Reactions of aminoboron compounds with palladium and platinum complexes

Christopher M. Vogels, Heather L. Wellwood, Kumar Biradha, Michael J. Zaworotko, and Stephen A. Westcott

Abstract: Reactions of 3-$NH_2C_6H_4B(OH)_2$ (**1**, APBA) with $[MCl_4]^{2-}$ (M = Pd, Pt) give the boronic acid-containing complexes, $MCl_2(APBA)_2$ (M = Pd, **2**; M = Pt, **3**). Addition of **1** to $[PdCl_2(COE)]_2$ (COE = η^2-C_8H_{14}) ultimately led to $PdCl_2(APBA)_2$ (**2**). The pinacol derivative $PdCl_2(APBpin)_2$ (**5,** pin = $O_2C_2Me_4$) was characterized by an X-ray diffraction study. Crystals of **5** were monoclinic, a = 13.836(5), b = 14.937(5), c = 11.287(5) Å, β = 99.042(9)°, Z = 2, with space group $P2_1/c$. Monoalkene complexes $PtCl_2(COE)(APBA)$ (**8**) and $PtCl_2(COE)(APBpin)$ (**9**) were generated from the addition of APBA and APBpin, respectively, to $[PtCl_2(COE)]_2$. Reactions of 2-$NMe_2CH_2C_6H_4B(OH)_2$ (**10**) with palladium complex $[PdCl_2(COE)]_2$ proceed via selective B—C bond cleavage to give the cyclopalladated dimer $[PdCl(2\text{-}NMe_2CH_2C_6H_4)]_2$ as the major amine-containing product. Likewise, reactions with borinic esters $H_2NCH_2CH_2OBR_2$ (R = Bu, **14**; R = Ph, **15**) give products derived from cleavage of the B—O bond. The unique palladium complex $PdCl_2[3\text{-}NC_5H_4B(OH)_2]_2$ (**19**) was prepared by addition of $(3\text{-}NC_5H_4BEt_2)_4$ (**18**) to $[PdCl_2(COE)]_2$ in wet methylene chloride, where adventitious water was used to convert the organoborane product into the corresponding boronic acid moiety.

Key words: aminoboronic acids, platinum, palladium, cyclometallation.

Résumé : Le 3-$NH_2C_6H_4B(OH)_2$ (**1**, APBA) réagit avec les ions $[MCl_4]^{2-}$ (M = Pd, Pt) pour donner des complexes contenant de l'acide boronique, $MCl_2(APBA)_2$ (M = Pd, **2**; M = Pt, **3**). L'addition de **1** au $[PdCl_2(COE)]_2$ (COE = η^2-C_8H_{14}) conduit finalement au $PdCl_2(APBA)_2$ (**2**). Le dérivé du pinacol, $PdCl_2(APBpin)_2$ (**5**, pin = $O_2C_2Me_4$) a été caractérisé par une étude de diffraction des rayons X. Les cristaux du produit **5** sont monocliniques, groupe d'espace $P2_1/c$, avec a = 13,836(5), b = 14,937(5) et c = 11,287(5) Å, β = 99,042(9)° et Z = 2. On a généré des complexes monoalcéniques, $PtCl_2(COE)(APBA)$ (8) et $PtCl_2(COE)(APBpin)$ (**9**), par addition respectivement de APBA et de APBpin sur le $[PtCl_2(COE)]_2$. Les réactions du 2-$NMe_2CH_2C_6H_4B(OH)_2$ (**1**0) avec le complexe de palladium $[PdCl_2(COE)]_2$ se font avec un clivage sélectif de la liaison B—C et la formation du dimère cyclopalladié $[PdCl(2\text{-}NMe_2CH_2C_6H_4)]_2$ comme principal produit contenant de l'amine. De la même manière, les réactions avec des esters de l'acide boronique, $H_2NCH_2CH_2OBR_2$ (R = Bu, **14**; R = Ph, **15**), conduisent à la formation de produits dérivés du clivage de la liaison B—O. On a préparé le complexe de palladium unique, $PdCl_2[3\text{-}NC_5H_4B(OH)_2]_2$ (**19**) par addition de $(3\text{-}NC_5H_4BEt_2)_4$ (**18**) sur du $[PdCl_2(COE)]_2$ dans du chlorure de méthylène humide dont l'eau accidentelle est utilisée sert à transformer le produit organoborane en portion acide boronique correspondante.

Mots clés : acides aminoboroniques, platine, palladium, cyclométallation.

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Introduction

The bioinorganic chemistry of compounds containing boronic acid groups, $B(OH)_2$, is an area of growing interest and has recently expanded to include boron-containing purine nucleosides (1), psuedocryptands (2) (which mimic the naturally occurring antibiotics boromycin and aplasmomycin), steroids (3), calixarenes (4), carbohydrates (5), fatty acids (6), porphyrins (7), and amino acids (8). Interestingly, boronic acids have been found to facilitate the transport of various ribonucleosides in and out of liposomes (9). Recent interest in compounds containing boronic acid groups arises from the ability of the boron atom to coordinate (via an empty *p*-orbital) with certain atoms, such as nitrogen and oxygen, of biomolecules. As a result, compounds containing boronic acids are able to act as selective targets for specific

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binding sites. For example, aromatic boronic acids have been shown to inhibit the serine proteases chymotrypsin and subtilisin (10). Serine proteases are a diverse group of proteolytic enzymes whose physiological functions include digestion of proteins, blood clotting, and cell lysis in the immune response. The crystal structure of subtilisin complexed with either phenylboronic acid or phenylethaneboronic acid (11) shows that the boron moiety exists as a tetrahedral adduct with the active hydroxyl site of the serine protease.

Work by Matteson et al. (12*d*) has shown that (*R*)-acetamido-2-phenylethaneboronic acid, a boron analogue of *N*-acetyl-phenylalanine, also acts as an effective and reversible inhibitor of serine proteases. Indeed, this compound is several orders of magnitude more effective than the corresponding aromatic boronic acids for the inhibition of chymotrypsin even in the micromolar concentration range. Since this discovery, much effort has focused on the synthesis of related boron-containing amino acid and peptide derivatives for possible applications as enzyme inhibitors (12, 13).

The observed biochemical activities and ability of boronic acids to facilitate the transport of molecules intracellularly prompted us to investigate the use of aminoboron compounds as ligands for biologically active transition metals. For instance, while both *cis* and *trans* amine complexes of platinum display anticancer properties, the overall efficacy of these chemotherapeutic compounds is limited by their numerous toxicities and poor cellular-uptake rates (arising from low solubility in water). As a result, a great deal of research has focused on improving aminoplatinum-based drugs for use in cancer therapy (14). With this in mind, we have begun to examine the possibility of generating new complexes of platinum and palladium containing aminoboron appendages. The results of our initial investigations are described herein.

Experimental

General procedures

Reagents and solvents used were obtained from Aldrich Chemicals. Palladium chloride and potassium tetrachloroplatinate were obtained from Strem. NMR spectra were recorded on a JEOL JNM-GSX270 FT NMR spectrometer. ^{1}H NMR chemical shifts are reported in ppm and referenced to residual protons in deuterated solvent at 270.05 MHz. ^{11}B{^{1}H} NMR chemical shifts are referenced to external $F_3B{\cdot}OEt_2$ at 86.55 MHz. ^{13}C{^{1}H} NMR chemical shifts are referenced to solvent carbon resonances as internal standards at 67.80 MHz. Multiplicities are reported as (s) singlet, (d) doublet, (t) triplet, (q) quartet, (quint) quintet, (m) multiplet, (br) broad, and (ov) overlapping. Infrared spectra were obtained using a Mattson Polaris FT-IR spectrometer and reported in cm^{-1}. Melting points were measured uncorrected with a Mel-Temp apparatus. Microanalyses for C, H, and N were carried out at Desert Analytics (Tucson, Ariz.).

μ-[Dichloro(*cis*-cyclooctene)palladium(II)]

μ-[Dichloro(*cis*-cyclooctene)palladium(II)], $[PdCl_2(COE)]_2$, was prepared by modification of a known synthesis (15*a*). Sodium chloride (363 mg, 6.21 mmol) was added as a solid to an isopropanol–water suspension (11:16 mL ratio by volume) of palladium chloride (500 mg, 2.82 mmol). After 1 h of stirring, cyclooctene (3 mL, 23.03 mmol) and a catalytic amount of tin(II) chloride (27 mg, 0.14 mmol) were added. After 20 h, solvent was removed under vacuum to afford a dark orange solid. $[PdCl_2(COE)]_2$ was extracted with methylene chloride, filtered to remove impurities, and collected following the removal of methylene chloride under vacuum. Yield: 620 mg (77%) of an orange solid; mp 164°C (decomposition). NMR spectroscopic data (in $CDCl_3$): ^{1}H δ: 6.20 (m, 4H, =C*H*R), 2.33 (s, 8H), 1.67 (s, 8H), 1.40 (s, 8H); ^{13}C{^{1}H} δ: 109.5 (br, =*C*HR), 29.1, 28.8, 26.3.

$PdCl_2(APBA)_2$ (2)

Method A

Sodium chloride (36 mg, 0.62 mmol) was added in small portions as a solid to a 25 mL methanol suspension of palladium chloride (50 mg, 0.28 mmol) to generate the methanol soluble species, sodium tetrachloropalladate. After 1 h of stirring, a 5 mL methanol solution of 3-aminophenylboronic acid (87 mg, 0.56 mmol) was added dropwise to the clear amber solution. Within 2 h, an isomeric mixture of *cis* and *trans* **2** precipitated and was collected by filtration and washed with methanol (3 × 5 mL) and methylene chloride (3 × 5 mL). Yield: 110 mg (81%) of a yellow solid.

Method B

In another reaction, 3-aminophenylboronic acid (91 mg, 0.58 mmol) was added in small portions as a solid to a stirred 25 mL methylene chloride solution of $[PdCl_2(COE)]_2$ (75 mg, 0.13 mmol). After 20 h, the reaction was filtered and a yellow solid was collected. The solid was washed three times with 10 mL portions of hexane and methylene chloride. Complex **2** was crystallized from a tetrahydrofuran–hexane solution. Yield: 50 mg (39%) of a yellow solid; mp 276°C (decomposition). IR (nujol): 3233 (m), 3125 (m), 2946 (s), 1582 (m), 1462 (m), 1377 (m). NMR spectroscopic data (in DMSO-d_6): ^{1}H δ: 8.14 (s, 4H, B(O*H*)$_2$), 7.63 (s, 2H), 7.33 (ov, 4H), 6.86 (s, 2H), 6.07 (s, 4H, N*H*$_2$); ^{11}B{^{1}H} δ 35.1 (br); ^{13}C{^{1}H} δ 147.6, 135.2 (br, *C*-B), 130.6, 125.0, 122.4, 120.4. Anal. calcd. for $PdCl_2C_{12}H_{16}N_2B_2O_4$: C 31.94, H 3.58, N 6.21; found: C 32.04, H 3.66, N 5.90.

$PtCl_2(APBA)_2$ (3)

A 25 mL aqueous solution of 3-aminophenylboronic acid (224 mg, 1.45 mmol) was added dropwise to a 25 mL water solution of potassium tetrachloroplatinate (300 mg, 0.72 mmol). Within 4 h, the solution became yellow, and a fine brown–yellow precipitate was collected by filtration and discarded. The clear yellow filtrate was chilled to 0°C, and after 24 h, **3** precipitated and was collected by filtration. Yield: 230 mg (55%) of a yellow solid; mp 267°C (decomposition). IR (nujol): 3266 (w), 3186 (w), 2885 (s), 1582 (m), 1461 (s), 1377 (s). NMR spectroscopic data (in acetone-d_6): ^{1}H δ: 7.88 (s, 2H), 7.72 (d, J_{H-H} = 5 Hz, 2H), 7.45 (m, 2H), 7.24 (t, J_{H-H} = 5 Hz, 2H), 6.74 (s, 4H, N*H*$_2$); ^{11}B{^{1}H} δ 30.9 (br); ^{13}C{^{1}H} δ: 141.5, 136.3 (br, *C*-B), 132.6, 129.5, 129.4, 124.0. Anal. calcd. for

$PtCl_2C_{12}H_{16}N_2B_2O_4$: C 26.69, H 2.99; found: C 26.34, H 2.92.

APBpin (4)

3-Aminophenylboronic acid (250 mg, 1.61 mmol) and 10 g of activated molecular sieves (BDH 4A) were added to a 25 mL methylene chloride solution of pinacol (190 mg, 1.61 mmol). After 5 days, the sieves were removed by filtration, and methylene chloride was removed under vacuum to give **4**. Yield: 350 mg (95%) of a light yellow solid; mp 93°C. IR (nujol): 3465 (w), 3375 (w), 3125 (s), 1628 (m), 1578 (m), 1452 (s), 1376 (s), 1145 (m). NMR spectroscopic data (in $CDCl_3$): ^{1}H δ: 7.20 (m, 2H), 7.14 (s, 1H), 6.80 (m, 1H), 3.63 (s, 2H, N*H*$_2$), 1.31 (s, 12H, BO_2C_2*Me*$_4$); ^{11}B{^{1}H} δ 31.8 (br); ^{13}C{^{1}H} δ: 145.9, 129.2 (br, *C*-B), 128.4, 124.9, 121.2, 118.1, 83.7 (BO_2*C*$_2$Me$_4$), 24.9 (BO_2C_2*Me*$_4$). Anal. calcd. for $C_{12}H_{18}NBO_2$: C 65.78, H 8.30, N 6.39; found: C 65.87, H 8.39, N 6.33.

$PdCl_2$(APBpin)$_2$ (5)

Method A

Complex **2** (250 mg, 0.51 mmol) was added slowly as a solid to a tetrahydrofuran solution of pinacol (140 mg, 1.20 mmol) and 10 g of activated molecular sieves (BDH 4A). After 3 days, the sieves and unreacted **2** were removed by filtration, and the filtrate was collected. Complex **5** was collected following the removal of tetrahydrofuran under vacuum. Yield: 50 mg (16%) of an orange solid.

Method B

To a 50 mL methylene chloride solution of $[PdCl_2(COE)]_2$ (200 mg, 0.35 mmol), a 15 mL methylene chloride solution of **4** (305 mg, 1.39 mmol) was added dropwise. The reaction was allowed to proceed for 2 h before the solvent was removed under vacuum. Complex **5** was crystallized from a tetrahydrofuran–hexane solution. Yield: 300 mg (70%) of an orange solid; mp 152°C (decomposition). IR (nujol): 3187 (w), 3121 (w), 2968 (s), 2891 (s), 1583 (w), 1461 (s), 1377 (s), 1148 (m), 722 (w). NMR spectroscopic data (in $CDCl_3$): ^{1}H δ 7.67 (s, 4H), 7.57 (s, 2H), 7.32 (s, 2H), 5.06 (br s, 4H, N*H*$_2$), 1.33 (s, 24H, BO_2C_2*Me*$_4$); ^{11}B{^{1}H} δ: 31.5 (br); ^{13}C{^{1}H} δ: 139.3, 132.7, 130.8 (br, *C*-B), 129.0, 127.7, 125.5, 84.2 (BO_2*C*$_2$Me$_4$), 25.1 (BO_2C_2*Me*$_4$). Anal. calcd. for $PdCl_2C_{24}H_{36}N_2B_2O_4$: C 46.82, H 5.91, N 4.55; found: C 46.46, H 5.89, N 4.48.

$PtCl_2$(APBpin)$_2$ (6)

Complex **3** (360 mg, 0.63 mmol) and 10 g of activated molecular sieves (BDH 4A) were added to a tetrahydrofuran solution of pinacol (163 mg, 1.34 mmol). The mixture was allowed to stand for 3 days before the sieves and unreacted **3** were removed by filtration. Complex **6** was isolated following removal of solvent under vacuum. Yield: 40 mg (9%) of a yellow solid; mp 224°C. IR (nujol): 1591 (m), 1400 (m), 1359 (m), 1332 (w), 1145 (m), 853 (w). NMR spectroscopic data (in DMSO-d_6): ^{1}H δ: 7.63 (s, 2H), 7.49 (m, 4H), 7.30 (m, 4H), 1.36 (s, 24H), ^{11}B{^{1}H} δ: 32.6 (br); ^{13}C{^{1}H} δ: 148.0, 141 (br, *C*-B), 128.3, 121.8, 120.1, 116.8, 67.0, 21.7. Anal. calcd. for $PtCl_2C_{24}H_{36}N_2B_2O_4$: C 40.93, H 5.16, N 3.98; found: C 40.63, H 5.31, N 4.02.

Reaction of $[PdCl_2(COE)]_2$ and 4

A 20 mL methylene chloride solution of **4** (114 mg, 0.52 mmol) was added dropwise to a stirred 50 mL methylene chloride solution of $[PdCl_2(COE)]_2$ (150 mg, 0.26 mmol). After 30 min, the clear orange solution became clear red, at which point methylene chloride was removed under vacuum to afford complex **7**, which was washed with hexane (3 × 5 mL). Yield: 120 mg (91%) of a red–orange solid; mp 138°C (decomposition). IR (nujol): 3194 (m), 3123 (m), 2973 (s), 2885 (s), 2842 (s), 1583 (m), 1461 (s), 1364 (s), 1146 (m), 695 (m). NMR spectroscopic data of **7** (in $CDCl_3$): ^{1}H δ: 7.65 (s, 2H), 7.56 (s, 1H), 7.29 (s, 1H), 6.03 (m, 2H, =CHR), 5.24 (s, 2H, N*H*$_2$), 2.31 (br s, 4H), 1.60 (br s, 4H), 1.45 (br s, 4H), 1.34 (s, 12H, BO_2C_2*Me*$_4$); ^{11}B{^{1}H} δ: 32.1 (br); ^{13}C{^{1}H} δ 139.0, 132.8, 131.0 (br, *C*-B), 129.1, 127.7, 125.5, 117.3 (br, =*C*HR), 84.2 (BO_2*C*$_2$Me$_4$), 29.3, 27.8, 26.3, 25.1 (BO_2C_2*Me*$_4$). Reactions gave minor amounts of the diamine complex, which complicated elemental analyses.

Reaction of 7 and PPh_3

Complex **7** (44 mg, 0.09 mmol) was dissolved in 10 mL of methylene chloride, and a 10 mL methylene chloride solution of triphenylphosphine (25 mg, 0.09 mmol) was added dropwise to the clear red solution. Within 1 h, a yellow precipitate formed and was collected by filtration. Yield: 25 mg of a yellow solid. Selected NMR data (in $CDCl_3$): ^{1}H δ: 7.70 (m, *Ar*, 2H), 7.41 (m, *Ar*, 3H); $PdCl_2(PPh_3)_2$.

$PtCl_2$(COE)(APBA) (8)

To a stirred 50 mL methylene chloride solution of $[PtCl_2(COE)]_2$ (100 mg, 0.13 mmol), 3-aminophenylboronic acid (41 mg, 0.26 mmol) was added in small portions as a solid. The cloudy, yellow mixture was filtered after 2 days, and the clear yellow filtrate was stored under dinitrogen at 0°C. Within 48 h, **8** precipitated and was collected by filtration. The yellow solid was washed with ether (3 × 10 mL), hexane (3 × 10 mL), and cold methylene chloride (1 × 2 mL). Yield: 80 mg (29%) of a yellow solid; mp 169°C. IR (nujol): 3186 (w), 3116 (w), 2965 (s), 2890 (s), 1584 (m), 1462 (s), 1377 (s), 723 (m). NMR spectroscopic data (in acetone-d_6): ^{1}H δ: 7.95 (s, 1H), 7.77 (s, 1H), 7.54 (m, 2H), 5.95 (s, J_{H-Pt} = 27 Hz, 2H, =C*H*R), 2.46 (s, 4H), 2.14 (s, 4H), 1.81 (s, 4H); ^{11}B{^{1}H} δ 29.6 (br); ^{13}C{^{1}H} δ: 146.9, 136.4 (br, *C*-B), 133.6, 129.3, 128.9, 126.4, 93.3 (s, J_{C-Pt} = 80 Hz, =*C*HR), 28.4, 26.8, 26.1.

$PtCl_2$(COE)(APBpin) (9)

To a 50 mL methylene chloride solution of $[PtCl_2(COE)]_2$ (145 mg, 0.19 mmol), a 10 mL methylene chloride solution of **4** (89 mg, 0.41 mmol) was added dropwise. After 5 h, methylene chloride was removed under vacuum to afford a yellow solid. Complex **9** was crystallized from a methylene chloride – hexane solution. Yield: 150 mg (66%) of a yellow powder; mp 236°C (decomposition). IR (nujol): 3116 (w), 2935 (s), 1578 (w), 1461 (s), 1377 (s), 1145 (m), 726 (m). NMR spectroscopic data (in $CDCl_3$): ^{1}H δ: 7.70 (s, 2H), 7.61 (s, 1H), 7.36 (s, 1H), 5.91 (br s, 2H, =C*H*R), 5.35 (s, J_{H-Pt} = 32 Hz, 2H, N*H*$_2$), 2.36 (br s, 2H), 2.25 (br s, 2H), 1.74 (br s, 2H), 1.41 (br s, 6H), 1.34 (s, 12H, BO_2*Me*$_4$); ^{11}B{^{1}H} δ 32.2 (br); ^{13}C{^{1}H} δ: 139.4, 131.7, 131.0 (br, *C*-B), 129.2, 126.7,

124.1, 93.1 (J_{C-Pt} = 164 Hz, =*C*HR), 84.3 ($BO_2C_2Me_4$), 29.3, 28.2, 26.3, 25.1 ($BO_2C_2Me_4$). Anal. calcd. for $PtCl_2C_{20}H_{32}NBO_2$: C 40.35, H 5.43, N 2.35; found: C 41.08, H 5.68, N 2.46.

2-$NMe_2CH_2C_6H_4B(OH)_2$ (10)

Compound **10** was prepared by modification of a known procedure (16). To a 20 mL ether solution of *N*,*N*-dimethylbenzylamine (10.0 g, 74 mmol), a 10.0 M solution of *n*-butyllithium in hexanes (8.2 mL, 82 mmol) was added dropwise under an atmosphere of dinitrogen. The lithiation of *N*,*N*-dimethylbenzylamine was allowed to proceed at room temperature for 18 h. Trimethylborate (10.0 mL, 88 mmol) was added at 0 °C, and the reaction mixture was allowed to warm to room temperature. After 4 h, 10 mL of water was added and the aqueous phase separated. The addition of 20 mL of isopropanol and subsequent cooling of the mixture to 0 °C resulted in the precipitation of lithium borate, which was removed by filtration. Complex **10** was isolated upon removal of water under vacuum. Yield: 3.25 g (25%) of an off-white powder. NMR spectroscopic data (in D_2O): ^{1}H δ: 7.41 (m, 1H), 7.20 (m, 2H), 7.08 (m, 1H), 3.81 (s, 2H, Ar-CH_2-N), 2.34 (s, 6H, NMe_2); ^{11}B{^{1}H} δ: 8.9 (br); ^{13}C{^{1}H} δ: 150 (br, *C*-B), 145.5, 135.0, 132.9, 132.4, 128.6, 69.6 (Ar-*C*H_2-N), 49.4 (NMe_2).

Reaction of Na_2PdCl_4 + 10

A fresh solution of sodium tetrachloropalladate was prepared by the addition of sodium chloride (36 mg, 0.62 mmol) to a 30 mL methanol suspension of palladium chloride (50 mg, 0.28 mmol). After 1 h of stirring, a 10 mL methanol solution of **10** (111 mg, 0.62 mmol) was added dropwise. The yellow precipitate that formed over 1 h was collected by filtration and washed with water (3 × 5 mL). Selected NMR data (in $CDCl_3$): ^{1}H δ: 7.16 (m, 2H), 6.97 (m, 2H), 6.87 (m, 4H), 3.93 (s, 4H, Ar-CH_2-N), 2.86 (s, 12H, NMe_2); $[PdCl(2\text{-}NMe_2CH_2C_6H_4)]_2$.

Reaction of $[PtCl_2(COE)]_2$ + 10

To a stirred 35 mL methylene chloride solution of $[PtCl_2(COE)]_2$ (150 mg, 0.20 mmol), compound **10** (75 mg, 0.42 mmol) was added in small portions as a solid. After 20 h, the reaction was filtered and methylene chloride removed under vacuum. Complex **13** was extracted from the resulting brown–orange solid with hexane (10 × 10 mL). Attempts at isolating compound **13** were complicated by the ubiquitous presence of a minor amount of an unidentified compound. IR (nujol): 3060 (w), 3001 (w), 2927 (s), 2854 (s), 1586 (w), 1471 (m), 717 (s), 651 (s). Selected NMR data (crude) for **13** (in $CDCl_3$): ^{1}H δ: 7.03 (m, 3H), 6.57 (s, J_{H-Pt} = 43 Hz, 1H), 4.84 (s, J_{H-Pt} = 68 Hz, 2H, =C*H*R), 4.05 (s, J_{H-Pt} = 38 Hz, 2H, Ar-CH_2-N), 2.99 (s, J_{H-Pt} = 32 Hz, 6H, NMe_2), 2.73 (br s, 4H), 2.28 (br s, 4H), 1.81 (br s, 4H); ^{13}C{^{1}H} δ: 147.3, 133.1, 127.4 (J_{C-Pt} = 43 Hz, *C*-Pt), 126.2, 124.9, 122.1, 87.7 (s, J_{C-Pt} = 191 Hz, =*C*HR), 74.8 (s, J_{C-Pt} = 44 Hz, Ar-*C*H_2-N), 51.8 (NMe_2), 30.0, 28.5, 26.5.

2-$NMe_2CH_2C_6H_4Bpin$ (11)

A 10 mL methylene chloride solution of pinacol (330 mg, 2.79 mmol) was added dropwise to a 35 mL methylene chloride suspension of **10** (600 mg, 3.35 mmol). Ten grams of activated molecular sieves (BDH 4A) were added to the mixture to facilitate the formation of **11**. The reaction was allowed to stand for 5 days at which point the sieves and unreacted **10** were removed by filtration. Compound **11** was isolated following removal of methylene chloride under vacuum. Yield: 0.52 g (72%) of an off-white solid; mp 75°C. IR (nujol): 3150 (s), 1476 (w), 1348 (m), 1151 (s), 1107 (s), 1043 (s), 748 (m). NMR spectroscopic data (in $CDCl_3$): ^{1}H δ: 7.55 (d, J_{H-H} = 5 Hz, 1H), 7.19 (app. quint, J_{H-H} = 8 Hz, 2H), 7.01 (d, J_{H-H} = 8 Hz, 1H), 3.86 (s, 2H, Ar-CH_2-N), 2.57 (s, 6H, NMe_2), 1.31 (s, 12 H, $BO_2C_2Me_4$); ^{11}B{^{1}H} δ: 15.3 (br); ^{13}C{^{1}H} δ: 143.9 (br, *C*-B), 139.8, 131.6, 127.6, 127.5, 123.1, 80.5 ($BO_2C_2Me_4$), 65.6 (Ar-*C*H_2-N), 45.9 (NMe_2), 26.8 ($BO_2C_2Me_4$). Anal. calcd. for $C_{15}H_{24}NBO_2$: C 68.97, H 9.28, N 5.36; found: C 68.80, H 9.60, N 5.38.

Reaction of Na_2PdCl_4 + 11

A fresh solution of sodium tetrachloropalladate was generated by the addition of sodium chloride (22 mg, 0.37 mmol) to a stirred 15 mL methanol suspension of palladium chloride (30 mg, 0.17 mmol). After 1 h of stirring, a 10 mL methanol solution of **11** (88 mg, 0.338 mmol) was added dropwise. After 3 h, a yellow precipitate had formed and was collected by filtration. Yield: 35 mg (75%) of a yellow solid. NMR spectroscopic data (in $CDCl_3$): ^{1}H δ: 7.16 (m, 1H), 6.97 (m, 2H), 6.87 (m, 4H), 3.93 (s, 4H, CH_2N(Me)$_2$), 2.86 (s, 12H, $CH_2N(Me)_2$), $[PdCl(2\text{-}NMe_2CH_2C_6H_4)]_2$.

Reaction of $[PdCl_2(COE)]_2$ + 11

A 10 mL methylene chloride solution of **11** (182 mg, 0.70 mmol) was added dropwise to a stirred 25 mL methylene chloride solution of $[PdCl_2(COE)]_2$ (100 mg, 0.17 mmol). After 6 h, solvent was removed under vacuum to yield an orange–brown oil. Selected NMR data (in $CDCl_3$): ^{1}H δ: 7.16 (m, 2H), 6.97 (m, 2H), 6.87 (m, 4H), 3.93 (s, 4H, CH_2N(Me)$_2$), 2.86 (s, 12H, $CH_2N(Me)_2$) $[PdCl(2\text{-}NMe_2CH_2C_6H_4)]_2$; 9.19 (br), 8.06 (m), 7.92 (m), 7.60 (m), 7.42 (m), 4.72 (m), 2.98 (s) [2-$HNMe_2CH_2C_6H_4Bpin]_2[PdCl_4]$; 1.38 (s) $(Bpin)_2O$. ^{11}B{^{1}H} δ: 31.9 (br, $[2\text{-}HNMe_2CH_2C_6H_4Bpin]_2[PdCl_4]$), 23.1 (br, $(Bpin)_2O$).

$PtCl_2(COE)(2\text{-}Me_2NCH_2C_6H_4Bpin)$ (12)

The addition of a 0.5 mL deuterated chloroform solution of **11** (24 mg, 0.09 mmol) to a 0.5 mL deuterated chloroform solution of $[PtCl_2(COE)]_2$ (35 mg, 0.05 mmol) was performed under an atmosphere of dinitrogen. The reaction was allowed to proceed for 4 h before characterization by NMR spectroscopy was performed. IR ($CHCl_3$): 2981 (m), 2929 (s), 2854 (m), 1600 (w), 1471 (m), 1346 (s), 1145 (m), 906 (s), 745 (s), 651 (s). NMR spectroscopic data (in $CDCl_3$): ^{1}H δ: 8.87 (s, 1H), 7.89 (s, 1H), 7.58 (s, 1H), 7.39 (s, 1H), 5.35 (ov m, J_{H-Pt} = 78 Hz, 2H, =C*H*R), 4.68 (s, 2H, Ar-CH_2-N), 2.80 (s, 6H, NMe_2), 2.53 (br, 2H), 2.23 (br, 2H), 1.81 (br, 2H), 1.40 (br, 6H), 1.35 (s, 12H, $BO_2C_2Me_4$); ^{11}B{^{1}H} δ: 35.1 (br); ^{13}C{^{1}H} δ: 139.9, 136.6, 133.0, 131.0, 129.0 (br, *C*-B), 128.1, 91.4 (s, J_{C-Pt} = 161 Hz, =*C*HR), 84.1 ($BO_2C_2Me_4$), 64.8 (Ar-*C*H_2-N), 52.1 (NMe_2), 29.2, 28.1, 26.3, 25.1 ($BO_2C_2Me_4$).

Reaction of Na_2PdCl_4 + 14

Sodium chloride (18 mg, 0.31 mmol) was added to a stirred 15 mL methanol suspension of palladium chloride (25 mg, 0.14 mmol) to produce sodium tetrachloropalladate. A 5 mL methanol solution of dibutylborinic acid, ethanolamine ester (57 mg, 0.31 mmol) was added dropwise to the solution, and the reaction was allowed to proceed for 45 h. The product was obtained upon removal of methanol under vacuum. NMR spectroscopic data (in D_2O): ^1H δ: 3.76 (m, 4H), 3.44 (br, 4H, N*H*$_2$), 2.68 (m, 4H); $PdCl_2(NH_2CH_2CH_2OH)_2$.

Reaction of K_2PtCl_4 + 14

Dibutylborinic acid, ethanolamine ester (29 mg, 0.16 mmol) was added as a solid to a stirred 20 mL aqueous solution of potassium tetrachloroplatinate (30 mg, 0.07 mmol). The reaction was allowed to proceed for 18 h. A yellow solid was isolated following the removal of water under vacuum. Selected NMR data (in D_2O): ^1H δ: 3.79 (m, 4H), 3.08 (m, 4H), 2.82 (br, 4H, N*H*$_2$), $PtCl_2(NH_2CH_2CH_2OH)_2$; $^{11}B\{^1H\}$ δ: 19.9 (s, $B(OH)_3$).

Reaction of Na_2PdCl_4 + 15

Sodium chloride (22 mg, 0.38 mmol) was added as a solid to a stirred 15 mL methanol suspension of palladium chloride (30 mg, 0.17 mmol) to produce the methanol soluble species, sodium tetrachloropalladate. After 1 h of stirring, a 10 mL methanol solution of diphenylborinic acid, ethanolamine ester (80 mg, 0.36 mmol) was added dropwise, and the clear amber solution became black immediately. Methanol was removed under vacuum, and the aqueous and organic soluble species were characterized by NMR spectroscopy. For the water soluble phase, NMR data (in D_2O): ^1H δ: 3.76 (m, 4H), 3.44 (m, 4H), 2.68 (m, 4H); $PdCl_2(NH_2CH_2CH_2OH)_2$. $^{11}B\{^1H\}$ δ: 19.9 (s, $B(OH)_3$). For the organic soluble phase, NMR data (in $CDCl_3$): ^1H δ: 8.22 (m), 7.57 (m), 7.45 (ov); $^{11}B\{^1H\}$ δ: 29.6 (br, $PhB(OH)_2$).

Reaction of K_2PtCl_4 + 15

Diphenylborinic acid, ethanolamine ester (29 mg, 0.13 mmol) was added in small portions as a solid to a stirred 20 mL aqueous solution of potassium tetrachloroplatinate (25 mg, 0.06 mmol). Water was removed under vacuum after 10 h, and the aqueous and organic soluble products were characterized by NMR spectroscopy. NMR data (in D_2O): ^1H δ: 3.79 (m, 4H), 3.08 (m, 4H), 2.82 (m, 4H); $PtCl_2(NH_2CH_2CH_2OH)_2$. $^{11}B\{^1H\}$ δ: 19.9 (s, $B(OH)_3$). For the organic soluble phase, NMR data (in $CDCl_3$): ^1H δ: 8.22 (m), 7.57 (ov) 7.45 (ov); $^{11}B\{^1H\}$ δ: 29.6 (br, $PhB(OH)_2$).

Reaction of $[PdCl_2(COE)]_2$ + 14

Under an atmosphere of dinitrogen using an MBraun glovebox, a 2 mL THF solution of dibutylborinic acid, ethanolamine ester (39 mg, 0.21 mmol) was added dropwise to a stirred 5 mL THF solution of $[PdCl_2(COE)]_2$ (30 mg, 0.05 mmol). The reaction was allowed to proceed for 1.5 h before solvent was removed under vacuum. The resulting yellow solid was washed with hexane (2 × 3 mL) to remove cyclooctene. The solid was dried under vacuum, and the product was extracted with 1 mL of deuterated chloroform. Selected NMR data (in $CDCl_3$): ^1H δ 4.12, (s), 3.24 (br), 2.84 (s), 1.31 (s), 0.89 (s); $^{11}B\{^1H\}$ δ 60.5 (br). The product decomposed (1 h) in solution to give palladium metal.

Reaction of $[PtCl_2(COE)]_2$ + 14

Under an atmosphere of dinitrogen using an MBraun glovebox, a 0.5 mL deuterated chloroform solution of dibutylborinic acid, ethanolamine ester (12 mg, 0.07 mmol) was added dropwise to a 0.5 mL deuterated chloroform solution of $[PtCl_2(COE)]_2$ (25 mg, 0.03 mmol). The reaction was allowed to proceed for 3 h before the product was characterized by IR and NMR spectroscopy. IR ($CHCl_3$): 3319 (w), 2930 (m), 1571 (w), 1468 (w), 1330 (w), 901 (s), 726 (s), 651 (s). Selected NMR data for $PtCl_2(COE)(NH_2CH_2CH_2OBBu_2)$ **16** (in $CDCl_3$): ^1H δ: 5.61 (br, 2H, C=C*H*R), 5.29 (br, J_{H-Pt} = 68 Hz, 2H, N*H*$_2$), 4.10, (br), 3.22 (br), 2.38 (br), 2.27 (br) 2.12, (br) 1.78, (br) 1.47 (br), 1.30 (br), 0.87 (br); $^{11}B\{^1H\}$ δ: 56.1 (br). The product decomposed (1 h) in solution to give platinum metal.

Reaction of $[PtCl_2(COE)]_2$ + 15

Under an atmosphere of dinitrogen using an MBraun glovebox, a 0.5 mL deuterated chloroform solution of diphenylborinic acid, ethanolamine ester (15 mg, 0.07 mmol) was added dropwise to a 0.5 mL deuterated chloroform solution of $[PtCl_2(COE)]_2$ (25 mg, 0.03 mmol). The reaction was allowed to proceed for 3 h before the clear yellow solution was characterized by NMR and IR spectroscopy. NMR data for $PtCl_2(COE)(NH_2CH_2CH_2OBPh_2)$ (**17**) (in $CDCl_3$): ^1H δ: 7.63 (m, 4H), 7.43 (m, 6H), 5.62 (br s, 2H, C=C*H*R), 5.30 (br s, J_{H-Pt} = 62 Hz, 2H, N*H*$_2$), 4.17 (s, 2H), 3.33 (s, 2H), 2.36 (br, 4H), 2.14 (br, 4H), 1.76 (br s, 4H); $^{11}B\{^1H\}$ δ: 47.8 (br); $^{13}C\{^1H\}$ δ 136.6 (br, *C*-B), 134.4, 131.7, 130.5, 130.1, 127.7, 93.7 (s, J_{C-Pt} = 165 Hz, *C*=*C*HR), 63.5, 46.6, 29.4, 28.0, 26.3. IR ($CHCl_3$): 2929 (w), 2853 (w), 1576 (w), 1470 (w), 1438 (w), 1322 (w), 905 (s), 727 (s), 851 (s).

$PdCl_2(3\text{-}NC_5H_4B(OH)_2)_2$ (19)

A 10 mL methylene chloride solution of 3-(diethylboryl)pyridine (102 mg, 0.69 mmol) was added dropwise to a stirred 30 mL methylene chloride solution of $[PdCl_2(COE)]_2$ (100 mg, 0.17 mmol). After 48 h, an orange precipitate was collected by filtration and washed with methylene chloride (3 × 5 mL). Yield: 60 mg (42%) of an orange solid; mp 234°C. IR (nujol): 3197 (w), 2923 (s), 2856 (s), 1576 (w), 1462 (m), 1377 (m). Selected NMR data (in acetone-d_6): ^1H δ: 9.24 (s, 4H, B(O*H*)$_2$), 8.94 (m, 2H), 8.41 (m, 4H), 7.61 (m, 2H); $^{11}B\{^1H\}$ δ: 29.2 (br). Solubility problems precluded $^{13}C\{^1H\}$ NMR data collection.

$PdCl_2(3\text{-}NC_5H_4Bpin)_2$ (20)

To a 40 mL methylene chloride suspension of **19** (134 mg, 0.32 mmol), pinacol (45 mg, 0.38 mmol) and 10 g of activated molecular sieves (BDH 4A) were added. The mixture was allowed to stand for 7 days before the sieves and unreacted **19** were removed by filtration. The filtrate was collected, and methylene chloride removed under vacuum to afford a yellow solid, which was washed with hexane (3 × 10 mL) to remove excess pinacol. The product was crystallized from a CH_2Cl_2–hexane solution. Yield: 160 mg (86%)

Table 1. Crystallographic data collection parameters for *trans*-$PdCl_2(APBpin)_2$ (**5**).

Complex	**5**
Formula	$C_{24}H_{36}B_2Cl_2N_2O_4Pd \cdot 4C_4H_8O$
fw	903.88
Crystal system	Monoclinic
Space group	$P2_1/c$
a, Å	13.836(5)
b, Å	14.937(5)
c, Å	11.287(5)
β, deg	99.042(9)
V, Å^3	2304(2)
Z	2
ρ_{calcd}, g cm^{-3}	1.303
Crystal size, mm	0.25 × 0.20 × 0.20
Temperature, K	203(2)
Radiation	MoKα (λ = 0.71073)
μ, mm^{-1}	0.567
Max 2θ, deg	25
Data collection method	ω
Total unique reflections	4023
Total observed reflections[a]	3893
No. of variables	258
Max. res. density/hole, e Å^{-3}	0.464/–0.532
R^b	0.0449
R_w	0.1161
GoF[c]	1.071

[a] $I_o > 3\sigma(I_o)$.
[b] $R = \Sigma||F_o| - |F_c||/\Sigma|F_o|$; $Rw = [\Sigma(w(|F_o| - |F_c|)^2/\Sigma(w|F_o|)^2]^{1/2}$.
[c] $[\Sigma(w(|F_o| - |F_c|)^2/(NO - NV)]^{1/2}$.

of a yellow solid, mp 276°C. IR (nujol): 2949 (s), 2859 (s), 1603 (w), 1461 (m), 1376 (m). NMR spectroscopic data (in $CDCl_3$): ^{1}H δ: 9.13 (s, 2H), 8.85 (d, J_{H-H} = 5 Hz, 2H), 8.12 (d, J_{H-H} = 8 Hz, 2H), 7.33 (t, J_{H-H} = 8 Hz, 2H), 1.35 (s, 24H, BO_2Me_4); ^{11}B{^{1}H} δ: 31.0 (br); ^{13}C{^{1}H} δ 158.7, 154.7, 144.5, 126.5 (br, *C*-B), 124.5, 84.9 ($BO_2C_2Me_4$), 24.9 ($BO_2C_2Me_4$). Anal. calcd. for $PdCl_2C_{22}H_{32}N_2B_2O_4 \cdot H_2O$: C 43.63, H 5.65, N 4.62; found: C 43.61, H 5.39, N 4.89.

X-ray crystallographic data for 5

Crystals of **5** suitable for X-ray diffraction studies were obtained by recrystallization from a THF–hexane mixture at 5°C. A summary of the crystal data and parameters for data collection is given in Table 1. Data were collected at 203 K on a Siemens SMART/CCD diffractometer equipped with an LT-II low-temperature device. Diffracted data were corrected for absorption using the SADABS[3] program. SHELXTL was used for structure solution, and refinement was based on F^2.[4] All non-hydrogen atoms were refined anisotropically. Hydrogen atoms were fixed at calculated positions. Selected bond distances and angles are given in Table 2 and final atomic coordinates in Table 3. Complete tables of bond distances and angles, final atomic coordinates, and anisotropic displacement parameters have been deposited as supporting material.[5]

Results and discussion

1. Reactions with 3-aminophenylboronic acid

The synthesis of amines containing boronic acid groups is often a complicated procedure requiring several complex organic transformations (12*d*). As a result, the range of compounds containing both an amine and a boronic acid functionality is surprisingly small. Indeed, the use of aminoboronic acids as ligands for transition metals has not yet been explored. As part of our initial investigation into this area, we set out to prepare palladium and platinum complexes containing commercially available 3-aminophenylboronic acid (3-$NH_2C_6H_4B(OH)_2$, APBA, **1**). We have found that addition of **1** to aqueous solutions of $[MCl_4]^{2-}$ (M = Pd, Pt) gives the corresponding boronic acid-containing complexes $MCl_2(APBA)_2$ (M = Pd, **2**; M = Pt, **3**). These complexes are insoluble in most common organic solvents, and attempts to dissolve them in coordinating solvents such as DMSO led to decomposition where the solvent was clearly displacing the weakly bound aminoboron group. Although aniline derivatives are known to coordinate to palladium and platinum (17), the addition of an electron-withdrawing boronic acid group to the phenyl moiety, not surprisingly, severely reduces the nucleophilicity of the already weak aniline group (pK_a = 4.6 for conjugate acid, anilinium ion). Attempts to generate diaqua complexes $[M(OH_2)_2(APBA)_2](NO_3)_2$ by addition of $AgNO_3$ to **2** and **3** in water gave rapid degradation to the corresponding metals along with the formation of boric acid.

Compounds containing boronic acids are extremely difficult to characterize in terms of elemental composition, owing to the ease with which they partially dehydrate to the corresponding trimeric or oligomeric anhydrides (12*a*). To alleviate this complication, as well as to increase solubilities in organic solvents, we replaced the hydroxyl groups on **1** with the more electron donating pinacol-derived group (pin = $O_2C_2Me_4$) (18) to give 3-$NH_2C_6H_4$Bpin (**4**, APBpin). Unfortunately, substitution reactions in water involving **4** and the tetrachloro salts suffered from competing cleavage of the pinacol groups to give complicated mixtures of products. However, transesterification of the boronic acid derivatives **2** and **3** with pinacol ultimately generated the corresponding complexes $MCl_2(APBpin)_2$ (M = Pd, **5**; M = Pt, **6**) in low yields (9–16%).

The molecular structure of diamine complex **5**, which crystallizes with four molecules of tetrahydrofuran per complex, is shown in Fig. 1, and selected bond distances and angles provided in Table 2. The aminoboron ligands lie in a *trans* configuration with Pd—N bond distances of 2.047(3) Å being similar to that observed for the analogous

[3] G.M. Sheldrick. SADABS Univ. Gottingen. 1996.
[4] G.M. Sheldrick. SHELXTL Release 5.03. Siemens Analytical X-ray Instruments Inc., Madison, Wis. 1994.
[5] A complete set of data may be purchased from: The Depository of Unpublished Data, Document Delivery, CISTI, National Research Council Canada, Ottawa, Canada, K1A 0S2. Tables of coordinates, bond distances and angles, and alternative views of **5** have also been deposited with the Cambridge Crystallographic Data Centre and can be obtained on request from: The Director, Cambridge Crystallographic Data Centre, University Chemical Laboratory, 12 Union Road, Cambridge, CB2 1EZ, U.K.

Table 2. Selected bond distances (Å) and angles (deg) for *trans*-$PdCl_2(3\text{-}NH_2C_6H_4Bpin)_2$ (**5**).

Pd(1)—N(1)	2.047(3)
Pd(1)—N(1)#1	2.047(3)
Pd(1)—Cl(1)#1	2.3028(11)
Pd(1)—Cl(1)	2.3028(11)
O(1)—B(1)	1.354(5)
O(1)—C(7)	1.481(4)
O(2)—B(1)	1.372(5)
O(2)—C(8)	1.464(4)
N(1)—C(1)	1.438(4)
B(1)—C(3)	1.555(5)
C(1)—C(6)	1.382(5)
C(1)—C(2)	1.394(4)
C(2)—C(3)	1.402(5)
C(3)—C(4)	1.390(5)
C(4)—C(5)	1.390(5)
C(5)—C(6)	1.380(5)
C(7)—C(11)	1.512(5)
C(7)—C(12)	1.514(5)
C(7)—C(8)	1.559(5)
C(8)—C(10)	1.518(5)
C(8)—C(9)	1.527(6)
O(1A)—C(1A)	1.361(6)
O(1A)—C(4A)	1.424(5)
C(1A)—C(2A)	1.453(7)
C(2A)—C(3A)	1.470(7)
C(3A)—C(4A)	1.493(6)
O(1B)—C(4B)	1.409(5)
O(1B)—C(1B)	1.427(5)
C(1B)—C(2B)	1.417(7)
C(2B)—C(3B)	1.458(7)
C(3B)—C(4B)	1.453(7)
N(1)-Pd(1)-N(1)#1	180.0
N(1)-Pd(1)-Cl(1)#1	90.14(11)
N(1)#1-Pd(1)-Cl(1)#1	89.86(11)
N(1)-Pd(1)-Cl(1)	89.86(11)
N(1)#1-Pd(1)-Cl(1)	90.14(11)
Cl(1)#1-Pd(1)-Cl(1)	180.0
B(1)-O(1)-C(7)	107.1(3)
B(1)-O(2)-C(8)	107.0(3)
C(1)-N(1)-Pd(1)	114.1(2)
O(1)-B(1)-O(2)	113.8(3)
O(1)-B(1)-C(3)	124.1(3)
O(2)-B(1)-C(3)	122.1(4)
C(6)-C(1)-C(2)	120.0(3)
C(6)-C(1)-N(1)	120.0(3)
C(2)-C(1)-N(1)	120.1(3)
C(1)-C(2)-C(3)	121.0(3)
C(4)-C(3)-C(2)	117.9(3)
C(4)-C(3)-B(1)	121.7(3)
C(2)-C(3)-B(1)	120.4(3)
C(3)-C(4)-C(5)	120.8(4)
C(6)-C(5)-C(4)	120.7(4)
C(5)-C(6)-C(1)	119.5(3)
O(1)-C(7)-C(11)	108.5(3)
O(1)-C(7)-C(12)	106.1(3)
C(11)-C(7)-C(12)	110.7(3)
O(1)-C(7)-C(8)	102.0(3)
C(11)-C(7)-C(8)	114.4(3)
C(12)-C(7)-C(8)	114.2(3)
O(2)-C(8)-C(10)	108.8(3)
O(2)-C(8)-C(9)	107.0(3)
C(10)-C(8)-C(9)	109.8(3)
O(2)-C(8)-C(7)	102.5(3)
C(10)-C(8)-C(7)	115.1(3)
C(9)-C(8)-C(7)	113.0(3)
C(1A)-O(1A)-C(4A)	105.6(3)
O(1A)-C(1A)-C(2A)	108.4(5)
C(1A)-C(2A)-C(3A)	105.5(5)
C(2A)-C(3A)-C(4A)	103.9(4)
O(1A)-C(4A)-C(3A)	105.4(4)
C(4B)-O(1B)-C(1B)	108.4(4)
C(2B)-C(1B)-O(1B)	106.6(4)
C(1B)-C(2B)-C(3B)	105.7(5)
C(4B)-C(3B)-C(2B)	105.7(5)
O(1B)-C(4B)-C(3B)	107.2(4)

Table 2 (*concluded*).

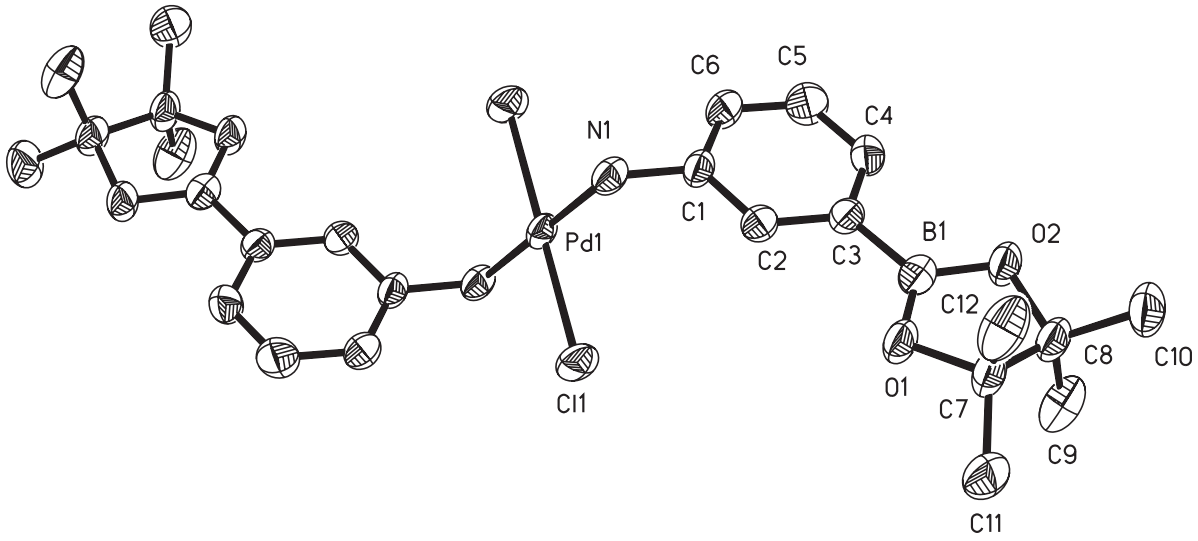
bonds in *trans*-$PdCl_2(NH_2CH_2Ph)_2$ (19). The boronate ester functionality (BO_2R_2) lies in the plane of the arene ring and has two short B—O bonds (1.354(5) and 1.372(5) Å). These results indicate that "dative" bonding is significant for both the aromatic ring π-electrons and oxygen atoms with boron. The slight difference in the two B—O bond lengths has been observed previously in chelate complexes of phenylboronic acid (20). To the best of our knowledge, this is the first structurally characterized example of an aminoboronate–metal complex.

To avoid problems arising from reactions carried out in aqueous solutions, we decided to examine the reactivities of both APBA and APBpin with $PtCl_2(COD)$ (COD = 1,5-cyclooctadiene) in organic solvents. Unfortunately, no reaction, or decomposition, was observed when this platinum complex was treated with either aminoboron species at room or elevated temperatures. We then decided to prepare the analogous *trans* amine complexes from the monoalkene metal compounds $[MCl_2(COE)]_2$ (M = Pd, Pt; COE = η^2-C_8H_{14}) (Scheme 1), as both *cis* and *trans* platinum amine complexes are known to be biologically active (14). The starting organometallic dimers, which are soluble in common organic solvents, were prepared by the addition of *cis*-cyclooctene to aqueous solutions of the corresponding metal tetrachloride salts (15). Diamine complex $PdCl_2(APBA)_2$ (**2**) was obtained in moderate yields (39%) from reactions of boronic acid **1** with $[PdCl_2(COE)]_2$. Interestingly, dropwise addition of 1 equiv. of pinacol derivative **4** to the palladium dimer gave rapid formation of the novel air-stable organometallic complex $PdCl_2(COE)(APBpin)$ (**7**). Attempts to generate the corresponding boronic acid derivative via this route afforded equal amounts of disubstituted amine **2** along with starting alkene complex $[PdCl_2(COE)]_2$. The difficulty in generating the boronic acid analogue of **7** presumably arises from the insoluble nature of the amine starting material in organic solvents. In an attempt to generate a mixed phosphine-amine complex, we have found that addition of 1 equiv. of PPh_3 to **7**, however, afforded $PdCl_2(PPh_3)_2$ where the phosphines have displaced both the weakly bound cyclooctene and aminoboron ligands. Interestingly, subsequent addition of a second equivalent of

Table 3. Atomic coordinates ($\times 10^4$) and equivalent isotropic displacement coefficients for *trans*-$PdCl_2(3\text{-}NH_2C_6H_4Bpin)_2$ (**5**).

	x	*y*	*z*	*U*(eq)
Pd(1)	5000	0	5000	32(1)
Cl(1)	3525(1)	79(1)	3735(1)	47(1)
O(1)	724(2)	872(2)	6450(2)	43(1)
O(2)	663(2)	162(2)	8228(2)	47(1)
N(1)	4503(3)	910(2)	6120(3)	38(1)
B(1)	1228(3)	429(3)	7397(4)	38(1)
C(1)	3934(2)	523(2)	6951(3)	34(1)
C(2)	2919(2)	617(2)	6762(3)	35(1)
C(3)	2351(3)	259(2)	7572(3)	35(1)
C(4)	2827(3)	–228(3)	8540(3)	44(1)
C(5)	3838(3)	–333(3)	8715(4)	54(1)
C(6)	4392(3)	44(2)	7929(3)	43(1)
C(7)	–271(3)	1039(3)	6730(3)	44(1)
C(8)	–359(3)	308(3)	7693(4)	44(1)
C(9)	–749(3)	–581(3)	7148(4)	66(1)
C(10)	–934(3)	585(3)	8673(4)	63(1)
C(11)	–998(3)	941(3)	5588(4)	63(1)
C(12)	–266(3)	1989(3)	7197(4)	67(1)
O(1A)	3468(2)	2556(2)	9912(3)	69(1)
C(1A)	3648(4)	1812(4)	10 608(7)	113(2)
C(2A)	2751(5)	1562(5)	11 042(5)	112(2)
C(3A)	1960(3)	2019(4)	10 246(5)	81(2)
C(4A)	2475(4)	2482(3)	9352(4)	73(1)
O(1B)	5777(2)	2266(2)	7460(3)	80(1)
C(1B)	6819(3)	2229(4)	7730(5)	88(2)
C(2B)	7062(5)	2299(6)	8994(5)	136(3)
C(3B)	6252(5)	2780(5)	9387(5)	124(3)
C(4B)	5419(4)	2653(4)	8444(5)	86(2)

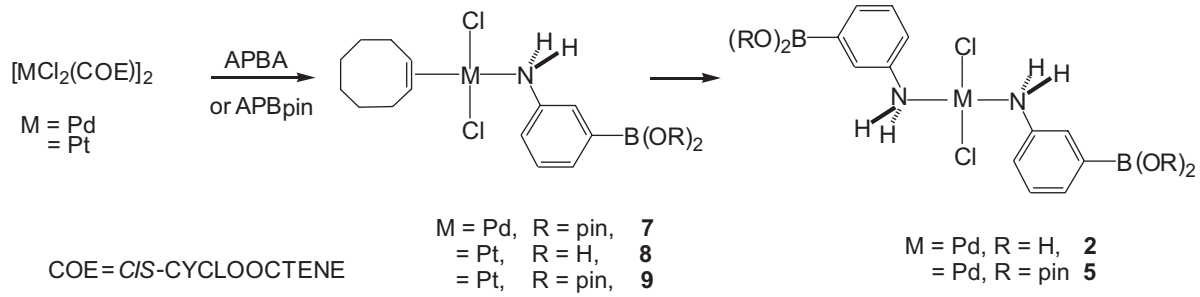
Fig 1. Molecular structure of $PdCl_2(APBpin)_2$ (**5**, pin = $O_2C_2Me_4$) with hydrogen atoms and molecules of THF omitted for clarity.



aminoboronic ester to **7** resulted in facile loss of the labile cyclooctene ligand with concomitant formation of $PdCl_2(APBpin)_2$ (**5**). Similar studies on the addition of pyridines to palladium monoalkene complexes have been reported previously (21).

Unlike reactions with palladium, only monoalkene complexes $PtCl_2(COE)(APBA)$ (**8**) and $PtCl_2(COE)(APBpin)$ (**9**) were generated from the addition of the corresponding aminoboron derivatives to $[PtCl_2(COE)]_2$. Attempts to displace the alkene proved unsuccessful, even with addition of

Scheme 1.



excess aminoboron ligand at elevated temperatures.[6] This observation is consistent with the known ability of platinum to form stronger M–alkene bonds than palladium, owing to an increase in the amount of π-backbonding (22). Spectroscopic and X-ray diffraction studies of similar *trans*-$PtCl_2(\eta^2$-alkene)(L) (L = nitrogen-containing ligand) complexes have been reported previously (23).

2. Reactions with *N*,*N*-dimethylbenzylamineboronic acid

Boron derivatives of *N*,*N*-dimethylbenzylamine, 2-$NMe_2CH_2C_6H_4B(OH)_2$ (**10**) and 2-$NMe_2CH_2C_6H_4$Bpin (**11**), were prepared by established procedures (16). Significant intramolecular interaction exists between the nitrogen atom and the boron atom in solution as evidenced by $^{11}B\{^1H\}$ NMR spectroscopy (24). Peaks at δ 8.9 and 15.3 ppm observed for **10** and **11**, respectively, are shifted considerably upfield from phenylboronic acid (δ 29.6 ppm), indicating that the boron atom is four coordinate. Not surprisingly, a distinct solvent effect is observed on the rates of N—B bond dissociation in these systems, as shown previously using NMR spectroscopy (25).

Reactions of **10** or **11** with Na_2PdCl_4 in water or methanol gave the known cyclopalladated dimer $[PdCl(2\text{-}NMe_2CH_2C_6H_4)]_2$ (26) as the major amine-containing product (identified using ^1H NMR spectroscopy and mp) along with formation of boric acid; this latter species presumably arising from the addition of water to liberated "Cl-$B(OH)_2$". The cyclopalladated compound has been prepared previously from the addition of *N*,*N*-dimethylbenzylamine to Na_2PdCl_4, along with concomitant formation of HCl, where the *ortho* C(sp^2)—H bond of the phenyl group is broken as a new C(sp^2)—Pd bond forms (26). Our observation is intriguing in that it shows a preference for activation of the C(sp^2)—B bond over the conventional C(sp^2)—H bond. This selectivity suggests that intramolecular coordination of the nitrogen atom to boron severely weakens the corresponding C—B bond. A strong base (typically NaOH or TlOH) is usually required to facilitate cleavage of the C—B in the Suzuki–Muyari cross-coupling reactions of organic halides with organoboronic acids (27). No reaction was observed in analogous reactions with the platinum salt, K_2PtCl_4, and either **10** or **11**.

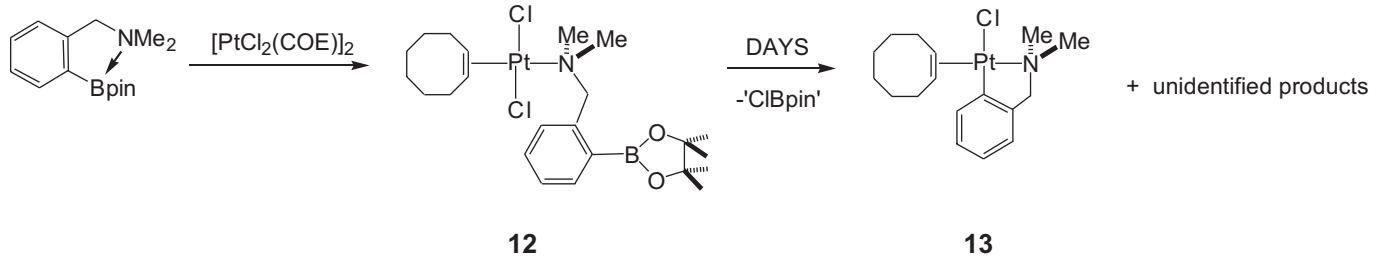
The cyclometallated dimer $[PdCl(2\text{-}NMe_2CH_2C_6H_4)]_2$ was also obtained from reactions of alkene complex $[PdCl_2(COE)]_2$ with **10** in reactions carried out in wet CH_2Cl_2. This reaction probably proceeds via initial coordination of the aminoboron ligand followed by loss of cyclooctene to provide a 14-electron intermediate "$PdCl_2L$" (where L = aminoboron ligand) (28). Addition of water or an extra equivalent of amine may coordinate putatively to the boron atom and facilitate rapid B—C bond cleavage to give the desired cyclopalladated fragment, which will subsequently dimerize to give $[PdCl(2\text{-}NMe_2CH_2C_6H_4)]_2$. No reaction was observed when $[PdCl_2(COE)]_2$ was treated with **10** in dry solvent under an inert atmosphere. Reactions of $[PdCl_2(COE)]_2$ with 2-$NMe_2CH_2C_6H_4$Bpin **11** in wet methylene chloride also generated the cyclopalladated dimer $[PdCl(2\text{-}NMe_2CH_2C_6H_4)]_2$ along with pinB-O-Bpin and the ammonium salt $[2\text{-}HNMe_2CH_2C_6H_4Bpin]_2[PdCl_4]$, where an extra equivalent of the aminoboron ligand has been used to mop up the liberated Cl-Bpin. Addition of Cl-Bpin to **11** would result in initial formation of $[2\text{-}pinBNMe_2CH_2C_6H_4Bpin]^+Cl^-$, which would rapidly degrade with addition of adventitious water to the protonated ammonium salt along with "HO-Bpin," the latter of which will further degrade to give pinB-O-Bpin (similar nucleophilic degradation reactions have been reported previously for catechol derivatives, see ref. 29).

Consistent with this proposed pathway, the pinacol derivative **11** reacts initially with $[PtCl_2(COE)]_2$ to give an air-sensitive species, which we have tentatively assigned as the coordination complex $PtCl_2(COE)(\eta^1\text{-}2\text{-}NMe_2CH_2C_6H_4Bpin)$ (**12**). The proton NMR spectrum of **12** indicates that one C(sp^2)-H is significantly deshielded (δ 8.87 ppm) with respect to starting aminoboron compound (δ 7.55 ppm), which we postulate may lie over the metal square plane, as noted previously for the bisamine adduct $PdCl_2$(1-tetralone oxime)$_2$ (30). Attempts to grow crystals of this coordination complex suitable for X-ray diffraction studies were unsuccessful, as compound **12** decomposes to give a number of unidentified products (by NMR spectroscopy) along with the cycloplatinated monomer $PtCl(COE)(2\text{-}NMe_2CH_2C_6H_4)$ (**13**) (Scheme 2).

Initial loss of cyclooctene followed by oxidative addition of the B—C bond with subsequent reductive elimination of the Cl-Bpin fragment and recoordination of the alkene moiety would give the cycloplatinated product (28, 31). Formation of this cycloplatinated species was also observed in analogous reactions with the boronic acid **10**. Interestingly, no reaction was observed between alkene complex

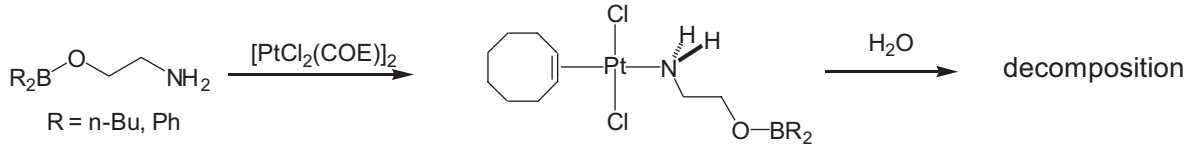
[6] A minor amount (<5%) of the diamine complex *trans*-$PtCl_2(APBpin)_2$ was generated upon heating for prolonged periods (days). An X-ray diffraction study on this compound was carried out, and the platinum analogue proved to be isostructural with complex **5**. Complete details of this study are provided in the supplementary data.

Scheme 2.



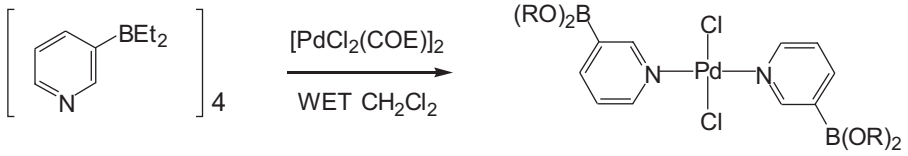
12 **13**

Scheme 3.



R = n-Bu, **16**
R = Ph, **17**

Scheme 4.



R = H, **19**
R = pin, **20**

$[PtCl_2(COE)]_2$ and *N*,*N*-dimethylbenzylamine even at elevated temperatures.

3. Reactions with borinic esters

Reactions of dibutylborinic acid, ethanolamine ester, $H_2NCH_2CH_2OBBu_2$ (**14**), or diphenylborinic acid, ethanolamine ester, $H_2NCH_2CH_2OBPh_2$ (**15**), with the tetrachloro salts, $[MCl_4]^{2-}$, in aqueous solvents proceed via cleavage of the B—O bond to give a mixture of metal–ethanolamine complexes (32). Formation of these degradation products was confirmed by independently adding commercially available ethanolamine to the corresponding metal salts. Reactions with **14** gave boric acid, and presumably butane, while phenylboronic acid, $PhB(OH)_2$, was generated as the major boron-containing product in reactions using **15**. Although the boron atom is initially stabilized by intramolecular coordination of the amine nitrogen atom in the free ligand, nucleophilic degradation of the borinic group appears to be rapid once the B←N bond is broken and the amine coordinates to the metal centre. Cleavage of the B—O bond in these ligands has been observed previously (33). Likewise, similar degradation products were observed with reactions of **14** and **15** with $[PdCl_2(COE)]_2$. Reactions with $[PtCl_2(COE)]_2$, however, gave the corresponding monoamine complexes $PtCl_2(COE)(NH_2CH_2CH_2OBBu_2)$ (**16**) (^{11}B NMR δ 56.1 ppm) and $PtCl_2(COE)(NH_2CH_2CH_2OBPh_2)$ (**17**) (^{11}B NMR δ 47.8 ppm), respectively, both of which rapidly decompose in air to give a number of unidentified ethanolamine-derived products (Scheme 3).

4. Reactions with 3-(diethylboryl)pyridine

3-(Diethylboryl)pyridine (**18**) was originally prepared in 1983 (34) and its use in coupling reactions is well established (35). The remarkable stability of this compound under ambient conditions is due to its cyclic-tetrameric nature in the solid state and in solution. Four molecules of **18** are bound together through intermolecular nitrogen–boron bonds (36). We hypothesized that reactions of **18** with either $[MCl_4]^{2-}$ or $[MCl_2(COE)]_2$ (M = Pd, Pt) would result in the formation of metal–pyridine complexes by breaking the N→B bonds. Nucleophilic attack by water on the boron atom should therefore result in breaking the B—C_{Et} bonds and concomitantly generating the corresponding pyridine – boronic acid metal complexes. Interestingly, although no product formation was observed using the metal chloride salts, reactions with $[PdCl_2(COE)]_2$ in wet methylene chloride gave modest yields (42%) of the desired boronic acid complex $PdCl_2[NC_5H_4B(OH)_2]_2$ (**19**) (Scheme 4). This result implies that coupling reactions carried out in an aqueous or basic environment may initially transform tetrameric **18** to the corresponding boronic acid analogue in the presence of a palladium catalyst (35). We are presently investigating coupling reactions using aminoboronic acid derivatives and

will report our findings in due course. Complex $PdCl_2(NC_5H_4Bpin)_2$ (**20**) was prepared by transesterification of **19** with pinacol. Not surprisingly, no reaction was observed using the less reactive platinum complex $[PtCl_2(COE)]_2$.

Conclusions

We have investigated the reactivity of several aminoboron compounds with $[MCl_4]^{2-}$ salts and monoalkene dimers $[MCl_2(COE)]_2$ (M = Pd, Pt). Addition of 3-aminophenylboronic acid (APBA) to $[MCl_4]^{2-}$ (M = Pd, Pt) gave the corresponding metal derivatives $MCl_2(APBA)_2$. Diamine complexes were also generated by addition of APBA and APBpin (pin = $O_2C_2Me_4$) to the palladium alkene dimer $[PdCl_2(COE)]_2$. The aminoboron ligands were ineffective in displacing the coordinated cyclooctene group in analogous reactions with the platinum dimer. Interestingly, cleavage of the B—C and B—O bonds dominated reactions involving aminoboron ligands, $2\text{-}NMe_2CH_2C_6H_4B(OR)_2$ and $H_2NCH_2CH_2OBR_2$, respectively. Although 3-(diethylboryl)pyridine is stabilized by intramolecular N→B interactions, the novel boronic acid-containing complex $PdCl_2[NC_5H_4B(OH)_2]_2$ was prepared by addition of this aminoboron ligand to the palladium alkene dimer. We are presently investigating the biological activities of several of these new platinum derivatives, the results of which will be published in due course.

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