

**DATE** 18 July 2013**PROJECT No.** 13514250010.518/B.1**TO** Didier Fohlen  
Lydian International Ltd**CC****FROM** Gareth Digges La Touche**EMAIL** gdiggeslatouche@golder.com**AMULSAR GOLD PROJECT: MAJOR ION AND ISOTOPE ANALYSIS IN WATERS****Introduction**

Golder Associates (UK) Ltd has been commissioned by Lydian International Ltd to undertake a study to investigate the sources of water supplying selected water receptors in the Vorotan and Arpa river basins in the province of Vyots-Dzor, Armenia. Specifically the objectives of this study are to improve the understanding of:

- The source of water currently discharging from the Kechut-Spandaryan tunnel at its outfall to the Kechut Reservoir; and
- The source of waters flowing to the Jermuk thermal springs.

A water sampling program has been undertaken by Geoteam and samples have been analysed, at appropriate laboratories in the UK, for major ions and natural isotope signatures (Deuterium -  $\delta^2\text{H}$ , Oxygen 18 -  $\delta^{18}\text{O}$ , Carbon 13 -  $\delta^{13}\text{C}$  and Tritium).

Sampling and analysis was completed at five surface water locations, at the Jermuk hydrothermal springs and from two groundwater wells located at the peak of Amulsar mountain, and on the mountain flank. Sampling locations are summarised in Table 1 and shown in Figure 1.

**Table 1: Water Sampling Locations, June 2013**

Location	Easting	Northing	Water Type	Description
AW003a	568095	4391558	Surface water	Spandaryan Reservoir
AWJ001	559354	4411527	Surface water	Arpa river, upstream of Jermuk
AWJ4a	556330	4406912	Surface water	Kechut reservoir, upstream end
AWJ006	556312	4404800	Surface water	Kechut-Spandaryan tunnel outfall at Kechut
AW042	554978	4401388	Surface water	Gndevaz pond
DWJ6	557900*	4409900*	Drinking water	30° Gallery
RCAW408	560868	4397977	Groundwater	Amulsar Mountain
GGDW002	555310	4401315	Groundwater	Lower mountain slopes (proposed HLF site)

\*Indicative general location of the mineral water springs

Sample analysis was completed by Jones Environmental Laboratory (ISO 17025/ILAC accredited) with the exception of tritium and  $\delta^{13}\text{C}$  which were sub-contracted to appropriately accredited UK laboratories.



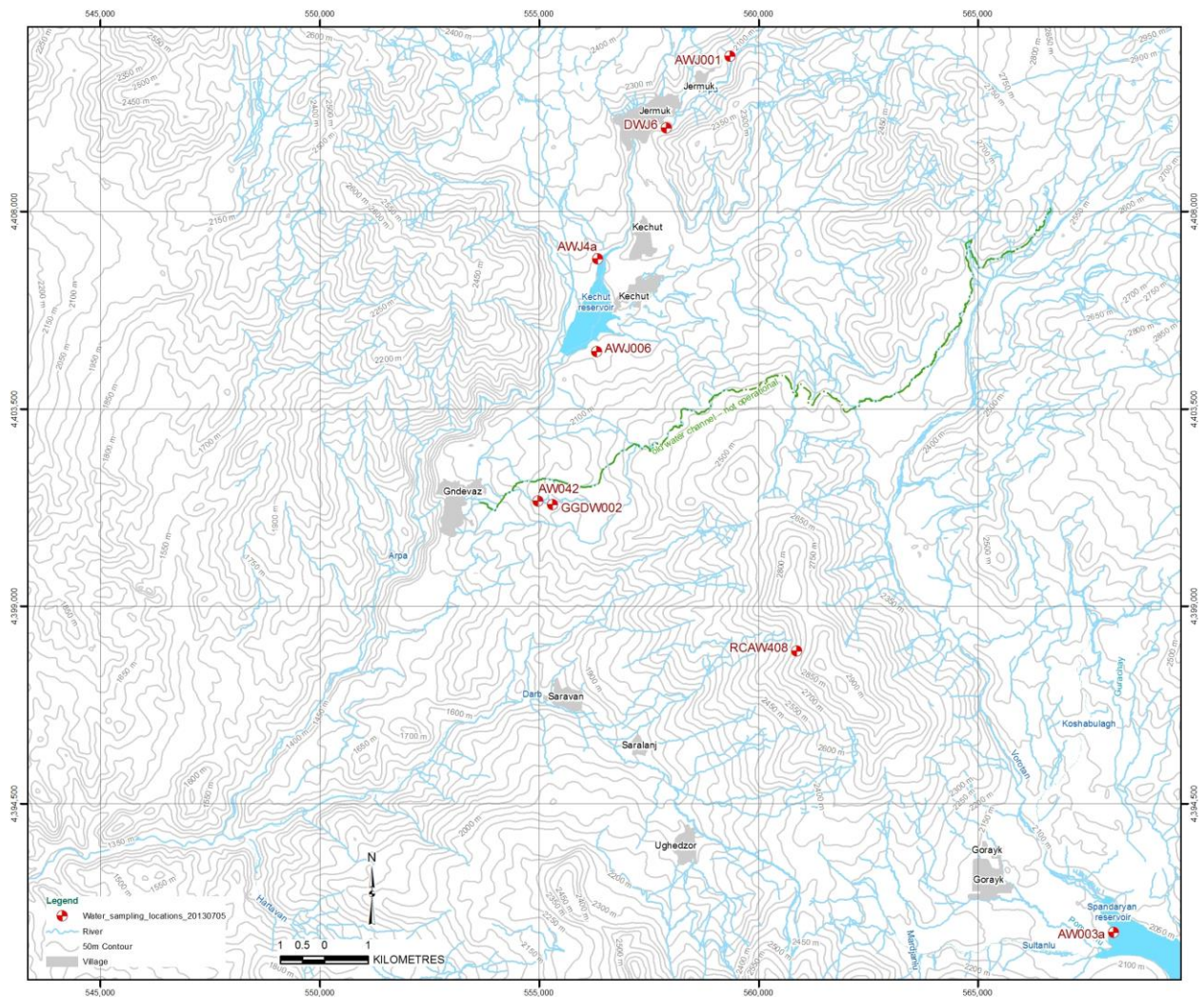


Figure 1: Water Sampling Locations

## MAJOR ION COMPOSITION

Major ion composition of the samples is illustrated in Piper and Durov diagrams (see Lloyd and Heathcote, 1985 for methodology) presented in Figures 2 and 3. Full analytical results are presented in Attachment A.

It is evident from Figures 2 and 3 that the chemistry of water discharging from the Spandaryan-Kechut tunnel is distinct to that in the Spandaryan reservoir. Water in the Spandaryan reservoir and Kechut reservoir are both  $\text{Ca-HCO}_3$  type water, consistent with a surface water sources from the Vorotan and Arpa rivers respectively, together with direct precipitation and runoff from the surrounding catchments. Water at the tunnel outfall, is distinct from that in the Spandaryan reservoir and has an elevated sulphate,  $\text{Ca-SO}_4$  signature indicative of the influence of oxidation of sulphide minerals and interaction with extrusive igneous rocks (Lloyd and Heathcote, 1985).

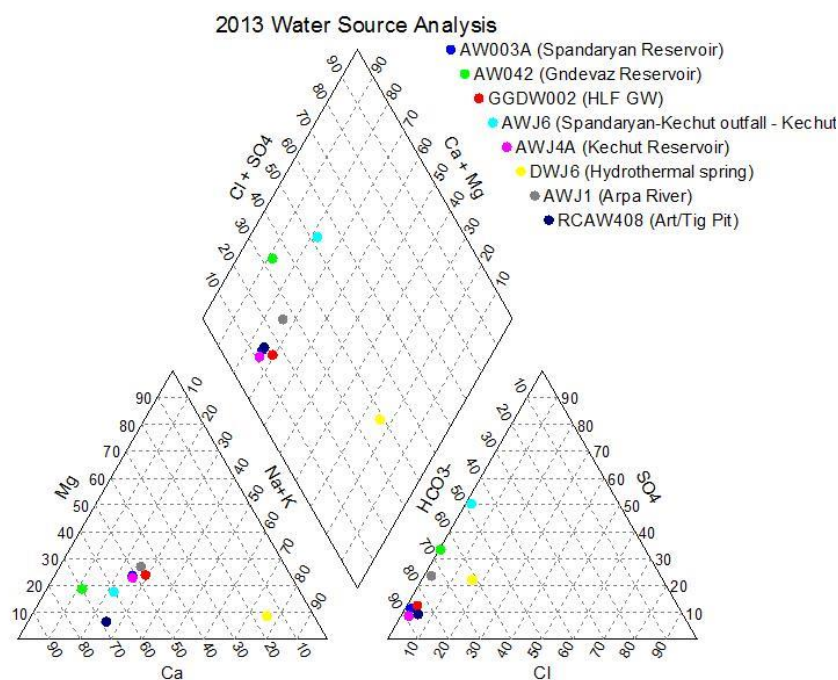


Figure 2: Piper Diagram of Major Ion Chemistry, June 2013 Samples

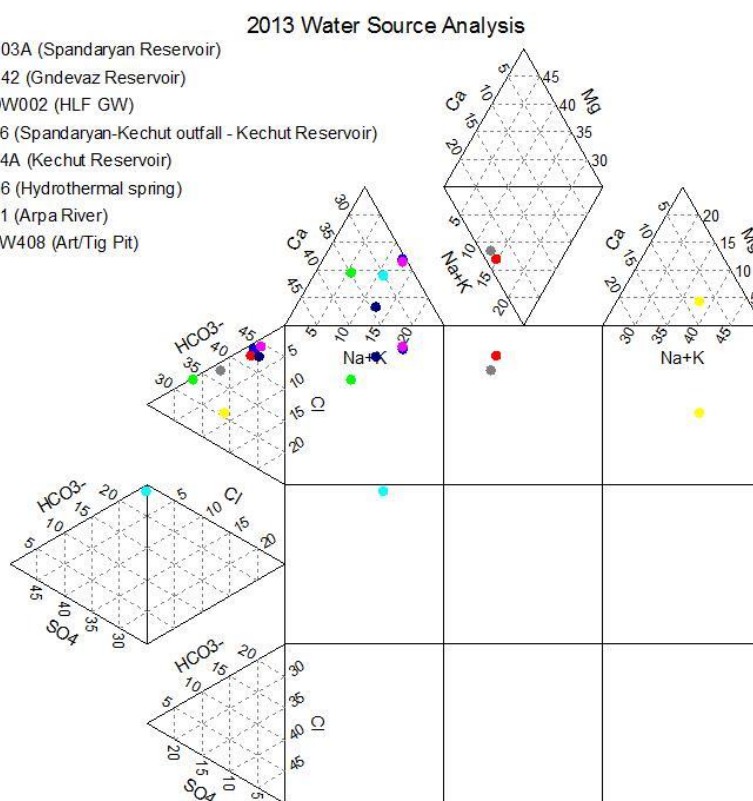


Figure 3: Durov Diagram of Major Ion Chemistry, June 2013 Samples



The sulphate enriched signatures of the waters may be indicative of the influence of acid drainage on the waters flowing in the tunnel, although the source of this drainage is not known. It is noted that a lead mine already intersects the tunnel, although little is known of this mine and the quality of any water discharging from it. Influence of naturally occurring acid drainage has been observed in waters discharging to the west and east of the peak of Amulsar mountain, but these springs are of small volume and groundwater in the intervening area does not show influence of acid drainage.

Water from the Jermuk springs is an evolved groundwater with elevated sodium, Na-HCO<sub>3</sub> type water. Such waters are indicative of the effects of ion exchange during groundwater transport, or potentially also may be indicative of interaction with CO<sub>2</sub> generation at depth (Lloyd and Heathcote, 1985). These waters are chemically distinct from waters in the upstream Arpa river, which may be expected to have an influence from shallow groundwater discharge in addition to surface runoff (as indicated by their higher magnesium and potassium concentration in comparison to downstream waters with a larger meteoric component). Although it is evident from their catchment geometry and position that the Jermuk springs are not fed by groundwater originating on Amulsar mountain area or from within the Vorotan river basin this interpretation is supported by the distinct groundwater chemistry.

## ISOTOPE GEOCHEMISTRY

Oxygen-18 and deuterium enrichment in the water samples is illustrated in Figure 4. Figure 4 also indicates the World Meteoric Water line (Craig, 1961) and the Mediterranean Meteoric Water line (Lloyd and Heathcote, 1985).

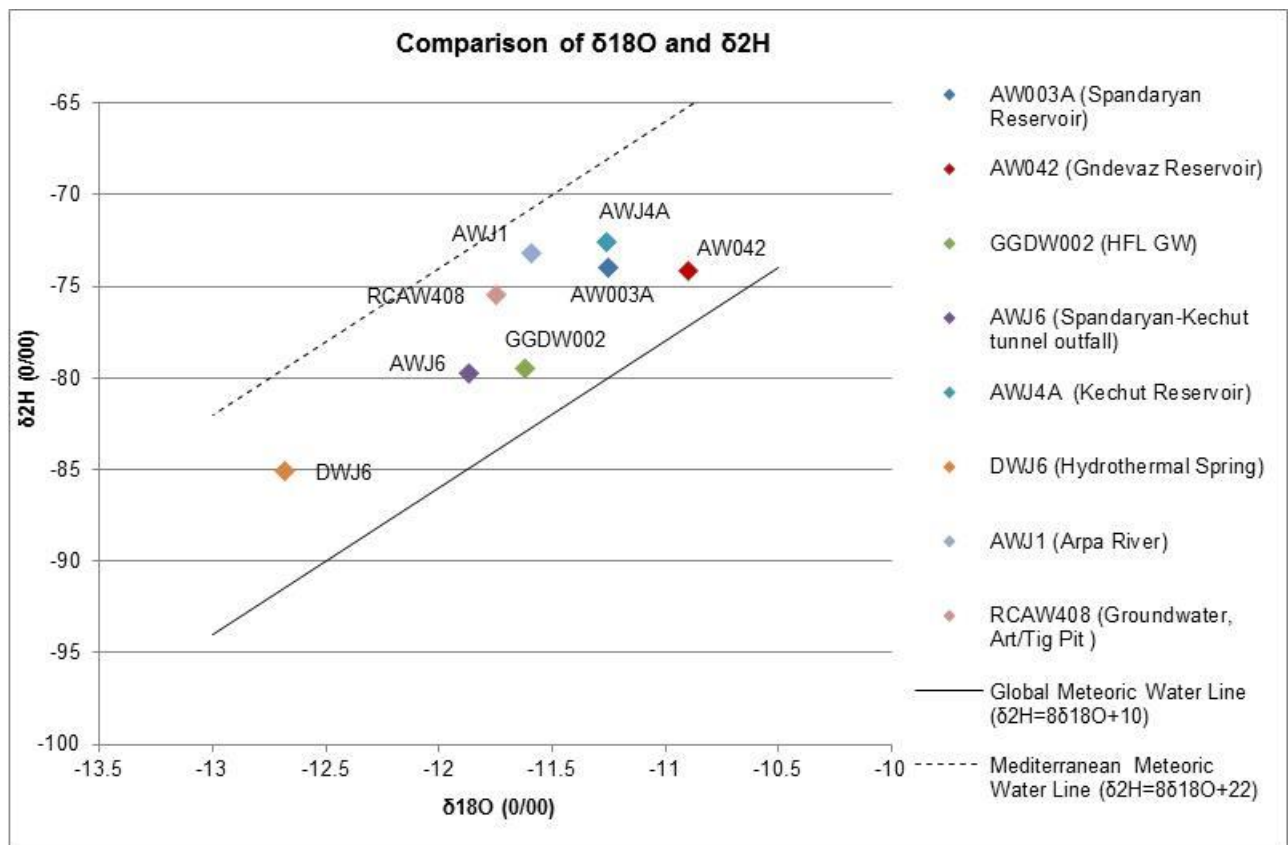


Figure 4: Oxygen-18 and Deuterium Enrichment in Water Samples

The isotopic composition of the spring water sample from Jermuk, DWJ6, has a depleted <sup>18</sup>O is typical of highly evolved hydrothermal waters. The <sup>2</sup>H:O ratio is consistent with the major ion data and is indicative of a more evolved “older” water and the <sup>2</sup>H:O ratio for surface water samples are consistent with a “younger” water suggestive of more recent recharge. The composition of AWJ6, from the Spandaryan-Kechut tunnel outfall, is distinct from that of the Spandaryan reservoir and is more depleted with respect to deuterium and <sup>18</sup>O than suggesting a different origin.

The results of  $\delta^{13}\text{C}$  and tritium analysis are shown in Table 2. Tritium was not detected in any water samples, this is consistent with water that is either modern (recent rainwater) or originated as rainfall pre 1950. Surface waters will reflect the modern tritium signature. In combination with the major ion chemistry shown above, it is likely that groundwater on Amulsar mountain is modern (recently recharged), whilst that at Jermuk springs is likely to be considerably more than 50 years old.

The majority of water sources studied are depleted in  $^{13}\text{C}$  in comparison to reference standards. In comparison, ratios of  $^{13}\text{C}:^{12}\text{C}$  are enriched in the Jermuk hydrothermal springs and are clearly distinct from other surface waters and groundwater sampled. This enrichment may indicate contact with metamorphosed carbonate rocks, or in an environment where carbonates are absent, contact with deep, metamorphic fluids containing  $\text{CO}_2$  of mantle origin (Marques et al, 2003).  $\delta^{13}\text{C}$  values indicate that the source of the Jermuk spring waters is distinct from groundwater's in the vicinity of Amulsar mountain.

Groundwater from Amulsar mountain has a highly depleted  $^{13}\text{C}:^{12}\text{C}$  ratio, this is likely to be due to the absence of carbonate in rocks in the mountain area, such that the little carbonate present in groundwater on the high mountain peak derives from breakdown of organic material.

**Table 2: Tritium and  $\delta^{13}\text{C}$  Analysis Results, June 2013 Samples**

Sample ID	Location	Tritium Bq/l	$\delta^{13}\text{C}(\text{‰})$
AW003A	Spandaryan Reservoir	<10	-10.75
AW042	Gndevaz Reservoir	<10	-9.34
GGDW002	Groundwater, proposed HLF location	<10	-11.61
AWJ6	Spandaryan-Kechut tunnel outfall	<10	-6.86
AWJ4A	Kechut Reservoir	<10	-8.12
DWJ6	Hydrothermal spring	<10	5.54
AWJ1	Arpa River	<10	-7.30
RCAW408	Groundwater, proposed pit area	<10	-16.66

## CONCLUSION

The geochemical analysis completed suggests that water discharging from the Spandaryan-Kechut tunnel is chemically distinct from waters in the Spandaryan Reservoir and represents a more evolved water chemistry suggestive of groundwater.

The analysis also indicates that the chemistry of waters in the Jermuk thermal springs is characteristic of hydrothermal waters, with a  $\text{Na-HCO}_3$  signature and depleted  $\delta^{18}\text{O}$ . The spring waters also have an enriched  $\delta^{13}\text{C}$  signature which is clearly distinct from other groundwater sampled. This water type is not similar to groundwater encountered in the vicinity of Amulsar mountain.

## REFERENCES

Craig, H., 1961. Isotopic variations in meteoric waters. *Science* 133 (3465) pp. 1702–1703.

Lloyd, J. W. and J. A. Heathcote, 1985. *Natural inorganic hydrochemistry in relation to groundwater: An Introduction*. Oxford University Press, New York.

Marques, J. M., Andrade, M., Carreira, P.M., Graca, R.C., Aires-Barros, L. 2003. Questions and answers about the evolution of CO<sub>2</sub>-rich thermomineral waters from Hercynian granitic rocks (N-Portugal): a review. *In* Krasny, J. and Sharp, J.M. (Ed), 2003. *Groundwater in fractured rocks: selected papers from the Groundwater in Fractured Rocks International Conference, Prague, 2003*.



Hollie Garrick  
Hydrogeologist

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Attachments: Attachment A: Final Laboratory Reports – Water Samples

## **ATTACHMENT A**

### **Final Laboratory Reports – Water Samples**



# Jones Environmental Laboratory

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No.4225

<b>Attention :</b>	Joanna Birch
<b>Date :</b>	17th July, 2013
<b>Your reference :</b>	Armenia
<b>Our reference :</b>	Test Report 13/5700 Batch 1
<b>Location :</b>	Geoteam CJSC
<b>Date samples received :</b>	20th June, 2013
<b>Status :</b>	Final report
<b>Issue :</b>	1

Eight samples were received for analysis on 20th June, 2013. Please find attached our Test Report which should be read with notes at the end of the report and should include all sections if reproduced. Interpretations and opinions are outside the scope of any accreditation, and all results relate only to samples supplied.

All analysis is carried out on as received samples and reported on a dry weight basis unless stated otherwise. Results are not surrogate corrected.

## Compiled By:

**Jamie Williams B.Sc**  
**Project Co-ordinator**

**Bob Millward B.Sc FRSC**  
**Principal Chemist**



***Client Name:*** Golder Associates Ltd  
***Reference:*** Armenia  
***Location:*** Geoteam CJSC  
***Contact:*** Joanna Birch  
***JE Job No.:*** 13/5700

**Report : Liquid**

**Liquids/products:** V=40ml vial, G=glass bottle, P=plastic bottle  
H=H<sub>2</sub>SO<sub>4</sub>, Z=ZnAc, N=NaOH, HN=HNO<sub>3</sub>

J E Sample No.	1-3	4-6	7-9	10-12	13-15	16-18	19-21	22-24			Please see attached notes for all abbreviations and acronyms		
Sample ID	AW003A	AW042	GGDW002	AWJ6	AWJ4A	DWJ6	AWJ1	RCAW408			LOD	Units	Method No.
Depth													
COC No / misc													
Containers	P	P	P	P	P	P	P	P					
Sample Date	13/06/2013	13/06/2013	13/06/2013	13/06/2013	13/06/2013	13/06/2013	13/06/2013	13/06/2013					
Sample Type	Surface Water	Surface Water	Ground Water	Surface Water	Surface Water	Surface Water	Surface Water	Ground Water					
Batch Number	1	1	1	1	1	1	1	1					
Date of Receipt	20/06/2013	20/06/2013	20/06/2013	20/06/2013	20/06/2013	20/06/2013	20/06/2013	20/06/2013					
Dissolved Calcium #	7.1	14.1	39.2	51.8	4.8	147.6	6.6	8.4			<0.2	mg/l	TM30/PM14
Dissolved Magnesium #	2.0	2.3	12.2	9.3	1.3	50.8	2.3	0.5			<0.1	mg/l	TM30/PM14
Dissolved Potassium #	1.5	0.7	2.5	3.1	0.9	89.0	1.2	1.0			<0.1	mg/l	TM30/PM14
Dissolved Sodium #	3.1	2.2	26.7	19.8	2.2	787.9	3.5	3.0			<0.1	mg/l	TM30/PM14
Sulphate #	4.02	16.44	24.32	97.28	2.01	552.10	8.24	2.76			<0.05	mg/l	TM38/PM0
Chloride #	0.5	<0.3	4.8	2.8	0.4	301.2	0.6	1.1			<0.3	mg/l	TM38/PM0
Total Alkalinity as CaCO3 #	32	34	170	96	21	1592	27	26			<1	mg/l	TM75/PM0
Total Cations	0.69	1.01	4.19	4.29	0.47	48.09	0.70	0.62				None	TM0/PM0
Total Anions	0.74	1.01	4.03	4.02	0.48	51.80	0.73	0.61				None	TM0/PM0
% Cation Excess	-3.1	-0.4	1.8	3.2	-1.5	-3.7	-1.9	0.3				None	TM0/PM0
d Deuterium*	-74.02	-74.21	-79.53	-79.75	-72.58	-85.12	-73.21	-75.45				per mil	Subcontracted
d18 Oxygen*	-11.25	-10.90	-11.62	-11.87	-11.26	-12.68	-11.59	-11.75				per mil	Subcontracted
Tritium*	<10	<10	<10	<10	<10	<10	<10	<10			<10	Bq/l	Subcontracted

# NOTES TO ACCOMPANY ALL SCHEDULES AND REPORTS

JE Job No.: 13/5700

## SOILS

Please note we are only MCERTS accredited for sand, loam and clay and any other matrix is outside our scope of accreditation.

Where an MCERTS report has been requested, you will be notified within 48 hours of any samples that have been identified as being outside our MCERTS scope. As validation has been performed on clay, sand and loam, only samples that are predominantly these matrices, or combinations of them will be within our MCERTS scope. If samples are not one of a combination of the above matrices they will not be marked as MCERTS accredited.

It is assumed that you have taken representative samples on site and require analysis on a representative subsample. Stones will generally be included unless we are requested to remove them.

All samples will be discarded one month after the date of reporting, unless we are instructed to the contrary. If we are instructed to keep samples, a storage charge of £1 (1.5 Euros) per sample per month will be applied until we are asked to dispose of them.

If you have not already done so, please send us a purchase order if this is required by your company.

Where appropriate please make sure that our detection limits are suitable for your needs, if they are not, please notify us immediately.

All analysis is reported on a dry weight basis unless stated otherwise. Results are not surrogate corrected. Samples are dried at 35°C ±5°C unless otherwise stated. Moisture content for CEN Leachate tests are dried at 105°C ±5°C.

Where Mineral Oil or Fats, Oils and Grease is quoted, this refers to Total Aliphatics C10-C40.

Where a CEN 10:1 ZERO Headspace VOC test has been carried out, a 10:1 ratio of water to wet (as received) soil has been used.

## WATERS

Please note we are not a Drinking Water Inspectorate (DWI) Approved Laboratory. It is important that detection limits are carefully considered when requesting water analysis.

UKAS accreditation applies to surface water and groundwater and one other matrix which is analysis specific, any other liquids are outside our scope of accreditation

As surface waters require different sample preparation to groundwaters the laboratory must be informed of the water type when submitting samples.

Where Mineral Oil or Fats, Oils and Grease is quoted, this refers to Total Aliphatics C10-C40.

## DEVIATING SAMPLES

Samples must be received in a condition appropriate to the requested analyses. All samples should be submitted to the laboratory in suitable containers with sufficient ice packs to sustain an appropriate temperature for the requested analysis. If this is not the case you will be informed and any test results that may be compromised highlighted on your deviating samples report.

## SURROGATES

Surrogate compounds are added during the preparation process to monitor recovery of analytes. However low recovery in soils is often due to peat, clay or other organic rich matrices. For waters this can be due to oxidants, surfactants, organic rich sediments or remediation fluids. Acceptable limits for most organic methods are 70 - 130% and for VOCs are 50 - 150%. When surrogate recoveries are outside the performance criteria but the associated AQC passes this is assumed to be due to matrix effect. Results are not surrogate corrected.

## NOTE

Data is only accredited when all the requirements of our Quality System have been met. In certain circumstances where the requirements have not been met, the laboratory may issue the data in an interim report but will remove the accreditation, in this instance results should be considered indicative only. Where possible samples will be re-extracted and a final report issued with accredited results. Please do not hesitate to contact the laboratory if further details are required of the circumstances which have led to the removal of accreditation.

**ABBREVIATIONS and ACRONYMS USED**

#	UKAS accredited.
B	Indicates analyte found in associated method blank.
DR	Dilution required.
M	MCERTS accredited.
NA	Not applicable
NAD	No Asbestos Detected.
ND	None Detected (usually refers to VOC and/SVOC TICs).
NDP	No Determination Possible
SS	Calibrated against a single substance.
SV	Surrogate recovery outside performance criteria. This may be due to a matrix effect.
W	Results expressed on as received basis.
+	AQC failure, accreditation has been removed from this result, if appropriate, see 'Note' on previous page.
++	Result outside calibration range, results should be considered as indicative only and are not accredited.
*	Analysis subcontracted to a Jones Environmental approved laboratory.
CO	Suspected carry over
OC	Outside Calibration Range
NFD	No Fibres Detected

**JE Job No** 13/5700

[illegible]

## LABORATORY REPORT

Prepared for: Lydian International Ltd.      Contact: Carl Nicholson

Iso-Analytical Ref No: **130620-1**

Client Ref:

Material: Water

Analysis: Carbon-13 of DIC

Date Arrived: 20/06/2013

Report Date: 09/07/2013

Prepared by: Charles Belanger

Results File: 130620-1-results.XLS

We have completed analysis of the samples. The results of analysis can be found as an e-mail attachment in MS Excel format. The analysis proceeded as follows:

### Carbon-13 Analysis of Dissolved Inorganic Carbon

For analysis, a suitable sample aliquot of filtered (0.2 micron) sample water was pipetted into Exetainer vials. The vials then had their headspaces flushed with pure helium (99.995%). After flushing, an appropriate amount of pure phosphoric acid was injected into the vials and the contents vortex mixed. The samples were left to react with the acid for 24 hours at ambient temperatures to ensure complete conversion to carbon dioxide.

The CO<sub>2</sub> gas was then analysed by continuous flow isotope ratio mass spectrometry. In brief, the CO<sub>2</sub> is flushed from the septum vial using a double holed needle and resolved on a packed column gas chromatograph. The carbon dioxide then enters the ion source of a Europa Scientific 20-20 IRMS and is ionised and accelerated. Here, gas species of different mass are separated in a magnetic field then simultaneously measured using a Faraday cup collector array at m/z 44, 45, and 46.

### Reference Standards and Quality Control

The reference gas used to determine the  $\delta^{13}\text{C}$  value of the CO<sub>2</sub> was IA-R060 ( $\delta^{13}\text{C} = -36.14\text{‰}$  vs. V-PDB). IA-R060 is traceable to NBS-19 ( $\delta^{13}\text{C}$  value of  $+1.95\text{‰}$  vs. V-PDB), which is distributed as an isotope reference standard by the International Atomic Energy Agency, Vienna. Samples of IA-R060 were analysed as check samples along with the samples for quality control. Results for the check samples have been supplied.



## Sample Storage and Disposal

The unused portion of the samples will be returned to you if you request us to do so; otherwise the samples will be placed in storage for a period of three months, after which time they will be disposed of.

If you require any further information regarding the analysis or wish to discuss any related issues, please do not hesitate to contact us.

Analysed & Reported by:

Checked by:

Charles Belanger, BSc

Steve Brookes, PhD

For and on behalf of:

**Iso-Analytical Limited**

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## LABORATORY REPORT: Results Files

### Client Details

*Name:* Lydian International Ltd  
*Contact:* Carl Nicholson

### Sample Details

*Number:* 8  
*Material:* Waters

### Sample Tracking

*IA Reference No.:* 130620-1  
*Date of Arrival:* 20-Jun-2013

### Analysis Details

*Isotope(s):* Carbon-13  
*Method:* ea-irms  
*Report Date:* 9-Jul-2013

## Carbon-13 of Dissolved Inorganic Carbon: Results

Sample Identification	Result $\delta^{13}\text{C}_{\text{V-PDB}}$ (‰)	Mean $\delta^{13}\text{C}_{\text{V-PDB}}$ (‰)
AWJ1	-7.17	
"	-7.43	-7.30
AWJ4a	-8.17	
"	-8.07	-8.12
AWJ6	-6.93	
"	-6.79	-6.86
AW003a	-10.53	
"	-10.98	-10.75
AW042	-9.30	
"	-9.39	-9.34
DWJ6	5.56	
"	5.51	5.54
GGDW002	-11.46	
"	-11.77	-11.61
RCAW408	-16.58	
"	-16.75	-16.66

## Quality Control Reference Standards

Reference Standard	Result $\delta^{13}\text{C}_{\text{V-PDB}}$ (‰)
IA-R060	-36.23
"	-36.30
"	-36.12
Mean=	-36.22
Accepted=	-36.14