	19, 20		**
$[\text{Au}_8(\text{P})_7]^{2+}$	189, 189a		**
$[\text{Au}_7(\text{P})_7]^+$	190		\$\$
$[\text{Au}_7\text{Sn}_2]^{4+}$	191	$\bar{3} m$	
$[\text{Au}_6(\text{P})_6]^{2+}$	18	$\bar{1}$	
$[\text{Au}_6(\text{PP})_4]^{2+}$	192	$\bar{4} 2m$	††
$[\text{Au}_6(\text{P})_4[\text{Co}(\text{CO})_4]_2]$	193, 189a	$\bar{1}$	
$[\text{Au}_5(\text{PP})_3(\text{PP}^-)]^{2+}$	17, 180		
$[\text{Au}_4(\text{P})_4(\mu - \text{I})_2]$	194	2	
$[\text{Au}_4(\text{PP})_3(\mu - \text{I})_2]$	195		
$[\text{Au}_2(\text{P})_2]$	196		f

* P = monodentate phosphine ligand

PP = bidentate phosphine ligand

X = monovalent anionic ligand

** Where applicable, centred icosahedron or fragment thereof

‡ Charge unknown

†† Disorder/pseudosymmetry

\$ Centred crown

\$\$ Four crystallographically independent clusters

f Few crystallographic details given

glass. It has now been shown that at least two products are involved, both of which contain selenium in oxidation state +IV rather than +VI. $\text{Au}_2\text{Se}_4\text{O}_{11}$ contains selenite and diselenite ions and can be rewritten as $\text{Au}_2(\text{SeO}_3)_2(\text{Se}_2\text{O}_5)$ (181); the structure consists of three cross-linked chains of the form $[\dots\text{Au}-(\text{selenite or diselenite})-\text{Au}\dots]$. $\text{Au}_2\text{Se}_2\text{O}_7$ is a layer structure containing selenite and oxide ions and can be regarded as $\text{Au}_2(\text{SeO}_3)_2\text{O}$ (182); the structure is of limited accuracy because of pseudosymmetry. Although strictly not a ternary compound, the related material $\text{Au}(\text{SeO}_3)\text{Cl}$ also has a layer structure, and can best be mentioned here (183; Figure 31).

II. Gold Cluster Compounds

Interest in these compounds, which have an aesthetic as well as a scientific appeal, continues unabated. Despite appreciable practical difficulties both with synthesis/purification and with crystal structure determination (gold cluster compounds often display disorder and/or pseudosymmetry (183a)), several new structures have appeared in the last two years. Some of those mentioned here were briefly alluded to in footnotes to Parts I and II. A summary of crystallographically characterized clusters is given in Table VIII. A discussion of the physical characteristics of gold clusters by D.M.P.

Fig. 32 The cluster $[\text{Au}_9(\text{PPh}_3)_8]^+$. Phenyl groups and bonds to the central Au omitted for clarity. Note the cubane-type Au_8 framework and the vertical threefold axis. After (187)

Fig. 33 The Au skeleton of $[\text{Au}_8(\text{PPh}_3)_7]^{2+}$ fitted to an icosahedral framework. The dotted atom completes the $[\text{Au}_9(\text{PPh}_3)_8]^{3+}$ structure. Reproduced from (189)

Mingos will appear in the next issue of *Gold Bulletin*.

Au_{13} clusters. The compound $[\text{Au}_{13}(\text{PMe}_2\text{Ph})_{10}\text{Cl}_2](\text{PF}_6)_3$ contains a centred icosahedron of gold atoms (184); this unit is recognised as the parent polyhedron of many smaller clusters. A similar unit could be identified in the $[\text{Au}_{13}(\text{dppm})_6]$ ion (180), but disorder of the ligands and the additional presence of an unidentified disordered cluster rendered the structure of low accuracy; the ionic charge could not be determined.

Au_{11} clusters. The Au_{11} core geometry in $[\text{Au}_{11}(\text{dppp})_3](\text{SCN})_3$ (185, 186) is the same as that in previously reported Au_{11} clusters (22, 23, 24). Disorder of some ligand and light atoms limited the accuracy of the structure. A further Au_{11} halide cluster $[\text{Au}_{11}(\text{Ph}_3\text{P})_7\text{I}_3]$ (184a) also differs little from the earlier structures.

Au_9 clusters. The first neutral Au_9 cluster is $[\text{Au}_9(\text{Pcy}_3)_3(\text{SCN})_3]$ (166; see conclusion to Part II). It can be formally regarded as derived from a centred icosahedron by removal of four vertices, although one peripheral Au-Au bond must also be broken.

The $[\text{Au}_9(\text{PPh}_3)_8]^{3+}$ cluster (21, 186a) can be electrochemically reduced to give $[\text{Au}_9(\text{PPh}_3)_8]^+$; the centred Au_6 chair is effectively unchanged, but the remaining two atoms now lie on the three-fold axis (Figure 32). Again the structure determination was somewhat inaccurate, only gold and phosphorus atoms being located (187).

A complete departure from icosahedral frameworks is provided by $[\text{Au}_9\{\text{P}(p\text{-C}_6\text{H}_4\text{OMe})_3\}_3]^{3+}$; the Au_9 skeleton is a centred crown (188). The authors suggest that $\text{Au}_p\text{-Au}_p$ bonds (for nomenclature see Part I) may not be energetically significant in centred gold clusters, since there are four fewer such bonds in the centred crown than in the other Au_9^{3+} clusters.

Au_8 clusters. Chemical removal of one ligand from the known cluster $[\text{Au}_8(\text{PPh}_3)_8]^{2+}$ (19, 20) gives $[\text{Au}_8(\text{PPh}_3)_7]^{2+}$; as would be expected from the long $\text{Au}_c\text{-P}$ bond of the former cluster, it is the Au_c atom which loses its ligand (189). The gold framework remains based on the central icosahedron, the Au_c atom being rather exposed (Figure 33).

Au_7 clusters. $[\text{Au}_7(\text{Ph}_3\text{P})_7]^+$ is prepared by the evaporation of metallic gold into a toluene solution of the ligand. The crystal structure (190) is one of unusual complexity, with four independent but very similar clusters. The Au_7 skeleton is a pentagonal bipyramid with a very short axial-axial Au-Au bond of 258.4 pm. This geometry can be formally regarded as derived from a centred icosahedron by removal of a pentagonal pyramid, but this may be extending the formal analogy too far!

Although alloys have been specifically excluded from these articles, an exception should be made in the case of $\text{Rb}_4\text{Au}_7\text{Sn}_2$ (191). This contains Au_7 clusters (Au-Au bond length = 275.7, 278.0 pm) in the form of two tetrahedra linked at a common vertex; Sn_2 units link these clusters (Figure 34) (Au-Sn = 260.1, Sn-Sn = 286.8 pm).

Au_6 clusters. $[\text{Au}_6(\text{dppp})_4](\text{NO}_3)_2$ contains a tetrahedron of gold atoms, each bonded to one phosphorus of a bidentate dppp ligand, and two further gold atoms bridging opposite edges of the

Fig. 34 The Au_6 core of $\text{Rb}_4\text{Au}_6\text{Sn}_2$, showing the Sn_2 units which bridge to further clusters. After (191)

Fig 35 The $[\text{Au}_6(\text{dppp})_4]^{2+}$ cluster. Phenyl groups omitted for clarity. After (192)

Fig. 36 The $[\text{Au}_4(\text{dppm})_2\text{I}]$ cluster. Phenyl groups omitted for clarity. Au-I bond lengths: to terminal I, 259.3 pm; to bridging I, 313.2, 334.3, 366.8 pm. After (195)

tetrahedron and each bonded to two phosphorus atoms (Figure 35; 192). This contrasts with the distorted octahedral geometry of the previously known Au_6 cluster (18). A heteronuclear Au_6 cluster with $\text{Co}(\text{CO})_4$ ligands has also been reported (193); the Au_6 moiety in $[\text{Au}_6(\text{PPh}_3)_4\{\text{Co}(\text{CO})_4\}_2]$ consists of two tetrahedra with a common edge, the cobalt atoms being bonded to the apical golds.

Au_4 clusters. The cluster $[\text{Au}_4(\text{PPh}_3)_4\text{I}_2]$ contains a tetrahedral Au_4 unit bridged on two opposite edges by iodide ligands (194). The assembly of six heavy atoms is thus strikingly similar to the $[\text{Au}_6(\text{dppp})_4]^{2+}$ cluster mentioned above. A further iodine-

Fig. 37 Compounds containing bridged gold-metal bonds.
(a) the hydride-bridged $[(\text{CO})_3\text{Cr}(\mu\text{-H})\text{AuPPh}_3]$
(b) the CHR-bridged $[(\text{cp})(\text{CO})_2\text{W}(\mu\text{-CHR})\text{AuPPh}_3]$
After (200, 202) respectively; parts of some phenyl rings omitted for clarity.
In (b) the H of CHR was not found

containing cluster $[\text{Au}_4(\text{dppm})_3\text{I}_2]$ 195 also contains a tetrahedron of gold atoms; one is coordinated to iodine, while the remaining triangle is bound to the three diphosphine ligands and capped asymmetrically by a distant iodine atom (Figure 36).

Au₂ 'cluster'. As was mentioned in a footnote to Part II, the zerovalent $[\text{Au}_2(\text{PPh}_3)_2]$, prepared by methods analogous to those used for many larger clusters, has been structurally characterized (196). Regrettably, few details of this interesting structure are available (although slightly more than were given in Part II): the P-Au-Au-P sequence adopts a *trans*-bent geometry, with Au-Au = 276 pm, Au-Au-P = 129°.

III. Compounds with Gold-Transition Metal Bonds

An Au-V bond of 269.0 pm occurs in $[\text{PPh}_3\text{AuV}(\text{CO})_6]$ (197), which possesses crystallographic 3 symmetry along the P-Au-V axis. A more complex gold-vanadium species, which may be regarded as a mixed cluster, is $[(\text{Ph}_3\text{PAu})_3\text{V}(\text{CO})_5]$ (189), which was found to contain an Au_3V tetrahedron (Au-V = 270.9–275.6 pm, and Au-Au = 276.8–285.5 pm). The allyl-iron derivative $[\text{Ph}_3\text{PAuFe}(\text{CO})_3(\eta^3\text{-C}_3\text{H}_5)]$ (199) shows an Au-Fe bond of length 251.9 pm, appreciably shorter than in the loosely related cyclopentadienyl species (31); the carbonyl ligands bend back towards the gold atom, as in $[\text{Au}[\text{Co}(\text{CO})_4]_2]^-$ (29).

An important new class of compounds is that of the mixed metal hydrides containing $\text{Au} \xrightarrow{\text{H}} \text{M}$ bridges. The first compound known to involve an Au-H bond is $[(\text{CO})_3\text{Cr}(\mu\text{-H})\text{AuPPh}_3]$ (200). The hydrogen atom cannot be located precisely in such structures, but the Au-H bond is approximately 172 pm (e.s.d. = 11 pm); Au-Cr = 277.0 and Cr-H = 164 pm (Figure 37a). In a similar complex $[(\text{PPh}_3)_3\text{IrH}_2(\mu\text{-H})\text{AuPPh}_3]^+$, the bridging hydrogen atom could not be found (201), but its presence could be inferred from the bent P-Au...Ir geometry, and on chemical grounds.

The compound $[(\text{cp})(\text{CO})_2\text{W}(\mu\text{-CHR})\text{AuPPh}_3]$ (where R = *p*-C₆H₄Me) (202) displays a $\text{W} \xrightarrow{\text{C}} \text{Au}$ triangle, with Au-W = 272.9(1) and Au-C = 226.8(1.4) pm (Figure 37b).

It is a surprising but theoretically justifiable fact that the Ph_3PAu group is electronically analogous to hydride. This fact has been exploited in the syntheses of many mixed metal clusters with peripheral Ph_3PAu groups, and/or in the rationalization of their structures. More than one gold atom may be incorporated into a cluster, sometimes with the formation of an Au-Au bond. A summary of mixed clusters is given in Tables IX and X; see also (174). One mixed cluster is unusual enough to be omitted from these Tables, because it contains no phosphine group; the Au-PR₃ bond of $[\text{Os}_3(\text{CO})_{10}\text{H}(\text{AuPR}_3)]$ (174) breaks on reaction with $[\text{N}(\text{PPh}_3)_2]\text{Cl}$, to give $[\text{Os}_6\text{Au}(\text{CO})_{20}\text{H}_2]$ (213). This cluster contains a planar four-coordinated gold atom on a crystallographic symmetry centre, bonded to edges of two Os₃ triangles (Au-Os = 280.6–281.4 pm); the overall geometry is thus two Os₃Au butterflies with a shared Au wingtip (Figure 38).

A completely different kind of mixed-metal aggregate is seen in the chain polymer $[(\text{C}_6\text{F}_5)\text{AuAg}(\text{SC}_4\text{H}_8)]$ (214); Au₂ units (Au-Au = 288.9 pm) are bridged by pairs of Ag atoms (Au-Ag = 271.7, 272.6 pm) (Figure 39). This is the first known example of an Au-Ag bond.

Table IX
Mixed Clusters Involving Peripheral AuP Units*

Compound	Reference	Geometry excluding Au	Au position	Au-M bond length(s), pm
[FeCo ₃ (CO) ₁₂ (AuP)]**	203	FeCo ₃ tetrahedron	Triply bridges Co ₃ face	271.4 (av)
[RuCo ₃ (CO) ₁₂ (AuP)]**	203a	RuCo ₃ tetrahedron	ditto	267.9–274.5
[CoRu ₃ (CO) ₁₃ (AuP)]**	203b	CoRu ₃ tetrahedron	Triply bridges CoRu ₂ face	None given
[Fe ₄ C(μ-H)(CO) ₁₂ (AuP)]	204	Fe ₄ butterfly	Bridges wingtips*	285.4, 288.0 Au-C 207.7
[Fe ₅ C(CO) ₁₄ (AuP) ₂]	205	Fe ₅ square pyramid	Au(1) bridges basal edge+ Au(2) caps square base	269.6, 270.1 282.8–303.6 Au-C 212
[Ru ₃ (CO) ₉ (C ₂ Bu')(AuP)]**	206	Ru ₃ triangle	Completes butterfly as wingtip	275.7, 276.3
[Ru ₃ (CO) ₁₀ (COMe)(AuP)]**	207	ditto	ditto	276.0, 276.2‡
[Ru ₃ (CO) ₉ (μ-H)(μ ₃ -PPh)(AuP)]	208	ditto	ditto	274.9, 276.3
[Ru ₃ (CO) ₉ (μ-H)(μ ₃ -COMe)(AuP)]	209	ditto	ditto	272.7, 276.3
[Os ₄ (CO) ₁₃ (μ-H)(AuP)]**	210	Os ₄ tetrahedron	Edge bridging	274.5, 279.9
[Os ₄ (CO) ₁₂ (μ-H) ₃ (AuP)]**	210	ditto	ditto	278.3, 280.3

* P = monodentate phosphine ligand

+ Carbide C at centre of cluster

** Direct analogue of a hydride species

‡ Two independent molecules; only one set of bond lengths given

Table X
Mixed Clusters with Au-Au Bonds

Compound*	Reference	Geometry	Bond Lengths, pm	
			Au-Au	Au-M
[V(CO) ₅ (AuP) ₃]	198	Tetrahedron	276.8–285.5	270.9–275.6
[Fe ₄ (CO) ₁₂ C(AuP) ₂]	204	Fe ₄ butterfly plus Au-Au unit gives distorted octahedron**	301.7	277.0–299.9
[Os ₄ (CO) ₁₂ H ₂ (AuP) ₂]	211	Os ₄ tetrahedron; one edge bridged by Au-Au unit	279.3	283.9–300.4
[Os ₃ (CO) ₁₁ H ₂ (AuP) ₂]	212	Planar Os ₃ Au 'butterfly'; Au-Os edge bridged by a second Au atom	284.5	267.0–303.0
[Ru ₃ Co(CO) ₁₂ (AuP) ₃]	203b	AuCoRu ₃ trigonal bipyramid; AuRu ₂ and AuCoRu adjacent faces capped by two further Au atoms	283.6, 278.4	271.2, 272.6 (Co) 278.3–305.4 (Ru)
[Ru ₃ (CO) ₉ (μ ₃ -COMe)(AuP) ₃]	209	AuRu ₃ tetrahedron; two faces triply bridged by two further Au atoms	293.0, 301.0 281.9, 284.2	279.6–298.7 282.5–301.2
[Ru ₄ (CO) ₁₂ (μ-H)(AuP) ₃]	209	Ru(CO) ₃ replaces μ ₃ -COMe of previous structure		
[Os ₃ (CO) ₄ (AuP) ₂]	209a	No information (conference Abstract)		

* P = monodentate phosphine ligand

** Carbide C at centre of cluster

Fig. 38 The mixed cluster $[\text{Os}_6\text{Au}(\text{CO})_{10}\text{H}_2]^{2-}$, in the preparation of which a gold- PR_3 bond is broken. The H atoms were not located. After (213)

IV. Gold (I) Complexes with Short Au ... Au Contacts

Pride of place in this section must go to the dimeric 2-pyridylphosphine complex $[2-\text{C}_5\text{H}_4\text{N}.\text{PMe}_3.\text{Au}]_2^{2+}$ (215), with Au ... Au as low as 277.6 pm (Figure 40). The ligand was deliberately chosen to force a short contact. A further 8-membered dimeric ring is found in $[\text{Au}(\text{Ph}_2\text{P})_2\text{CH}]_2$ (216), with Au ... Au = 288.8 pm; the structure exhibits disorder, the molecules adopting either of two orthogonal orientations. The complicated mixed nickel/gold complex of penicillamine (Pen = $\text{HSCMe}_2\text{CH}(\text{NH}_2)\text{COOH}$), formula $\text{Na}_2[\text{Au}_2\text{Ni}_2\text{Pen}_2]^{2-}$, also contains this common structural feature; the rings are of the form $(-\text{S}-\text{Au}-\text{S}-\text{Ni}-)_2$ and the Au ... Au contacts are 294, 299 pm in two independent molecules (217).

The tridentate ligand $\text{CH}_3\text{C}(\text{CH}_2\text{PPh}_2)_3$ (= PPP) forms a simple gold (I) complex $[\text{PPP}(\text{AuCl})_3]$, in which two of the P-Au-Cl 'arms' form an intramolecular Au ... Au contact of 309.1 pm (218).

The mixed complex $[(\text{Ph}_3\text{P})_2\text{Au}_2(\text{bbzim})\text{Rh}(\text{cod})]^+$ (where cod = cycloocta-1,5-diene, bbzim = bibenzimidazolate) (219) contains two N-Au- PPh_3 moieties; since the nitrogen atoms are close together on the bbzim ligand, a short Au ... Au distance of 313.4 pm results.

The series of complexes $[(\text{Ph}_3\text{PAu})_3\text{X}]^+$, where X is an element of periodic table main group VI, is now structurally characterized for X = O, S and Se (220, 48, 221). All three form dimeric units with short Au ... Au distances of about 300-330 pm, thus giving rise to Au_6 'chairs' (see Part I). The structure of the related neutral complex $[(\text{Ph}_3\text{PAu})_2\text{S}]$ was also determined (221) but was of limited accuracy because of pseudosymmetry. The Au-S bond lengths are appreciably (about 16 pm) shorter than in $[(\text{Ph}_3\text{PAu})_3\text{S}]^+$; a slightly acute Au-S-Au angle gives an Au ... Au contact of 301.8 pm. The ease of formation of such Au_3X^+ units is also reflected in the breaking of an Au-P bond in the formation of the $[\text{Au}\{\text{S}(\text{AuPPh}_2)_2\}_2]^+$ cation

(222), which has Au ... Au in the range 303-321 pm and all Au-S-Au angles acute.

The $[(\text{Ph}_3\text{PAu})_3\text{O}]^+$ cation has been used as an aurating reagent in organometallic chemistry; for example reaction with malonitrile, $\text{H}_2\text{C}(\text{CN})_2$, gives $[(\text{Ph}_3\text{PAu})_2\text{C}(\text{CN})_2]$, with Au-C = 209.5, 210.7 (.9) pm, Au ... Au = 291.2 pm (223). A more complicated series of reactions with tetraphenylcyclopentadiene, $\text{Ph}_4\text{C}_5\text{H}_2$, leads to $[\text{Ph}_4\text{C}_5(\text{AuPPh}_3)_3]^+$ (224, 225); an Au_2C triangle (Au ... Au = 282.0 pm) is more weakly linked to the third Au atom (Au ... Au = 302.1 pm), which is itself bonded to the cyclopentadienyl ring by one short (221 pm) Au-C bond and two appreciably longer contacts of 260 and 271 pm (Figure 41).

V. Other Au(I) Complexes

The reaction of the aurating agent $[(\text{Ph}_3\text{PAu})_3\text{O}]^+$ (see previous section) with tetraphenylcyclopentadiene gives $\text{Ph}_4\text{C}_5\text{H}(\text{AuPPh}_3)$ (224, 226); this compound, like the triply aurated derivative mentioned above, is unusual in that the bonding mode of gold to the ring is intermediate between η^1 and η^3 (Au-C = 215, 267, 276 pm).

The two dicyanoaurate (I) salts $\text{Co}[\text{Au}(\text{CN})_2]_2$ (227) and $\text{KCo}[\text{Au}(\text{CN})_2]_3$ (228) show no unusual features; the same can be said for the 2-pyridylphosphine complex $(\text{C}_5\text{H}_4\text{N}.\text{PPh}_2)\text{AuCl}$ (229), although one ring is disordered.

The anti-rheumatoid arthritis drug AURANOFIN (the triethylphosphinegold (I) complex of a penta-acetyl thioglucosate anion) is only the second gold (I) thiolate for which a structure determination has been performed (230). The bond lengths at gold are comparable with the previous study (51).

Compounds $[(\text{Ph}_3\text{P})_2\text{XPt-AuPPh}_3]$, synthesized from $(\text{Ph}_3\text{P})_3\text{Pt}$ and Ph_3PAuX , are assumed to contain an Au-Pt bond (as is implied

Fig. 39 (Top) Part of the linear chain polymer $[(C_6F_5)_2AuAg(SC_4H_8)]_n$. After (214)

Fig. 40 (Middle) When is a bond not a bond? The two gold atoms here are formally non-bonded, but only 277.6 pm apart. After (215)

Fig. 41 (Bottom) The $[Ph_4C_5(AuPPh_3)_3]^+$ cation; ligand phenyl rings omitted, other rings represented by the first atom only. Weaker interactions indicated by open bonds. After (225)

Fig. 42 The central part of the $[(\text{Ph}_3\text{P})_2\text{PtCl}(\text{C}_6\text{Cl}_4)\text{AuPPh}_3]$ molecule. Phosphine phenyl rings omitted for clarity. After (232)

Fig. 43 The four-coordinate gold(I) complex $[(\text{Ph}_3\text{P})_3\text{AuCl}]$. After (236)

by this formula). For $\text{X} = \text{C}_6\text{Cl}_5$, however, a C-Cl bond is broken and the product is $[(\text{Ph}_3\text{P})_2\text{ClPt}(\mu\text{-}3,4,5,6\text{-C}_6\text{Cl}_4)\text{AuPPh}_3]$, as shown by its crystal structure (Figure 42; 231, 232).

The important synthetic intermediate carbonyl gold(I) chloride, $(\text{OC})\text{AuCl}$, consists of exactly linear molecules. The bond lengths were systematically in error because of thermal motion and must be regarded as unreliable. Despite the expected ease of packing of linear molecules, the shortest Au ... Au contacts are 338 pm (233).

VI. Gold(I) Complexes with Higher Coordination Number

The three-coordinate $[(\text{Ph}_3\text{P})_2\text{Au}(\text{SCN})]$ shows regular planar geometry, with Au-P = 234.6, 234.9 pm, Au-S = 246.8 pm (234). The Au-P bond lengths are in good agreement with those in $[(\text{Ph}_3\text{P})_2\text{AuCl}]$ (See Part I). The tricyclohexylphosphine analogue $[(\text{cy}_3\text{P})_2\text{Au}]^+\text{SCN}^-$ contains linearly coordinated gold, the thiocyanate not being bonded to the metal (81); the difference is thought to be due to steric effects of the bulky cyclohexyl groups.

A new modification of the three-coordinate $[(\text{Ph}_3\text{P})_2\text{AuCl}]$ formed only twinned crystals, as had been previously reported. Nevertheless, a structure of moderate accuracy was obtained (234a). The Au-Cl bond length was 252.6(1.0), with Au-P = 231.3(.8), 223.0(.9) pm, and bond angles Cl-Au-P = 115.1, 108.1(.3), P-Au-P = 136.4(.3)°. The geometry is thus somewhat different from that of the hemibenzenate (89).

A three-coordinate mixed gold-silver complex of formula $[(\text{Ph}_3\text{P})_3\text{M}]^+(\text{NO}_3)^-$ where $\text{M} = 2/3 \text{ Au}, 1/3 \text{ Ag}$ has been characterized (234b). The cation geometry is similar to that in other $[(\text{Ph}_3\text{P})_3\text{Au}]^+$ salts.

Following the author's provocative statement that '... the assumption of tetrahedral coordination in gold(I) complexes is not justified...' (based on structures of three modifications of $[(\text{Ph}_3\text{P})_4\text{Au}^+]\text{BPh}_4^-$ (97)), several tetrahedral complexes have been characterized. In $[(\text{Ph}_2\text{MeP})_4\text{Au}^+]\text{PF}_6^-$ (235) the cation displays crystallographic $\bar{4}$ symmetry (Au-P = 244.9 pm) and in $[(\text{Ph}_3\text{Sb})_4\text{Au}^+][\text{Au}(\text{C}_6\text{F}_5)_2]^-$ (236) there are three independent cations of symmetry 3 (Au-Sb = 259–267 pm). It is likely that steric effects are important in deciding whether regular tetrahedral coordination can be achieved.

Four-coordinate species of the form L_3AuX (L = phosphine, X = anionic ligand) have also been studied. $[(\text{Ph}_3\text{P})_3\text{AuCl}]$ (Figure 43; 236) completes the series $[(\text{Ph}_3\text{P})_n\text{AuCl}]$ (see also 89, 78); Au-P and Au-Cl bond lengths increase with coordination number along this series (Au-P = 223.5, 233.1 (av.), 241.0 (av.), Au-Cl = 227.9, 250.0, 271.0 pm for $n = 1, 2, 3$). The related thiocyanate derivative $[(\text{Ph}_3\text{P})_3\text{Au}(\text{SCN})]$ shows av. Au-P = 239.9, 239.2 and unusually long Au-S = 279.1, 293 pm in two crystallographic modifications (237, 238). In all of these compounds the long Au-X bond represents a distortion towards trigonal geometry.

VII/VIII. Gold(III) Complexes

The two simple salts $\text{KAuCl}_4 \cdot 2\text{H}_2\text{O}$ (239) and $(\text{C}_2\text{H}_5\text{NO})_2\text{H}^+\text{AuCl}_4^-$ (240) show no unusual features (Au-Cl = 228.5, 229.1; 227.0, 227.1 pm respectively). The related bromo-derivative $\text{Bu}_4\text{N}^+\text{AuBr}_4^-$ (241) presented problems of disorder and space group ambiguity (Au-Br = 240.4 pm). The rather more complicated AuX_4^- compound $\text{Cs}_3(\text{AuBr}_4)_2(\text{Br}_3)$ (242) with av. Au-Br = 242.2 pm decomposes slowly at room temperature to give mixed valency, non-stoichiometric compounds in which the similarly shaped AuBr_2^- and Br_3^- ions can occupy the same site (243).

Planar macrocyclic complexes of gold(III) containing a central AuN_4 unit have been investigated in order to study the pattern of bond lengths in the ligands (244, 245). The accuracy of light atom bond lengths is, of course, somewhat limited in the presence of gold. One of the structures contains four complex cations of charge 1+ and eight chloride ions per cell (244); in fact the chloride ions are disordered over the eight sites with occupancy 1/2 (I thank the authors for clarifying this in a private communication).

The bis-1, 2-dithiolate complex $(\text{Bu}_4\text{N})^+ [\text{Au}(\text{C}_7\text{H}_6\text{S}_2)_2]^-$ could be isolated and structurally characterized (246), in spite of the general readiness of such ligands to reduce Au(III). Au-S bond lengths of from 229.0 to 231.9 pm are comparable with those in other 1,2-dithiolate complexes.

A rather unusual methylene-bridged compound $[(\text{Me}_2\text{P}(\text{CH}_2)_2\text{AuCl})_2\text{CH}_2]$ was obtained by the oxidative addition of dichloromethane to a gold(I) ylid complex (Figure 44; 247). Crystallographic evidence was also adduced for the formation of a dihydroxymethane ligand by hydration of a ketone; the structure of dichloro(dihydroxy-di-2-pyridylmethane)gold(III) chloride (248) shows a short intramolecular Au ... O contact (277 pm), thus completing irregular five-coordination at the metal atom. Deliberate attempts to prepare gold(III) derivatives with higher coordination number were unsuccessful. The normally bidentate arsenic ligand diars (*o*- $\text{C}_6\text{H}_4(\text{AsMe}_2)_2$) is monodentate in $[(\text{diars})\text{Au}(\text{C}_6\text{F}_5)_3]$ (249). Several complexes of normally polydentate nitrogen ligands were also examined; in compounds of the form $[\text{AuMe}_2\text{L}](\text{NO}_3)$, the shortest Au ... N contact outside the usual square planar coordination geometry was 314 pm (250) (L = tri-2-pyridylmethanol, tri-1-pyrazolylmethane or $\alpha\alpha$ -di-2-pyridyltoluene).

Three trimethylgold(III) complexes $[\text{Me}_3\text{AuL}]$ (L = PPh_3 , CH_2PPh_3 and $\text{CH}_2\text{S}(\text{O})\text{Me}_2$) were investigated to obtain information on gold(III) ylid structures (134, 179). Again the accuracy of molecular dimensions involving carbon atoms was limited. The Au-C bonds were slightly longer in the ylid complexes than in the reference compound $[\text{Me}_3\text{AuPPh}_3]$ (213.7 compared to 206.5 pm). The Au-C bond *trans* to L was shorter in all three compounds than those *cis* to L.

Concluding Remarks

Attention has been drawn in Part I of this review to one of the main problems involved in the X-ray structure determination of gold compounds, namely the inaccuracy of light atom positions (brought about by the dominance of the X-ray scattering power of the heavy atom). A further problem not yet discussed is that of X-ray absorption. Heavy atoms absorb X-rays to an appreciable extent; since the path lengths of X-rays through a crystal are, in general, different for different reflections, systematic errors in the measured intensities arise. This is a somewhat oversimplified explanation, since absorption effects lead to systematic errors even with spherical crystals. An extreme case is Au_2O_3 (2), for which the Mo K α X-rays

Fig. 44 The methylene-bridged gold(III) $[(\text{Me}_2\text{P}(\text{CH}_2)_2\text{AuCl})_2\text{CH}_2]$ complex. The bridge carbon atom (top) lies on a crystallographic twofold axis. After (247)

used in the structure determination are attenuated by a factor of about 50 000 after travelling 0.1 mm through the crystal. Fortunately most gold compounds show less severe absorption effects, although the systematic errors often remain highly significant.

It is thus clear that a correction for absorption effects is highly desirable (if not essential) for gold compounds. The mathematics involved is far from trivial, but recent advances in theory and practice have made the application of absorption corrections usually very straightforward. It is thus rather depressing to find published gold structures based on data lacking absorption corrections. In many cases the effort involved in inventing an excuse for this omission is much greater than would have been needed to perform an adequate correction (for example 'the expense to information ratio was deemed too high'). This supplement thus concludes with a plea to all crystallographers to be dissatisfied with data containing systematic errors, and therefore to perform absorption corrections as a matter of routine.

References

- 168 G. Tunell and L. Pauling, *Acta Crystallogr.*, 1952, 5, 375-381
- 169 A. J. Frueh jr., *Am. Mineralog.*, 1959, 44, 693-721
- 170 P. Messien and M. Baiwir, *Bull. Soc. Roy. Sci. Liège*, 1966, 35, 234-243
- 171 P. Messien, M. Baiwir and B. Tavernier, *Bull. Soc. Roy. Sci. Liège*, 1966, 35, 727-733
- 172 V.B. Lazarev, A.A. Zakharov and I.S. Shaplygin, *Zh. Neorg. Khim.*, 1979, 24, 1151-1158 (640-645 in the English translation)
- 173 D.E. O'Reilly, E.M. Peterson, C.E. Scheie and J.M. Williams, *J. Chem. Phys.*, 1971, 55, 5629-5635
- 174 B.F.G. Johnson, D.A. Kaner, J. Lewis and P.R. Raithby, *J. Organomet. Chem.*, 1981, 215, C33-C37
- 175 D.B. Dell'Amico, F. Calderazzo, F. Marchetti and S. Merlino, *J. Chem. Soc., Dalton Trans.*, 1982, 2257-2260
- 176 H.-N. Adams, W. Hiller and J. Strähle, *Z. anorg. allg. Chem.*, 1982, 485, 81-91
- 177 H. Klassen and R. Hoppe, *Z. Naturforsch.*, 1981, 36b, 1395-1399
- 178 H.-N. Adams and J. Strähle, *Z. anorg. allg. Chem.*, 1982, 485, 65-80
- 179 J. Stein, J.P. Fackler jr., C. Paparizos and H.W. Chen, *J. Am. Chem. Soc.*, 1981, 103, 2192-2198
- 180 J.W.A. van der Velden, F.A. Vollenbroek, J.J. Bour, P.T. Beurskens, J.M.M. Smits and W.P. Bosman, *Recueil J. R. Neth. Chem. Soc.*, 1981, 100, 148-152
- 181 P.G. Jones, E. Schwarzmann, G.M. Sheldrick and H. Timpe, *Z. Naturforsch.*, 1981, 36b, 1050-1051
- 182 P.G. Jones, G.M. Sheldrick, E. Schwarzmann and A. Vielmäder, *Z. Naturforsch.*, 1983, 38b, 10-11
- 183 P.G. Jones, M. Kraushaar, E. Schwarzmann and G.M. Sheldrick, *Z. Naturforsch.*, 1982, 37b, 941-943

- 183a J.M.M. Smits, P.T. Beurskens and J.J. Steggerda, *J. Cryst. Spectrosc. Res.*, 1983, 13, 381-384
- 184 C.E. Briant, B.R.C. Theobald, J.W. White, L.K. Bell, D.M.P. Mingos and A.J. Welch, *J. Chem. Soc., Chem. Commun.*, 1981, 201-202
- 184a J.M.M. Smits, P.T. Beurskens, J.W.A. van der Velden and J.J. Bour, *J. Cryst. Spectrosc. Res.*, 1983, 13, 373-379
- 185 J.M.M. Smits, J.J. Bour, F.A. Vollenbroek and P.T. Beurskens, *J. Cryst. Spectrosc. Res.*, 1983, 13, 355-363
- 186 J.J. Steggerda, J.J. Bour and J.W.A. van der Velden, *Recueil J. R. Neth. Chem. Soc.*, 1982, 101, 164-170
- 186a J.M.M. Smits, P.T. Beurskens, J.J. Bour and F.A. Vollenbroek, *J. Cryst. Spectrosc. Res.*, 1983, 13, 365-372
- 187 J.W.A. van der Velden, J.J. Bour, W.P. Bosman and J.H. Noordik, *Recueil J. R. Neth. Chem. Soc.*, 1983, 102, (in press)
- 188 K.P. Hall, B.R.C. Theobald, D.I. Gilmour, D.M.P. Mingos and A.J. Welch, *J. Chem. Soc., Chem. Commun.*, 1982, 528-530
- 189 J.W.A. van der Velden, J.J. Bour, W.P. Bosman and J.H. Noordik, *J. Chem. Soc., Chem. Commun.*, 1981, 1218-1219
- 189a J.W.A. van der Velden, J.J. Bour, W.P. Bosman and J.H. Noordik, *Inorg. Chem.*, 1983, 22, 1913-1918
- 190 J.W.A. van der Velden, P.T. Beurskens, J.J. Bour, W.P. Bosman, J.H. Noordik, M. Kolenbrander and J.A.K.M. Buskes, *Inorg. Chem.*, 1983, (in press)
- 191 H.-D. Sinnen and H.-U. Schuster, *Z. Naturforsch.*, 1981, 36b, 833-836
- 192 J.W.A. van der Velden, J.J. Bour, J.J. Steggerda, P.T. Beurskens, M. Roseboom and J.H. Noordik, *Inorg. Chem.*, 1982, 21, 4321-4324
- 193 J.W.A. van der Velden, J.J. Bour, B.F. Otterloo, W.P. Bosman and J.H. Noordik, *J. Chem. Soc., Chem. Commun.*, 1981, 583-584
- 194 F. Demartin, M. Manassero, L. Naldini, R. Ruggeri and M. Sansoni, *J. Chem. Soc., Chem. Commun.*, 1981, 222-223
- 195 J.W.A. van der Velden, J.J. Bour, R. Pet, W.P. Bosman and J.H. Noordik, *Inorg. Chem.*, 1983, (in press)
- 196 D.M.P. Mingos, *Pure and Appl. Chem.*, 1980, 52, 705-712
- 197 M.G.B. Drew, *Acta Crystallogr.*, 1982, B38, 254-255
- 198 J.E. Ellis, *J. Am. Chem. Soc.*, 1981, 103, 6106-6110
- 199 R.E. Simon and J.W. Lauher, *Inorg. Chem.*, 1980, 19, 2338-2343
- 200 M. Green, A.G. Orpen, I.D. Salter and F.G.A. Stone, *J. Chem. Soc., Chem. Commun.*, 1982, 813-814
- 201 H. Lehner, D. Matt, P.S. Pregosin, L.M. Venanzi and A. Albinati, *J. Am. Chem. Soc.*, 1982, 104, 6825-6827
- 202 G.A. Carriedo, D. Hodgson, J.A.K. Howard, K. Marsden, F.G.A. Stone, M.J. Went and P. Woodward, *J. Chem. Soc., Chem. Commun.*, 1982, 1006-1008
- 203 J.W. Lauher and K. Wald, *J. Am. Chem. Soc.*, 1981, 103, 7648-7650
- 203a P. Braunstein, J. Rose, Y. Dusauroy and J.-P. Mangeot, *C.R. Acad. Sci., Ser. 2*, 1982, 294, 967-970
- 203b M.I. Bruce and B.K. Nicholson, *J. Chem. Soc., Chem. Commun.*, 1982, 1141-1143
- 204 B.F.G. Johnson, D.A. Kaner, J. Lewis, P.R. Raithby and M.J. Rosales, *J. Organomet. Chem.*, 1982, 238, C59-C64
- 205 B.F.G. Johnson, D.A. Kaner, J. Lewis and M.J. Rosales, *J. Organomet. Chem.*, 1982, 238, C73-C78
- 206 P. Braunstein, G. Predieri, A. Tiripicchio and E. Sappa, *Inorg. Chim. Acta*, 1982, 63, 113-118
- 207 M. Green, K.A. Mead, R.M. Mills, I.D. Salter, F.G.A. Stone and P. Woodward, *J. Chem. Soc., Chem. Commun.*, 1982, 51-53
- 208 M.J. Mays, P.R. Raithby, P.L. Taylor and K. Henrick, *J. Organomet. Chem.*, 1982, 224, C45-C48
- 209 L.W. Bateman, M. Green, J.A.K. Howard, K.A. Mead, R.M. Mills, I.D. Salter, F.G.A. Stone and P. Woodward, *J. Chem. Soc., Chem. Commun.*, 1982, 773-775
- 209a J.A.K. Howard, *Acta Crystallogr.*, 1981, A37, C197
- 210 B.F.G. Johnson, D.A. Kaner, J. Lewis, P.R. Raithby and M.J. Taylor, *J. Chem. Soc., Chem. Commun.*, 1982, 314-316
- 211 B.F.G. Johnson, D.A. Kaner, J. Lewis, P.R. Raithby and M.J. Taylor, *Polyhedron*, 1982, 1, 105-107
- 212 J.A.K. Howard, L. Farrugia, C. Foster, F.G.A. Stone and P. Woodward, *Abstr. Eur. Crystallogr. Meeting (Barcelona)*, 1980, 73
- 213 B.F.G. Johnson, D.A. Kaner, J. Lewis and P.R. Raithby, *J. Chem. Soc., Chem. Commun.*, 1981, 753-755
- 214 R. Usón, A. Laguna, M. Laguna, P.G. Jones and G.M. Sheldrick, *J. Chem. Soc., Chem. Commun.*, 1981, 1097-1098
- 215 Y. Inoguchi, B. Milewski-Mahrla and H. Schmidbaur, *Chem. Ber.*, 1982, 115, 3083-3095
- 216 C.E. Briant, K.P. Hall and D.M.P. Mingos, *J. Organomet. Chem.*, 1982, 229, C5-C8
- 217 P.J.M.W.L. Birker and G.C. Verschoor, *Inorg. Chem.*, 1982, 21, 990-995
- 218 M.K. Cooper, K. Henrick, M. McPartlin and J.L. Latten, *Inorg. Chim. Acta*, 1982, 65, L185-L186
- 219 R. Usón, L.A. Oro, J. Gimeno, M.A. Citrino, J.A. Cabeza, A. Tiripicchio and M. Tiripicchio Camellini, *J. Chem. Soc., Dalton Trans.*, 1983, 323-330
- 220 A.N. Nesmeyanov, G.G. Perevalova, Y.T. Struchkov, M.Y. Antipin, K.I. Grandberg and V.P. Dyadchenko, *J. Organomet. Chem.*, 1980, 201, 343-349
- 221 C. Lensch, P.G. Jones and G.M. Sheldrick, *Z. Naturforsch.*, 1982, 37b, 944-949
- 222 P.G. Jones, C. Lensch and G.M. Sheldrick, *Z. Naturforsch.*, 1982, 37b, 141-143
- 223 E.I. Smyslova, E.G. Perevalova, V.P. Dyadchenko, K.I. Grandberg, Y.L. Shlovokhotov and Y.T. Struchkov, *J. Organomet. Chem.*, 1981, 215, 269-279
- 224 E.G. Perevalova, K.I. Grandberg, V.P. Dyadchenko and T.V. Baukova, *J. Organomet. Chem.*, 1981, 217, 403-413
- 225 T.V. Baukova, Y.L. Shlovokhotov and Y.T. Struchkov, *J. Organomet. Chem.*, 1981, 220, 375-384
- 226 T.V. Baukova, Y.L. Shlovokhotov and Y.T. Struchkov, *J. Organomet. Chem.*, 1981, 220, 125-137
- 227 L.E. Zyontz, S.C. Abrahams and J.L. Bernstein, *Acta Crystallogr.*, 1981, A37, C154
- 228 S.C. Abrahams, J.L. Bernstein, R. Liminga and E.T. Eisenmann, *J. Chem. Phys.*, 1980, 73, 4585-4590
- 229 N.W. Alcock, P. Moore, P.A. Lampe and K.F. Mok, *J. Chem. Soc., Dalton Trans.*, 1982, 207-210
- 230 D.T. Hill and B.M. Sutton, *Cryst. Struct. Comm.*, 1980, 9, 676-686
- 231 O. Rossell and J. Sales, *Inorg. Chim. Acta*, 1981, 64, L43-L44
- 232 X. Solans, C. Miravittles, J.M. Arrieta, G. Germain and J.P. Declercq, *Acta Crystallogr.*, 1982, B38, 1812-1815
- 233 P.G. Jones, *Z. Naturforsch.*, 1982, 37b, 823-824
- 234 J.A. Muir, M.M. Muir, and S. Arias, *Acta Crystallogr.*, 1982, B38, 1318-1320
- 234a M. Khan, C. Oldham and D.G. Tuck, *Can. J. Chem.*, 1981, 59, 2714-2718
- 234b P.T. Beurskens, R. Pet, J.H. Noordik, J.W.A. van der Velden and J.J. Bour, *Cryst. Struct. Comm.*, 1982, 11, 1039-1042
- 235 R.C. Elder, E.H. Kelle Zeiher, M. Onady and R.R. Whittle, *J. Chem. Soc., Chem. Commun.*, 1981, 900-901
- 236 P.G. Jones, G.M. Sheldrick, J.A. Muir, M.M. Muir and L. Bird Pulgar, *J. Chem. Soc., Dalton Trans.*, 1982, 2123-2125
- 237 J.A. Muir, M.M. Muir, S. Arias, C.F. Campana and S.K. Dwight, *Acta Crystallogr.*, 1982, B38, 2047-2049
- 238 J.A. Muir, M.M. Muir, S. Arias, P.G. Jones and G.M. Sheldrick, unpublished data
- 239 F. Theobald and H. Omrani, *Acta Crystallogr.*, 1980, B36, 2932-2935
- 240 M. Sakhawat Hussain and E.O. Schlemper, *J. Chem. Soc., Dalton Trans.*, 1982, 751-755
- 241 J.P. Johnson, H.B. Krause and E.G. Sherry, *Acta Crystallogr.*, 1981, A37, C227
- 242 B. Lehnis and J. Strähle, *Z. Naturforsch.*, 1981, 36b, 1504-1508
- 243 P. Gütlisch, B. Lehnis, K. Römhild and J. Strähle, *Z. Naturforsch.*, 1982, 37b, 550-556
- 244 J.-H. Kim and G.W. Everett, jr., *Inorg. Chem.*, 1981, 20, 853-856
- 245 C.H. Park, B. Lee and G.W. Everett, jr., *Inorg. Chem.*, 1982, 21, 1681-1682
- 246 M.A. Mazid, M. Tahir Razi and P.J. Sadler, *Inorg. Chem.*, 1981, 20, 2872-2877
- 247 P. Jandik, U. Schubert and H. Schmidbaur, *Angew. Chem.*, 1982, 94, 74-75
- 248 G. Annibale, L. Canovese, L. Cattalini, G. Natile, M. Biagini-Cingi, A.-M. Manotti-Lanfredi and A. Tiripicchio, *J. Chem. Soc., Dalton Trans.*, 1981, 2280-2287
- 249 R. Usón, A. Laguna, M. Laguna, E. Fernandez, P.G. Jones and G.M. Sheldrick, *J. Chem. Soc., Dalton Trans.*, 1982, 1971-1976
- 250 A.J. Canty, N.J. Minchin, P.C. Healy and A.H. White, *J. Chem. Soc., Dalton Trans.*, 1982, 1795-1802