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Geochemical Assessment of the Huntly Coalbed Methane (CBM) Field, New Zealand Using a Chloride, Bicarbonate, and Boron Ternary Diagramme

H. Abu Bakar, and S. J. Zarrouk, Department of Engineering Science, The University of Auckland

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Abstract

This study investigates the chemical signature of produced water from the Huntly coalbed methane (CBM) using a newly proposed Cl-HCO_3-B ternary diagram. This ternary diagram is used to identify the source of fluid in the different aquifers (ground water, CBM and deep basement) and the potential communication between these aquifers. A comparison study of Huntly with other CBM fields (Maramarua, Powder River Basin, San Juan Basin, Raton, Atlantic Rim, Liulin and Alberta) was also carried out to help characterize and verify the water being abstracted. Results from the ternary diagram show that produced water samples from Huntly CBM wells are plotted in the middle along chloride-bicarbonate axis. This indicates that the water samples are CBM water originated from moderate to good permeability coal seams. The water samples also indicate that they have some communication with shallow aquifer due to significant bicarbonate concentration. Meanwhile water samples from basement well (B1) are plotted near to Boron side along Boron-chloride axis, which signifies basement water. The water originated from low permeable formations and afar from recharge area. Furthermore, results from schoeller diagrams show that Huntly water samples from CBM wells, shallow monitoring well and basement well exhibit distinct water chemistry patterns. The CBM water pattern shows sodium, bicarbonte and chloride as the predominant ions. It is similar to the typical CBM water pattern and comparable with CBM water from selected methane producing CBM fields with minor differences. Water samples from the basement well on the other hand shows sulfate and magnesium as the primary ions and the concentration for all ions are lower than CBM water. Shallow water sample exhibits the lowest concentration for all ions compared to CBM water and basement water with bicarbonate as the main ion. In conclusion, this ternary diagram is a reliable tool to identify the possible links between deep and shallow aquifers, formation permeability and origin of the water in one diagram. It enhances the understanding of the natural CBM reservoir setting for future field development, wastewater management and water quality monitoring.

Keywords Coalbed methane (CBM) · produced water · Huntly · Cl-HCO_3-B ternary diagram

Introduction

Large volumes of water are extracted in the early stage of CBM field development to reduce hydrostatic pressure and allowing methane gas to desorb from coal seams (ALL Consulting, 2003; McBeth et al., 2003; Rice et al., 2000; Rogers, 1994). Generally, the volume of CBM produced water declines gradually over time while methane gas production increases (ALL Consulting, 2003, Rice et al., 2008). Due to large volume of water produced to the surface and its composition impacts to the environment, it has always been the concern that developers have to appropriately manage (Flores, 2013).

Produced water from CBM wells is known to have substantially high salinity with elevated sodium concentration (ALL Consulting, 2003; McBeth et al., 2003; Rice et al., 2000; Rogers, 1994). High saline water may cause detrimental effects to the environment when it does not treated, re-used and/or disposed appropriately. For instance, high salinity CBM water used for irrigation of certain crops that sensitive to saline-water (e.g. peas, carrot, orange and etc.) can affect the crop yield (Ayers and Westcot, 1985). This is because sodium reduces the water availability to the crop, disperses the soils and reduces the water infiltration rate significantly (Ayers and Westcot, 1985; Rogers, 1994). Furthermore, direct disposal of saline CBM water to the surface water may alter the surface water compositions (Clearwater et al., 2002). The existing communities of aquatic species may get affected and replaced with saline-water tolerant aquatic species (Clearwater et al., 2002; Keith, et al, 2003).

CBM produced water assessments are essential to obtain better understanding of the water composition and its quality for better CBM water management plan (Flores, 2013). It aids the developer to decide the proper treatment, re-usage and disposal plans of the produced water to prevent environmental damages. For example, CBM produced water from Wyoming (Powder River basin) is found as relatively less saline, hence some of the water has been re-used for irrigation of certain crops (e.g. alfalfa and grass) (National Research Council, 2010; Veil, et al., 2004). Apart from that, knowing the composition of the produced water can also give some insights about the reservoir setting for better understanding of the field (Rogers, 1994; Van Voast, 2003). The information includes reservoir permeability, depositional environment, the potential fluid flow paths in the reservoir and the source and the evolution of the water (Van Voast, 2003). It helps the developer to manage the field more efficiently.

The focus of this paper is about assessing the chemical signatures of produced water samples from Huntly coalfield as well as introducing a new way of assessing the produced water from CBM fields. Cl-HCO_3-B ternary diagram is a newly developed diagram that provides some qualitative information relating to the produced water origins, permeably and inter-aquifer communication. This diagram can be used as a water quality-monitoring tool to detect any groundwater contaminations incurred. In addition to that, produced water samples from selected producing CBM basins in the world (Powder River basin, San Juan basin, Raton, Atlantic Rim, Liulin, Alberta and Maramarua) are also evaluated for comparison study.

Study area

The Huntly coalfield (**Figure 1**) is located within the Waikato coal region in the North island of New Zealand. The coal measures are one of the predominant sources coal in New Zealand which contain seams that has thickness varies (50m – 100m) across short horizontal distances (e.g. <500m) (Mares and Zarrouk, 2009; PDP, 2010; Hall et al., 2006). There are three main coal seams in Huntly including Ngaro, Renown and Kupakupa and the coal seams range from sub-bituminous A to C (Edbrook et al., 1994; Newman et al., 1997) with vitrinite reflectance value, R_o of 0.34 – 0.54% (Edbrook et al., 1994; Twombly et al., 2004).

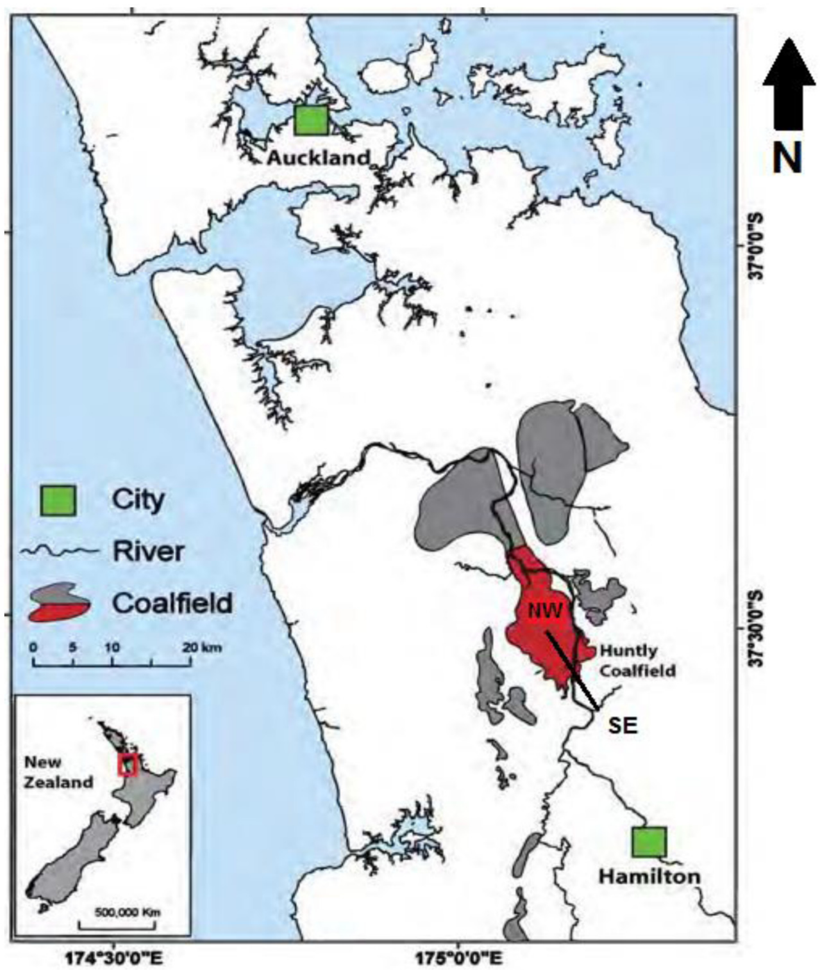

Figure 1—The map shows the location of Huntly coalfield (Mares and Moore, 2008b)

Geologically, The Waikato Coal Measures is the basal unit in Te Kuiti Group (**Table 1**). It is a thick trangressive sequence ranging from the coal seams to calcerous marine shelf sediments. Underneath the coal measures is the basement rock known as Greywacke. It belongs to the Newcastle Group, which consists of indurated sandstone and siltstones. Overlying the Waikato Coal Measures is Mangakotuku formation, which consists of grained non-calcerous mudstone. Then, it follows by Glen Massey and Whaigaroa formations, which are comprised of, glauconitic sandstones and non-calcerous siltstones respectively. Te Kuiti Group is overlained by Waitemata and Tauranga Groups (Kear and Schofield, 1987), and they consist of silty, medium to coarse sandstones, mudstones and clay sediments.

Table 1—The table is showing the stratigraphy column of Huntly coalfield (after Hall et. al., 2006)

Period	Thick (m)	Group	Formation	Member	Lithology	Detail of lithology
Pliocene	0 - 13	Tauranga				Yellow brown clay, grey-brown firm mudstone
Miocene	0 - 200	Waitemata	Amokura			Unfossliferous interbedded mustone, siltstones and sandstones
	0 - 100		Mercer Sst			Massive, brown, medium to coarse sandstones interbedded with thin carbonaceous light grey mudstone
	0 - 50		Koheroa Zst			Grey brown siltstones with sands
	0 - 50		Waikawau			Silty, fine to med sandstones
Oligocene	0 - 250	Te Kuiti	Whaingaroa Zst			Calcerous, glauconitic siltstone
	0 - 210		Glen Massey	Glen Massey Sst		Silty, fine, calcerous sandstones
				Dunphail Zst		Mudstone, muddy sands and glauconitic sandstones
				Elgood Sst		Flaggy, glauconitic limestone and thin glauconitic sandstones
Eocene	0 - 150		Mangakotuku	Rotowaro Sst		Non-calcerous dark-grey siltstones, weathers to ochre-brown
	0 - 35			Pukemiro Sst		Grey-green very glauconitic fine sandstones
	0 -60			Glen Afton Sst		Light to medium grey, non-calcareous mudstone
	0 - 240		Waikato Coal Measures			Slightly carbonaceous mudstones (fireclay) interbedded with black/dark brown very carbonaceous mudstones; sub-bituminous coal.
				Ngaro		
				Renown		
				Kupakupa		
Mesozoic		New Castle	Greywacke			Indurated sandstones and siltstones. Common fossils

Hydro geologically, recharge in the Greywacke basement is mainly from the outcrop area flows through the aquifer in a northerly direction (**Figure 2**). The coal seams in the coal measures are the aquifers where the steady states flow through the aquifers is to the north. Meanwhile the intervening siltstones and mudstones are the confining aquitards. The formations overlying the coal measures act as a series of aquifers and aquitards. Recharge to these aquifers is through the outcrop to the west and south of the area. Tauranga and Waitemata Groups are the aquifers and aquitard respectively. Recharge occurs on ridges and flatter areas away from incised streams.

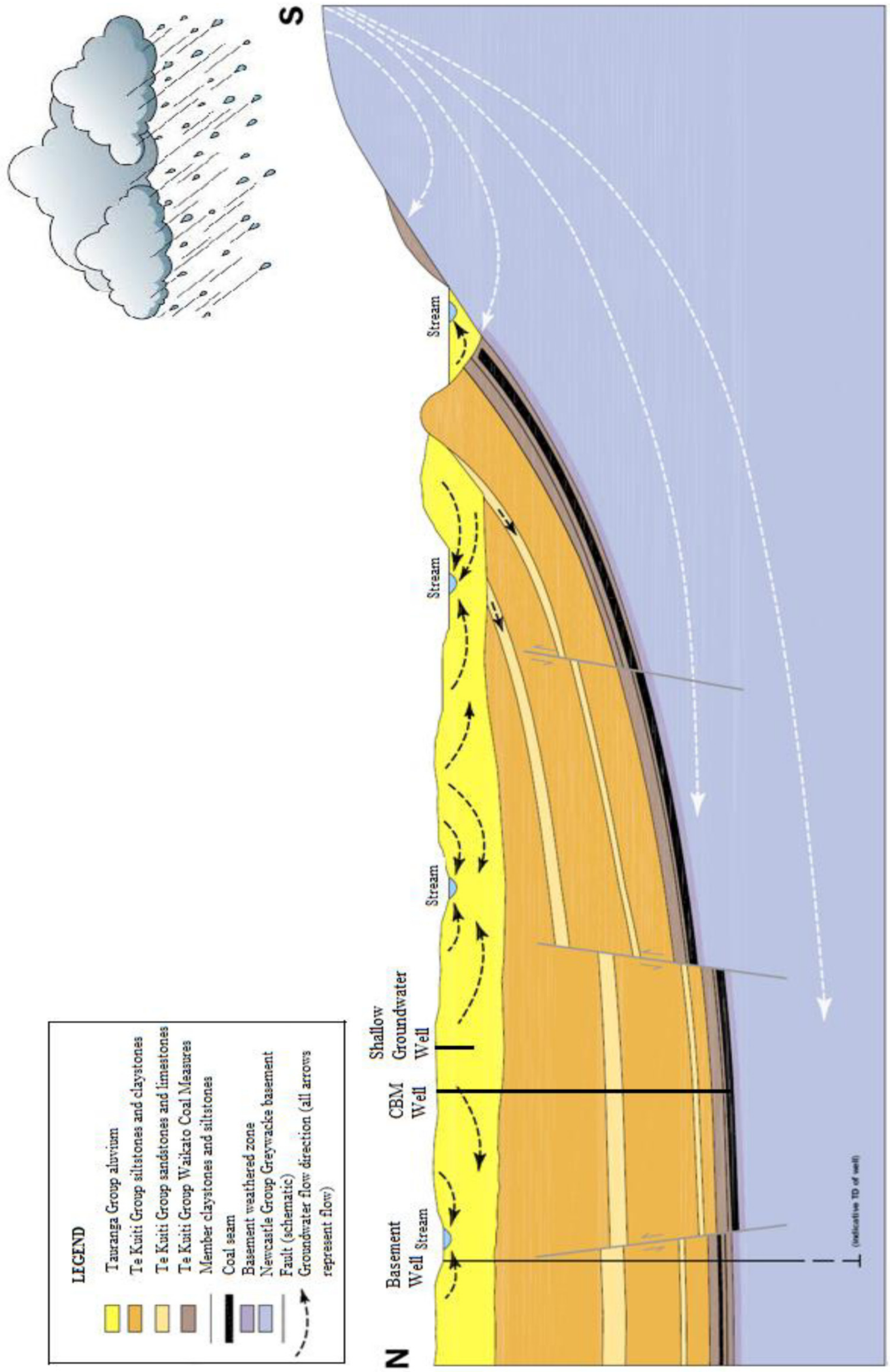

Figure 2—The model is showing Huntly hydrogeological setting (PDP, 2010), showing the Basment, CBM and ground water wells

Geochemical Assessment

Several geochemical assessment tools are carried out to analys produced water samples from ten wells in Huntly field and produced water samples from selected CBM basins. The assessments are including schoeller diagram, Cl-B-HCO3 ternary diagram (main) and Na-k-Mg geothermometer plot.

Produced water samples

Produced water samples were collected from the ten wells across the Huntly field, covering deep and shallow formations. The water sampling was carried out on September 2012 for basement water (with kind permission from Solid Energy New Zealand Ltd), on April 2012 for CBM water (with kind permission from Solid Energy New Zealand Ltd) and on October 2012 for shallower well (data courtesy of Waikato Regional Council, New Zealand). Table 2 lists the main components of produced water samples from each well in Huntly.

Table 2—The main components of different aquifers water from the Huntly coalfiled.

		ppm (parts per millions)						
Well	**ID**	**Ca2+**	**Mg2+**	**Na+**	**Cl-**	**SO42-**	**HCO3-**	**B**
Shallow groundwater	H1	3.9	3.6	19.8	18	2.6	62.1	0.013
CBM	CBM1	100	27	2100	3500	42	510	1.66
	CBM2	150	30	2500	5200	0.1	690	3.7
	CBM3	170	28	2420	5100	0.1	620	4.7
	CBM4	165	35	3000	5900	0.1	620	3.7
	CBM5	178	61	3100	5900	0.1	460	2.7
	CBM6	210	26	1920	3000	0.1	780	2.4
Basement	B1	220	0.45	1100	430	18	83	15.5
	B1	230	0.46	1100	580	18	70	15
	B1	220	0.46	1100	590	18	72	14.2
	B1	230	0.45	1000	590	18	69	14.3
	B1	220	0.46	1000	510	18	71	15
	B1	230	0.45	1000	520	18	71	14.2
	B1	220	0.46	1100	520	18	68	14.2

On top of that, some CBM produced water samples from other CBM basins in the world (Powder River basin, San Juan basin, Raton, Atlantic Rim, Liulin, Alberta and Maramarua) are collected from peer reviewed literature for comparison study. Table 3 lists the main components of CBM produced water components from different CBM basins.

Table 3—CBM produced water properties from selected CBM basins from around the world

Country	Basin	Average / Range Concentration (mg/L) Ca^{2+}	Mg^{2+}	Na^{+}	Cl^{-}	SO_4^{2-}	HCO_3^{-}	B	Reference
US	Powder River	32.09	14.66	356	21	5.64	1080	0.17	
	San Juan	53.29	15.45	1610	624	25.73	3380	1.3	(Dahm et. al., 2011)
	Raton	14.47	3.31	989	787	14.75	1124	0.36	
	Atlantic Rim	12.73	7.32	824	336	0.45	1630	1.15	
New Zealand	Maramarua	6	0.9	334	146	0.7	435	2.5	(Taulis and Mike, 2004)
China	Liulin -Shanxi formation:								
	sx-1	20.36	24.24	1698.47	1984.8	49.54	1454.4		
	sx-2	23.34	31.09	1648.25	1849.7	168.4	1487.8		
	sx-4	19.8	31.05	1681.25	1917.8	141.9	1454.4		
	CLY1 (Oct)	21.38	35.85	1809	1526	85.15	2063		
	CLY2	13.25	17.22	1788	1491	16.26	2074		
	CLY4 (Oct)	19.02	19.74	1816	1800	6.22	1837	0.24 – 0.58	(Yang et. al., 2013)
	CLY7 (Oct)	26.75	18.9	2266	2554	16.74	1454		
	CLY1 (Dec)	12.47	26.17	1591	1248	25.35	1902		
	CLY4 (Dec)	11.07	15.18	1678	1678	6	1643		
	CLY7 (Dec)	24.21	18.17	2121	2554	3	1476		
	Liulin - Taiyuan Formation:								
	CLY9	17.96	8.11	1398	771.4	20.09	2225		
	CLY8	21.48	9.62	1450	912	0	2271		
Canada	Alberta:								
	Mannville Formation	379.7 – 2956	225 – 918.9	11511 – 32013	16967 – 52364	8.18 – 80.6	99 – 1646	6 – 30.6	(Cheung et. al., 2010)
	Horseshoe	5.1 – 279.9	1.2 – 35.5	97.3 – 4420	35.7 – 1700	3.34 – 260	197 – 8864	0.05 – 1.27	

Schoeller diagram

Schoeller diagram is a semi-logarithmic diagram of the concentrations of the main ionic constituents in water (SO_4, HCO_3, Cl, Mg, Ca, Na/K) in equivalents parts per million of solution (mg/l) (Schoeller, 1965). It is usually carried out for water quality assessment, groundwater/surface water study, mineral explorations and wastewater potential study (Schoeller, 1965). In CBM industry, schoeller diagram is used to identify the signature of CBM produced water for evaluating the potential of methane production in wells (Rice et. al., 2000; Van Voast, 2003). Usually, CBM water signatures from methane producing CBM basin are showing low sulfate and primarily with chloride, bicarbonate and sodium (Rogers, 1994; Van Voast, 2003).

Figure 3 shows the analysis produced water samples from ten different wells in Huntly field. It is shown that there are three distinct patterns of anions and cations concentration from the water samples collected. These patterns imply that there are three different sources of water detected from the collected water samples.

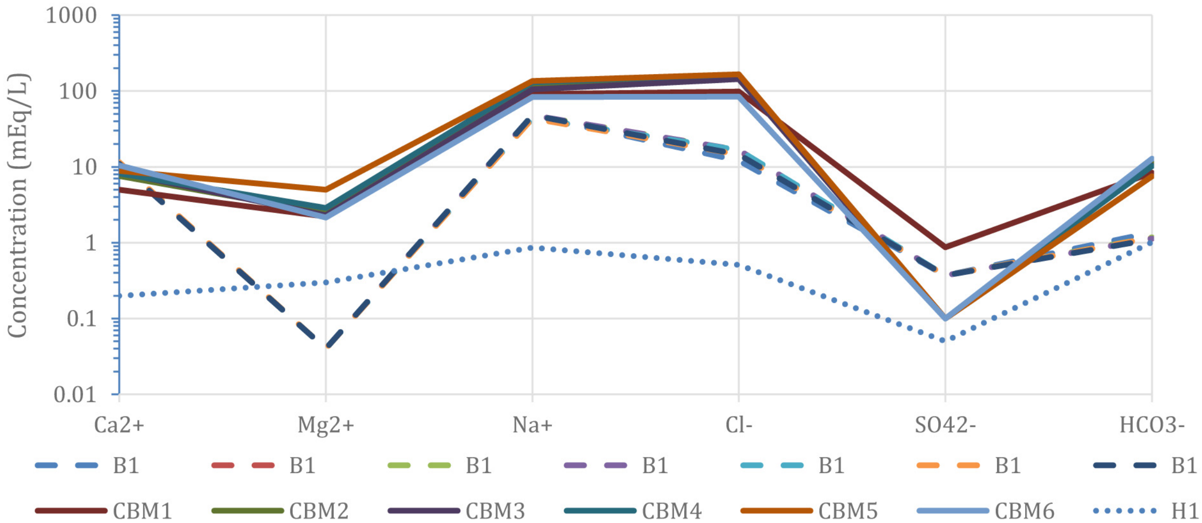

Figure 3—The schoeller diagram showing the different waters (aquifers) chemistry from the Huntly coalfield.

The first pattern indicates water samples from the shallow monitoring well, H1. It is observed that water sample has the principal constituents of bicarbonate and sodium with the concentration of 1 mg/L for both ions. However, the rest of the ions show lower than 1 meq/L concentration.

The second line pattern represents the anions and cations concentrations of water samples from the basement/injection well, B1. The water samples have high concentrations of sodium, chloride and calcium while the remaining ions show low concentrations (less than 1 mg/L). This water pattern shows that the water is saline.

Finally the third pattern is shown by CBM wells (CBM1- CBM6). The pattern of these water samples share about similar pattern and concentrations of anions and cations. They have high concentration of sodium, chloride and bicarbonate, low concentration of calcium and magnesium and lowest or near absence sulfate concentration. The CBM water samples are found more saline than basement water. This may be due to the water is from a reasonably isolated (capped) coal seams. However, the schoeller diagram (**Figure 3**) is not very useful when investigating potential mixing between the different aquifer

Figure 4 demonstrates the anions and cations concentrations pattern of CBM produced water from Huntly and selected CBM basins. It is found that all CBM water samples exhibit approximately similar CBM water patterns with moderate difference in concentration magnitudes. The diffrence concentration is due to seam permeability and its location near to the recharge area (Rice and Nuccio, 2000; Van Voast, 2003; Dahm et. al., 2011; Rogers, 1994).

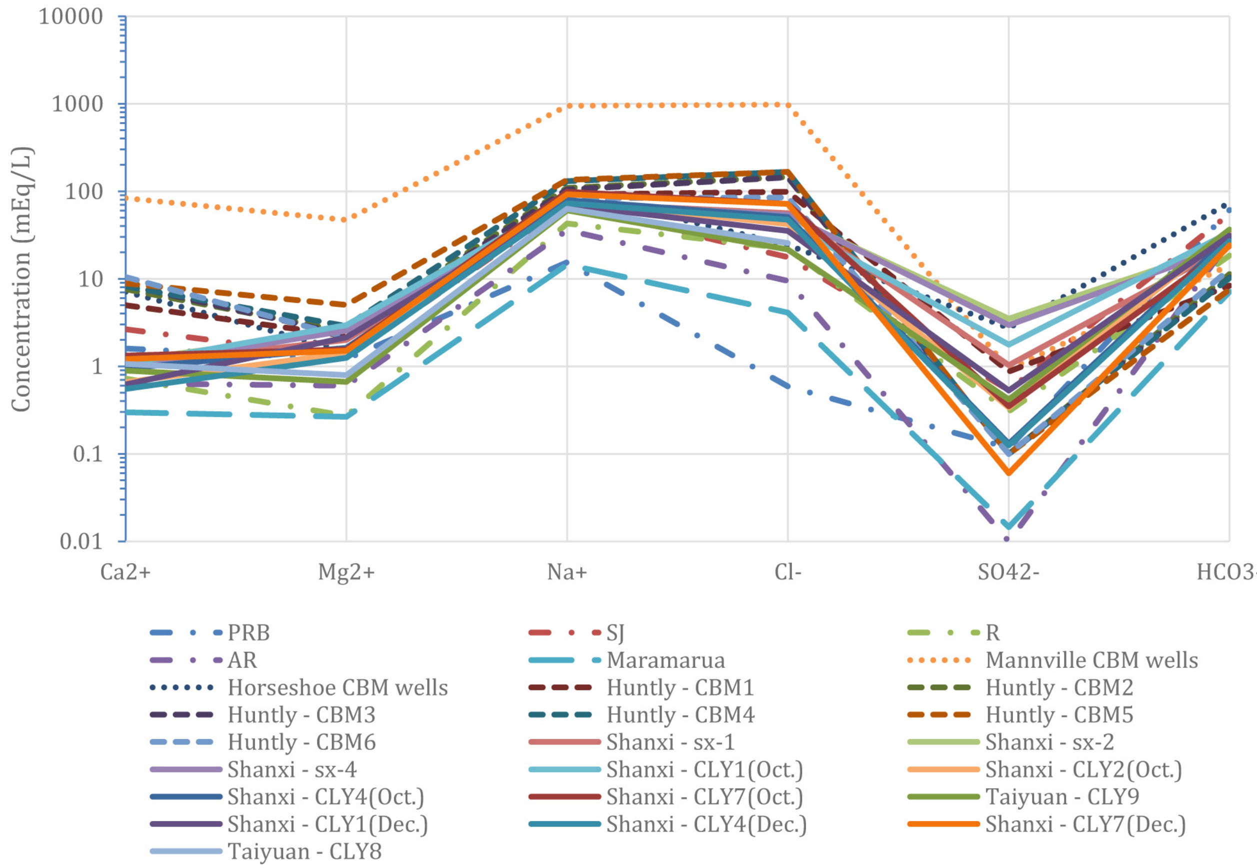

Figure 4—The schoeller plots of CBM water samples from different CBM basins around the world

Based on **Figure 4**, CBM water samples from Huntly show comparable CBM water quality and pattern with all the producing CBM basins. The samples indicate high concentrations for most of the ions except bicarbonate. The water samples also show close water pattern and water type (Na-Cl) to Manville CBM water yet exhibit significant differences in magnitudes. The magnitude differences may due to coal seam distance/location from recharge area (Dahm et al., 2011) or discontinuity degree in the coal seams (Rogers, 1994). It is observed that Manville CBM water has the highest magnitude for almost all ions except for bicarbonate. The water has very high salinity (up to 1000 mEq/l of chloride) and exhibit Na-Cl water type. Unlike CBM water from Horseshoe, the water sample shows significant quality difference from Manville eventhough the samples are from the same CBM basin. The water sample shows less saline and Na-HCO_3 water type. The concentrations difference may because of seams permeability and/or coal seams location. Horseshoe coal seam is shallower (up to 500m depth) relative to Manville (up to 1200m depth), thus it may have better contact with shallow groundwater or surface water (Cheung, et. al., 2010). Moreover, CBM water from Liulin has the concentrations of all ions in between CBM water from Huntly and Maramarua. The water samples are exhibiting a mixture of water types and quality. Some water samples show saline and Na-Cl water type (mostly from Shanxi samples) and others are less saline and Na-HCO_3 water type (Taiyuan samples). Apart from that, CBM water samples from United States basins are showing higher bicarbonate compared to chloride concentrations. These water samples are likely indicating Na-HCO_3 water types and low salinity. This pattern implies that CBM water from these basins has good connection with fresh/surface water. Finally, water sample from Maramarua shows the lowest concentrations for almost all ions except for chloride. The water is less saline and exhibits Na-HCO_3 water type. Na-HCO_3 water type has more potential to be re-used for other purposes (e.g. irrigation, livestock drinking, cooling tower water) and required less treatment compared to Na-Cl water. This is because the water has low salinity and safer to the environment compared to Na-Cl water.

Cl-HCO_3-B ternary diagram

Cl-HCO3-B ternary diagram is a diagram, which correlates three independent chemical constituents (chloride, bicarbonate and Boron) of water to provide some insights of the subsurface condition of a coalfield. This diagram demonstrates plots with inclined to Chloride, Boron and Bicarbonate are hosting coalbed water, basement water/deeper formation water and shallow groundwater respectively.

The concentration of Boron in fluids is related to the age of fluids in a subsurface. It is quite volatile in nature and is leached from rocks and organic matters at high temperature. It has been reported that Boron concentration shows some increments as temperature and depth increases (Kharaka, et al., 1985). Furthermore, fluids with high concentrations of Boron are relatively young (Huenges, 2010). Chloride on the other hand is a conservative element and its concentration will be relatively stable.

Apart from that, permeability and inter-aquifers communication information can be deduced from this diagram qualitatively. Plots that are inclined to chloride side are showing a discontinuity in the seams and/or poor permeability seams that leaves the water uncirculated (Rogers, 1994). Meanwhile, plots that closer towards bicarbonate side are signifying the water samples has relatively moderate to strong communication with shallow/surface water and are originated from good permeability seams. As for plots near to Boron, they indicate that the water samples are from low permeability formations and have some communication with deeper formation fluid.

From the explanation above, this diagram has a few advantages for the geochemical assessment of produced water. The advantages are as follows.

1. Predicting water samples origins,
2. Interpreting seams permeability qualitatively,
3. Understanding the coal seams communication with shallow and deep aquifers,
4. Water quality monitoring tool

The plots in **Figure 5** present the produced water samples from 10 Huntly wells in Cl-HCO3-B ternary diagram. It is found that there are three distinct data groups that exhibit different water chemistry.

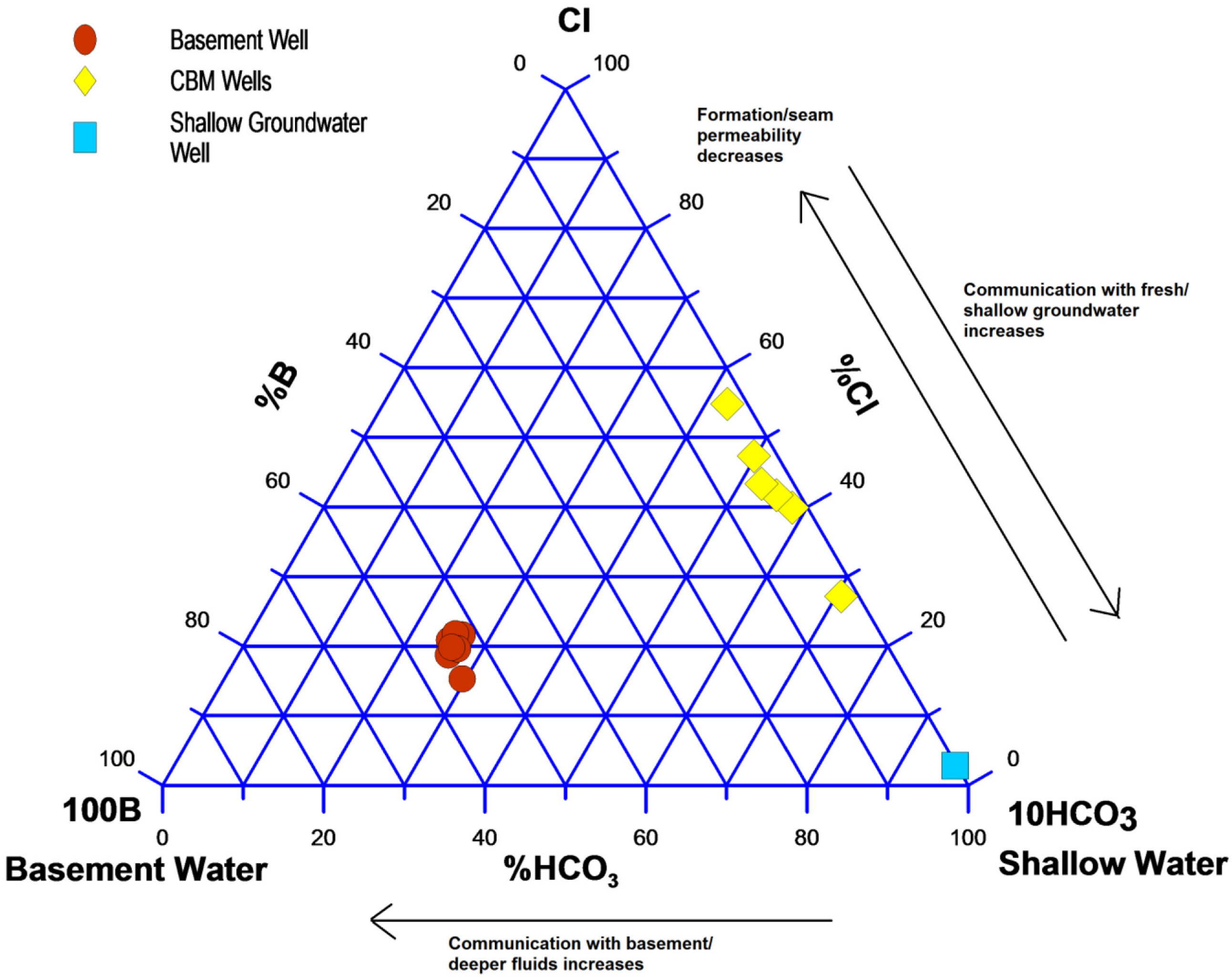

Figure 5—The ternary plot indicates water chemistry of 10 Huntly wells

The first data group belongs to the water samples from CBM wells (CBM1 - CBM6) completed in the coal seams. The wells are 400 m to 450 m deep cased (7″) through the coal seams then perforated and fracture stimulated into the target coal seams. The water samples contain the highest chloride concentration followed by moderate bicarbonate and low Boron. This indicates that these water samples are likely to be CBM water coming from low to moderate permeability of coal formations since the plots are placed in the middle along chloride-bicarbonate axis. It also implies that water samples from these wells have moderate communication with shallower water and reasonably isolated from basement water. Well CBM6 is observed to have the strongest communication with shallower water compared to the other CBM wells in the field. This is likely to be related to a shallow perforation hole in the casing, which was used to squeeze cement due to a bad cement job.

The second data group shows water samples from well B1. This is a CBM water reinjection well drilled into the Greywacke basement for wastewater disposal. The well has a 7″ casing with more than 700 m total deepth and cased/cemented about 50 meters into the basement with about 200 meters of open hole with a 4 1/2″perforated liner. The well was produced for few months as it was used for the drilling of other wells, and hence representative samples were collected and analysed. The water contains the highest Boron concentration, moderate concentration of bicarbonate and chloride ions. It is the Greywacke basement water originated from a quite low permeability basement formation.

The last group represents data from shallow (60m to 90m) ground water monitoring well (H1). The water sample has the highest concentration of bicarbonate with low concentration Boron and chloride. It is the shallower water originated from a good permeability shallow aquifer which is normally used for farm animals drinking water and for irrigation. In addition, low Boron indicates well H1 has no reasonable communication with basement water.

Figure 6 on the other hand represents the water chemistry of CBM water from CBM wells of Huntly and selected CBM basins. The purpose of this plot is to compare the permeability and the CBM water communication behavior among CBM water from different CBM basins.

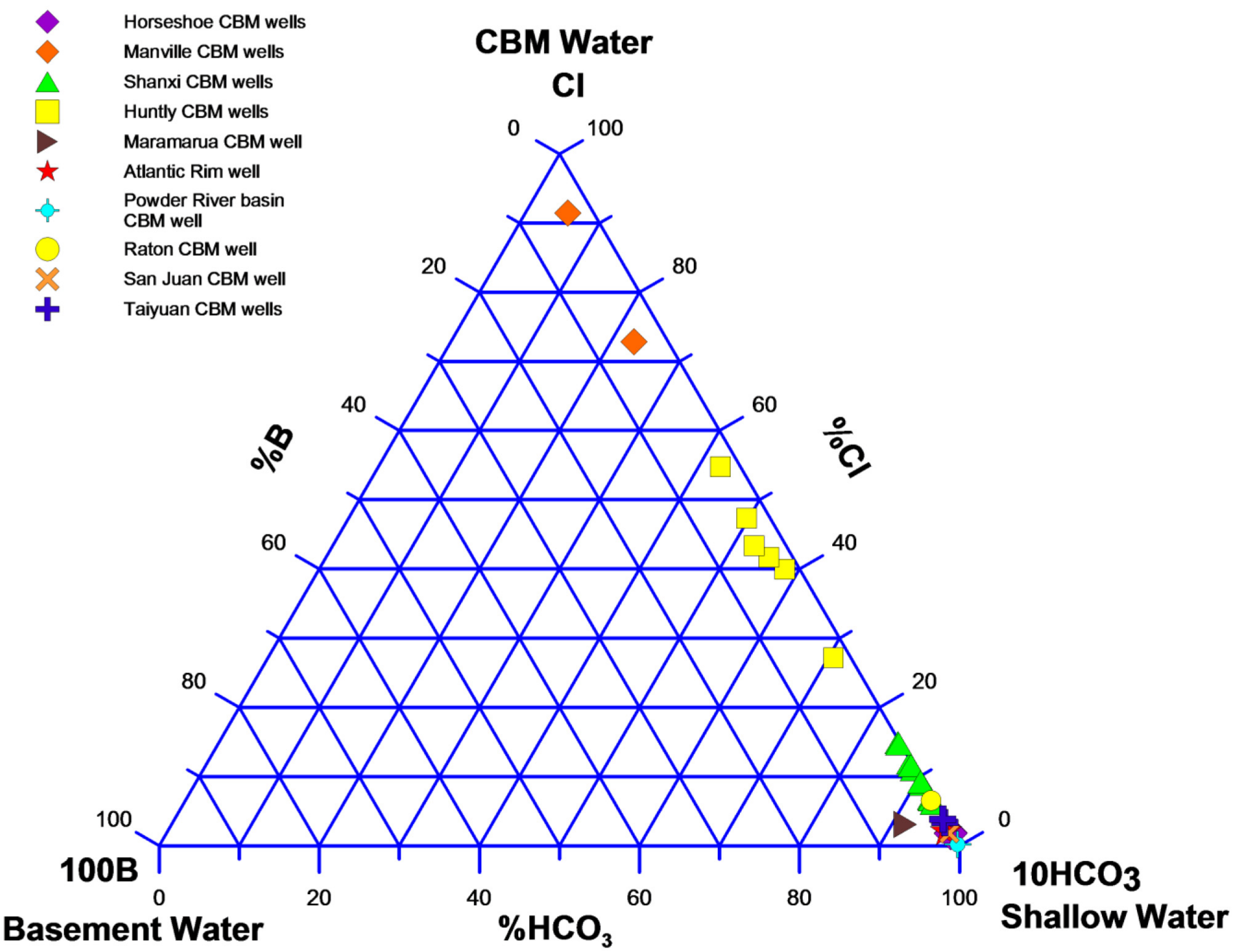

Figure 6—The plots of CBM water samples from different CBM basins in Cl-HCO_3-B, showing the CBM water is different from basement waters.

Based on the diagram, there are three clear groups of CBM water types. The first group belongs to the CBM water samples from Manville wells. It shows that the data inclines towards chloride implies that this water comes from low permeability formation/coal seam. It has less contact with the shallow/ surface water. On the other hand, the second group belongs to CBM water from Huntly wells. The plots are located in the middle between chloride and bicarbonate. These plots are showing that this water has moderate contacts with shallow/surface water and originated from average permeability formation/seam. Finally, the third group comprising of CBM water samples from Taiyuan, PRB, SJB, Raton, Atlantic rim, Maramarua and Shanxi wells. The plots are closer to bicarbonate side, which indicate that the CBM water is likely from good permeability coal seams and has strong communication with shallow/surface water.

The diagram also shows that there is minimum or no CBM water communication with deeper/basement fluids. All water samples show very low Boron concentrations (less than 5%).

Na-K-Mg ternary diagram

Na-K-Mg ternary diagram combines Na-K geothermometer with the K-Mg geothermometer (Powell and Cumming, 2010). It is used to classify waters and infer reservoir temperature according to the state of equilibrium at given temperatures (Giggenbach, 1988; Powell and Cumming, 2010).

There are three distinct water regions presented in the diagram including fully equilibrated water, partially equilibrated water and immature water. Fully equilibrated water indicates that the minerals in the water have reached fluid-rock equilibrium condition and is normally selected as geothermometers (Giggenbach, 1988; Powell and Cumming, 2010). Partially equalibrated water meanwhile signifies that mineral has dissolved and equilibrium reactions have set in, but equilibrium has not been reached (Giggenbach et al., 1983). It is also suggested that a mixture of equilibrium water with dilute unequilibrated water, such as cold groundwater (Giggenbach, 1983). As for immature water region, it signifies either the water samples are cold groundwater, sodium contents of the water being too low or contaminated (Giggenbach, 1988).

Figure 7 shows an evaluation of Huntly water samples from 10 wells in Na-K-Mg diagram. It is identified that most of the water samples are plotted within the partially equilibrium region. Water samples from well B1 meanwhile, are found in the fully equilibrated region, which are good as ionic geothermometers. The water sample from well H1 is located in the immature water region. It may be due to water sample was contaminated or cold.

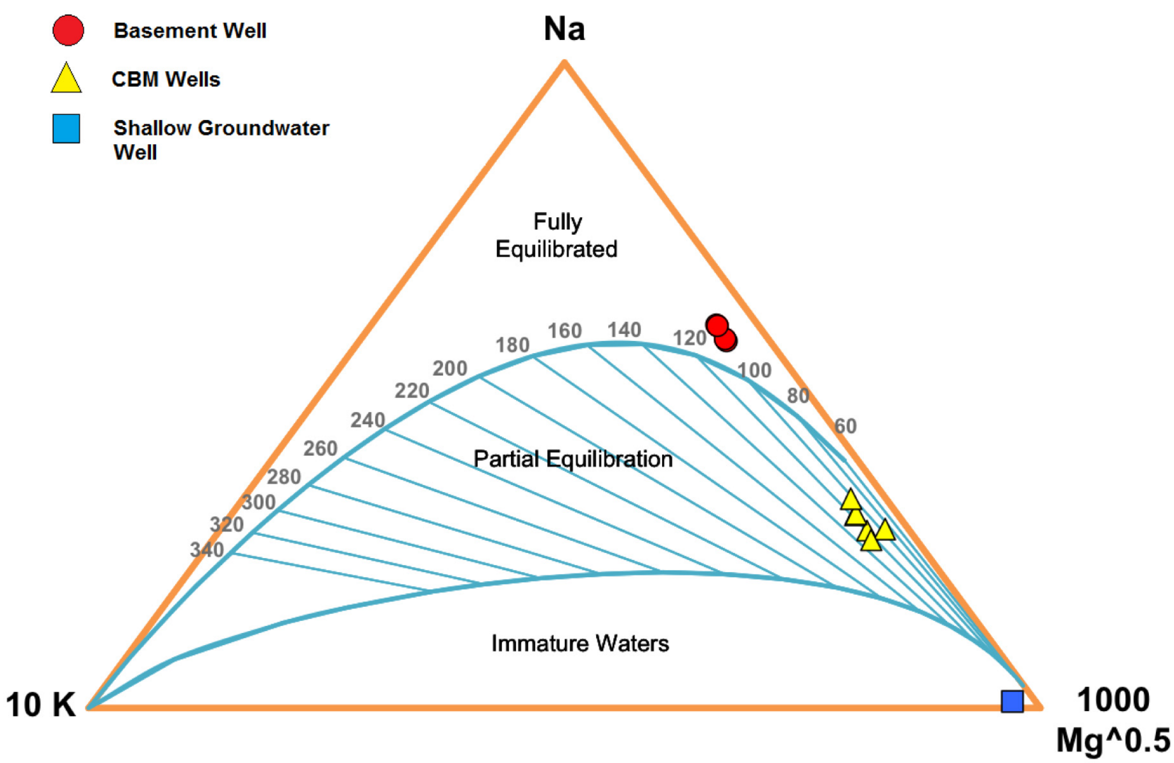

Figure 7—The Ma-K-Mg ternary diagram of water samples from Huntly wells, showing that: the Basment water Is fully equilibrated, the CBM water is partialy equilibrated and the immature ground water.

Furthermore, it is found that water samples from well CBM1 to well CBM6 exhibit estimated reservoir temperatures within range of 60°C to 110°C. As for water samples from well B1, the estimated temperature of the reservoir is around 100°C to 110°C. Note that these estimated temepratures are not representative since the measured stable temepratures are much less (see Zarrouk and Moore, 2007). However, Na-K-Mg ternary diagram provides another check/test on the origins of the water, within the same aquifer.

Figure 8 demostrates CBM water samples from Huntly and others selected CBM basins in Na-K-Mg ternary diagram. It is found that almost all CBM water samples are plotted within partial equilibrated region except water sample from Powder River Basin (PRB), which is slightly off the region. This may be due to sample contamination or sodium content being low.

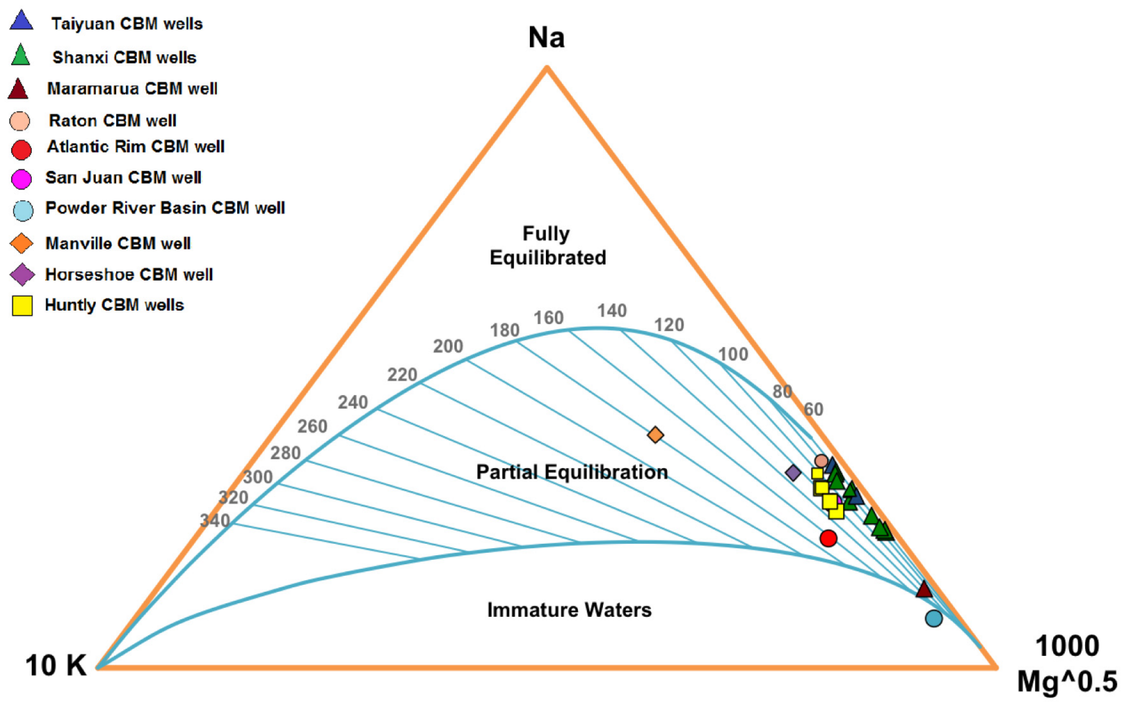

Figure 8—Na-K-Mg diagram of CBM water samples from Huntly and selected CBM basins around the world.

Conclusion

There are several conclusions that can be drawn from the water analysis carried out in this study.

1. The Cl-HCO3-B ternary diagram is a reliable tool for determining practical distinction of the origin of CBM produced water, coal seams permeability also to possible coal aquifers communication with deeper and shallow aquifers.
2. This ternary diagram can be used as water quality monitoring tool. For instance, shallow aquifer contamination can be detected when the water sample from the shallow monitoring well demonstrates some interactions with coal seams water or basement water (through faults).
3. Produced water samples from reinjection well, B1 exhibits basement water chemistry and distinct from CBM water as well as shallower water. Boron and chloride are the primary ions, which imply that these water samples came from a low permeability deep/basement formation and quite afar from recharge area.
4. Produced water samples from CBM wells (CBM1-CBM6) are showing CBM water signature with low sulfate and the predominant ions are sodium, bicharbonate and chloride. It is verified that Huntly CBM water samples exhibit similar water quality pattern with all selected CBM basins. The ions concentrations are comparable with Alberta and Liulin basins and higher than PRB, SJB,

Atlantic Rim and Maramarua. Furthermore, CBM water samples are signifying that they are from moderate permeability coal seams and have established some interactions with shallower waters.

5. Produced water from well H1 meanwhile indicates shallower immature water with very low Boron and high bicarbonate concentrations. It implies that the water is from a good permeability shallow aquifer and has no communication with the CBM with basement waters.

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