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Study of Root Cause and Contributing Factors
Keystone Pipeline
Corrosion Anomaly Investigation
Final Report
2/13/2013

Prepared for:

TransCanada

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Executive summary

TransCanada operates the Keystone Pipeline which is a 3,460-kilometre (2,150 miles) pipeline that transports crude oil from Hardisty, Alberta to markets in the American Midwest at Wood River and Patoka in Illinois, and at Cushing, Oklahoma. The Canadian portion of the pipeline runs from Hardisty, Alberta east into Manitoba where it turns south and crosses the border into North Dakota. From North Dakota, the pipeline runs south through South Dakota and Nebraska. At Steele City, Nebraska, one arm of the pipeline runs east through Missouri for deliveries into Wood River and Patoka, Illinois; another arm runs south through Oklahoma for deliveries into Cushing, Oklahoma.

TransCanada identified a segment of the 30-inch liquids transmission line which had significant In Line Inspection (ILI) external corrosion indications in the Salisbury to Patoka segment in the area of Mile Post 995 to Mile Post 1000 in St. Charles County, Lincoln County and Audrain County, Missouri.

The ILI run that was completed in September, 2012 identified several joints with external metal loss anomalies; some reported to be greater than 50% of the nominal pipe wall. TransCanada completed several direct examinations of the identified anomalies in response to the ILI results and retained Mears Group, Inc. (Mears) to assess the Root Cause and contributing factors to the observed corrosion.

The 30-inch Keystone Pipeline experienced localized external corrosion wall loss due to D-C stray current interference[1]. The corrosion induced wall loss occurred at an accelerated rate that can only be attributable to D-C stray current interference, microbiologically influenced corrosion (MIC), or Induced A-C corrosion. MIC may have played a role in some of the observed corrosion however it was not the primary cause. Induced A-C corrosion did not play a role in the observed corrosion.

It is recommended that TransCanada complete a thorough interference and cathodic protection analysis to ensure that appropriate mitigation strategies can be developed and implemented.

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[1] Stray current corrosion may occur during construction as the pipeline is being installed, but has not been provided protection. PHMSA has issued an advisory bulletin to Operators offering guidance on this subject.

Table of Contents

Section Page

List of Tables

Table Page

List of Figures

1.0 INTRODUCTION

TransCanada identified a segment of the 30-inch liquids transmission line, designated as the Keystone Pipeline, which had significant In Line Inspection (ILI) external corrosion indications in the Salisbury to Patoka segment in the area of Mile Post 995 to Mile Post 1000 in St. Charles County, Lincoln County and Audrain County, Missouri.

The ILI run that was completed in September, 2012 identified several joints with external metal loss anomalies; some reported to be greater than 50% of the nominal pipe wall. TransCanada completed several direct examinations of the identified anomalies in response to the ILI results and retained Mears Group, Inc. (Mears) to assess the Root Cause and contributing factors to the observed corrosion. This report presents the findings and opinions regarding causation and contributing factors along with recommendations as deemed appropriate. All relevant supporting information is included along with results of testing performed on samples obtained by TransCanada at select direct examination sites.

The information, material and documentation reviewed and relied upon in the formation of the opinions expressed include:

- Pipeline Alignment Sheets,
- Google Earth Imagery,
- Cathodic Protection annual Survey results,
- Close Interval Survey Results,
- Foreign Pipeline Rectifier Information,
- Baker Hughes ILI Reports,
- RTD Dig Reports,
- Kiefner KAPA Analysis Reports,
- Photographic Documentation,
- Direct Examination Sample Testing Results, and
- TransCanada Repair Summary.

For the purpose of this analysis, direct examination data were considered for Dig Sites #1-8, 16 and 17.

2.0 BACKGROUND

TransCanada operates the Keystone Pipeline which is a 3,460-kilometre (2,150 miles) pipeline that transports crude oil from Hardisty, Alberta to markets in the American Midwest at Wood River and Patoka in Illinois, and at Cushing, Oklahoma. The Canadian portion of the pipeline runs from Hardisty, Alberta east into Manitoba where it turns south and crosses the border into North Dakota. From North Dakota, the pipeline runs south through South Dakota and Nebraska. At Steele City, Nebraska, one arm of the pipeline runs east through Missouri for deliveries into Wood River and Patoka, Illinois; another arm runs south through Oklahoma for deliveries into Cushing, Oklahoma. Deliveries to Wood River and Patoka began in the summer of 2010, and deliveries to Cushing began in February of 2011. A Map of the existing system is shown in Figure 1.

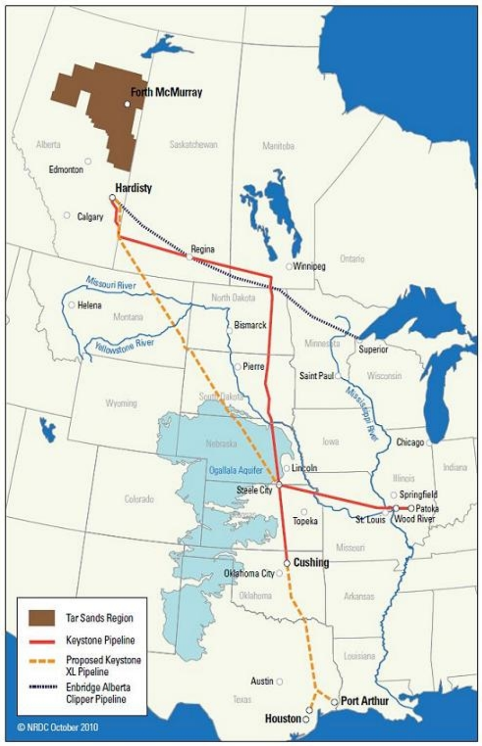

Figure 1. Keystone Pipeline System

The carbon steel pipeline was manufactured to API 5L X70 grade and is 30-inch diameter by 0.386 nominal wall. The pipeline has a Fusion Bonded Epoxy (FBE) external corrosion coating and utilizes a two part liquid epoxy girth weld coating. Cathodic Protection (CP) is afforded through impressed current ground beds. The pipeline is reported to have been constructed in 2009.

3.0 ROOT CAUSE ANALYSIS PROCESS

Although the pipeline did not experience a "failure" an adapted typical failure action sequence was used for the purposes of performing the Root Cause Analysis.

The basic role of a root cause analysis is as follows:

- Collect information.
- Understand what happened.
- Identify the problems that caused the incident.
- Analyze each problem's root causes.
- Look beyond root causes for systemic, cultural, and organizational factors.
- Develop recommendations for remediation to improve performance and prevent repeat incidents.

Since root cause analyses are normally associated with incidents or accidents, much of the existing terminology in use refers to "incidents". In this case, an accident did not occur and any reference to incident and incidents is a term of art and simply refers to the discovery of external metal loss corrosion anomalies.

A typical Failure Action Response Sequence adapted from Guidance for Plant Personnel on Gathering Data and Samples for Materials Failure Analysis MTI catalog MTI 9539 is shown in Figure 2.

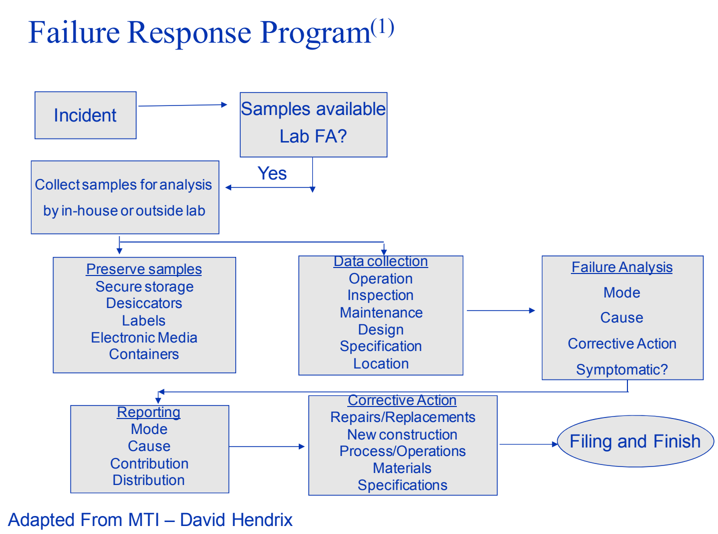

Figure 2. Failure Response Sequence

The root cause analysis focused on identifying the root cause(s) of the observed external corrosion and the contributing factors. Recommendations and guidance are provided with the goal of remediating the cause of the corrosion and monitoring the effectiveness of the recommended remedial measures.

4.0 DESCRIPTION OF INVESTIGATIVE PROCESS

The investigation into the cause and contributing factors to the observed external corrosion on the Keystone Pipeline has been undertaken through a review of available documents and information associated with the design, specification, construction, operation and maintenance of the pipeline infrastructure. Various dig site reports generated after the completion of the direct examinations were also reviewed.

Testing was performed on samples of pipe deposits in corroded areas on the pipe and soil samples obtained at previously mentioned Dig Sites. The data and information obtained from ten (10) ILI anomaly investigative digs was analyzed along with testing results for an assessment of microbial activity and elemental analysis of pipe deposits and soil samples in an effort to establish the root cause and contributing factors of the observed corrosion. Corrosion can often be characterized by the chemical, biological, and metallurgical features associated with the site. The type and form of corrosion is distinctively associated with morphology and supporting tests of elemental composition of pipe deposits.

The products and deposits obtained from areas of external corrosion at each of the dig sites along with soil samples were analyzed using a serial dilution MICKit V to assess for the presence and count (bacterium/ml) of five types of viable bacteria:

- Sulfate reducing bacterial (BIO-SRB),
- Acid producing bacteria (BIO-APB),
- Aerobic bacteria (BIO-AERO),
- Iron-related (depositing) bacteria (BIO-IRB), and
- Low-nutrient bacteria (BIO-LNB).

Supporting Analyses of deposits on the pipe was performed to assist in interpretation of MIC and other corrosion, or cathodic protection products using the MICkit IV. This kit is used to qualitatively analyze for the presence of carbonate (CO_3^{+2}), sulfide (S^{-2}), ferrous iron (Fe^{+2}), ferric iron (Fe^{+3}), calcium (Ca^{+2}), and hydrogen (H^{+1}, pH) ions. The details of the testing undertaken and the data obtained are included in this report.

5.0 DISCUSSION OF CORROSION RATES

A summary of the peak measured external wall loss at the 10 dig sites is shown in Table 1.

Table 1. Keystone Pipeline ILI Repair Summary

Site #	Type	MP	Feature	ILI Depth* %	Repair
1	Immediate	995.95	Corrosion	95	Plidco Clamp
2	Immediate	996.33	Corrosion	78	Armour plate
3	Immediate	1000.08	Corrosion	79	Armour plate
4	Immediate	1000.38	Corrosion	83	Armour plate
5	180-day	997.67	Corrosion	58	Armour plate
6	60-day	968.85	Dent with metal loss	2.5	Dec-12
7	180-day	925.81	Corrosion	42	Recoat
8	180-day	925.89	Corrosion	41	Recoat
16	180-day	999.97	Corrosion	42	Armour plate
17	Proximity to Site 4	1000.32	Corrosion	49	Recoat

* Indicates Tool Peak Measured Corrosion Depth

Excluding Dig Site #6, which was determined to be a dent with metal loss, the measured peak corrosion depth ranges from 30% (3mm) (116mils[2]) to 97% (9.5mm) (374mils). In the absence of specific data, linear growth rates[3] can be used to estimate the annual corrosion growth of external corrosion anomalies based on the peak metal loss depth divided by the years of exposure (Years since installation).

Using a linear corrosion growth rate and assuming corrosion initiated at the time of pipe installation, the external corrosion growth rate approached 4.75mm/yr (125mpy[4]). Absent accelerating factors, corrosion rates for carbon steel buried in soils are typically less than .25mm/yr (10mpy).

[2] A mil is equivalent to 1/1000th of an inch.
[3] Uncertainty as to when corrosion initiated, the effect of seasonal variation and CP effectiveness may contribute to errors in this approach however it can provide an approximation of growth rates.
[4] MPY is a mil/year and is equivalent to 1/1000 of an inch/year.

Data compiled in Table 2 from Uhlig's Corrosion Handbook lists corrosion rate data for carbon steel samples buried in soils of varying resistivity values and drainage conditions. Maximum general corrosion rates ranged from .022 to .064mm/yr (0.9 to 2.5mpy) while maximum pitting corrosion rates ranged from 0.18 to 0.45mm/yr (7.1 to 17.7mpy). Pitting rate data, although higher than general corrosion rates are still considerably lower than the rate experienced on the Keystone Pipeline.

Table 2. Corrosion Rate for Steel in Soil According to Soil Resistivity and Drainage

Environmental Factors	General Corrosion Rates, mpy			Pitting Corrosion Rates, mpy		
	Maximum	Minimum	Average	Maximum	Minimum	Average
Soil Resistivity						
Less Than 1,000	2.5	0.7	1.3	12.2	4.3	7.9
1,000 to 5,000	2.3	0.2	0.7	17.7	2.0	5.5
5,000 to 12,000	1.3	0.2	0.7	9.1	2.4	5.5
Greater Than 12,000	1.4	0.1	0.6	10.2	1.2	4.3
Drainage						
Very Poor	2.3	1.5	1.8	17.7	6.3	11.0
Poor	1.5	0.4	0.9	9.1	2.0	5.5
Fair	2.5	0.7	0.9	12.2	3.1	6.3
Good	0.9	0.1	0.4	7.1	1.2	4.3

One of the most comprehensive sources of corrosion data is contained in the US National Bureau of Standards Circular's C401 (Stray Current Electrolysis), C450 (Underground Corrosion) and C579 (Underground Corrosion). A recent publication by NIST (the National Institute of Science and Technology), the successor to National Bureau of Standards, republished the compiled corrosion rate data in a statistical manner. For the purposes of this analysis the data have been reproduced in Figure 3. These data clearly show that corrosion rates for carbon steel buried in soils do not approach the rates experienced on the Keystone Pipeline. These rates are even more surprising since they occurred in the presence of cathodic protection which is intended to control corrosion.

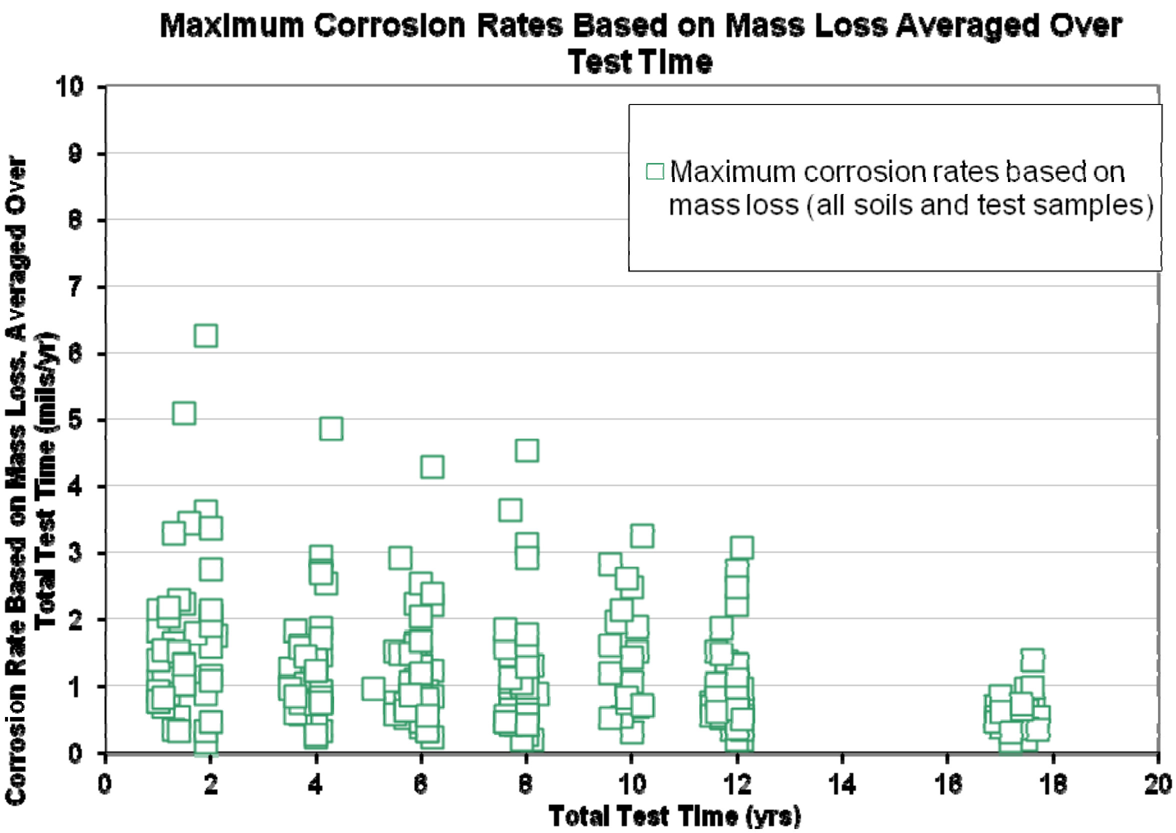

Figure 3. NIST Corrosion Rate Data

Establishing a reasonably conservative estimate of corrosion rates requires consideration for unique circumstances where corrosion of underground and submerged structures may be greatly accelerated. Mechanisms that can produce highly accelerated rates of corrosion on buried pipelines include:

- Microbially Influenced Corrosion (MIC),
- Stray Direct Current (D-C) Interference, and
- Stray Alternating Current (A-C) Interference.

MIC in soils has been documented to occur at rates approaching 4mm/yr (150mpy)). An example of the corrosion morphology associated with MIC is shown in Figure 4.

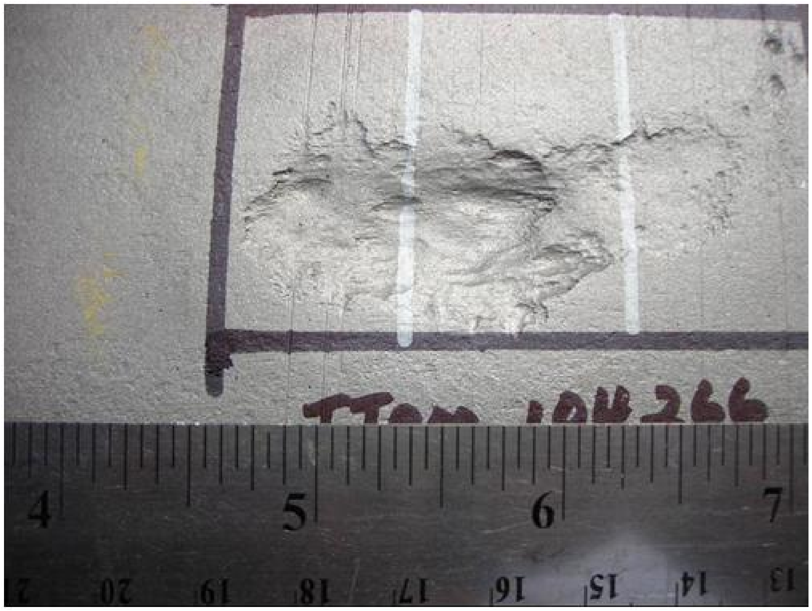

Figure 4. Typical MIC Morphology

The effects of stray direct current (D-C) on established corrosion rates cannot be readily quantified due to the significant metal removal power of D-C currents. Rates of 10mm/yr (250mpy) are expected. An example of the corrosion morphology associated with D-C interference current is shown in Figure 5.

Figure 5. Typical D-C Stray Current Corrosion Morphology

In recent years corrosion of carbon steel structures has been documented as a result of induced A-C caused by electromagnetic interference in collocated right-of-ways. Corrosion rates of 2.4mm/yr (60mpy) have been documented on pipelines with high quality dielectric coatings. Critical current densities of >20 amperes/m^2 are necessary for A-C assisted corrosion requiring pinhole defects in coatings to concentrate the current density. An example of the corrosion morphology associated with A-C interference current is shown in Figure 6.

Figure 6. Typical A-C Corrosion Morphology

5.1 Distinctive Features of Accelerated Corrosion Mechanisms

In addition to distinctive corrosion morphologies, accelerated corrosion mechanisms such as MIC, Stray D-C and Stray A-C interference have some notable characteristic features.

5.1.1 Microbially Influenced Corrosion (MIC)

MIC is characterized by "Dish Shaped" hemispherical pitting and the formation of corrosion products that can form tightly adherent nodules or tubercles above the pitted area. Ferrous corrosion occupies 6-10 times the volume of material lost in corrosion and therefore there is a characteristic build-up of corrosion product in the area due to the insolubility of iron oxides at the expected pH range of 3-5. Upon removal of the corrosion deposits, the pitted surface is characterized by the appearance of pits within pits and upon magnification; striations (linear indications) can be seen in the pitted area. The striations follow the rolling direction of the steel made into the pipe and is believed to be a result of preferential attack of the steel microstructural components. Active corrosion caused by MIC will produce pH values in the pitted areas of 3-5 and the appearance of the metal substrate will be clean and may be shiny.

5.1.2 Stray Direct Current (D-C) Interference

Stray D-C Interference also produces "Dish Shaped" hemispherical pitting, however, corrosion caused by Stray D-C is characterized by an absence of tubercles. Typical pH ranges are less than 2 and thus iron oxides are soluble in these ph environments. The effects of Stray D-C interference corrosion can be seen in the metallographic section shown in Figure 7. This metallographic section obtained from a corrosion leak site on a 4-inch diameter FBE coated pipeline subjected to Stray D-C shows characteristic "undercutting" of the coating to the left.

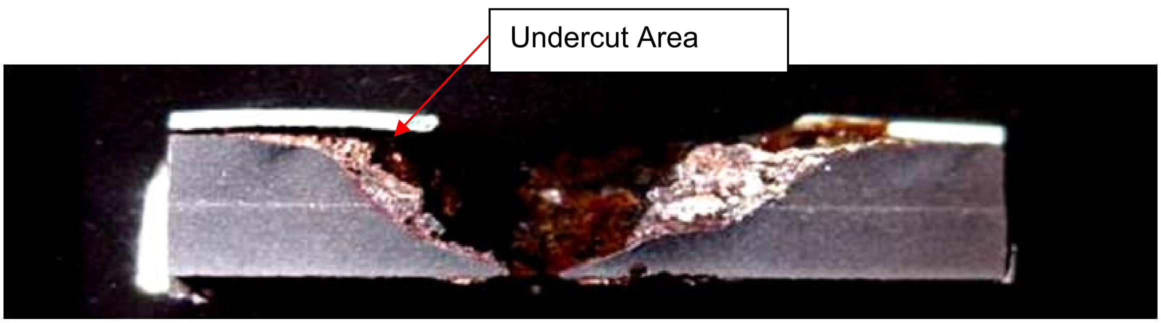

Figure 7. Metallographic Cross Section – Stray D-C Interference Corrosion (4-inch FBE Coated CS Pipeline)

5.1.3 Stray Alternating Current (A-C) Interference

Stray Alternating Current (A-C) corrosion is characterized by oval corrosion features and the build-up of corrosion products at small coating flaws coincident with the pitted area. The growth of the corrosion products typically causes the coating to separate and tent up ("lift-off') from the pipe substrate and is accompanied by cracks in the coating due to the expansive forces of the growth of the corrosion product as shown in Figure 8. The pH values in the pitted are typically range from 6-12 in the presence of cathodic protection which raises the pH, but does not control the corrosion.

Figure 8. A-C Corrosion – FBE Coating "lift-off" and Cracking

6.0 DISCUSSION OF SAMPLING TEST RESULTS

A total of 23 samples were received from the 10 ILI investigative dig sites that form the basis of the findings and opinions expressed in this report. As previously mentioned, the samples were subjected to MICKit IV and V analyses. A summary of the samples received is shown in Table 3.

Table 3. Samples Received

Sample	Asset Owner	Pipeline	Location	Client Cataloged As	Date Collected	Time Collected	Clock Position	DMA	RGW	CLS	Chainage	Sample Type	Containment
1	TransCanada	Keystone	Salisbury to Potoka	Dig 01 Soil Sample	10/19/2012	17:00	8:37	204496				Soil	Ziplock bag
2	TransCanada	Keystone	Salisbury to Potoka	Dig 01 Deposit Sample 1	10/19/2012	17:00	8:37	204496				Deposit	One of two vials in Ziplock bag
3	TransCanada	Keystone	Salisbury to Potoka	Dig 01 Deposit Sample 2	10/19/2012	17:00	7:30	204496				Deposit	Two of two vials in Ziplock bag
4	TransCanada	Keystone	Salisbury to Potoka	Dig 02 Soil Sample	10/20/2012	16:30	11:30	205022				Soil	Ziplock bag
5	TransCanada	Keystone	Salisbury to Potoka	Dig 02 Deposit Sample	10/20/2012	16:30	11:30	205022				Deposit	Small food jar in Ziplock bag
6	TransCanada	Keystone	Salisbury to Potoka	Dig 03 Soil Sample	10/20/2012	21:00	1:14			30000		Soil (Rock)	Ziplock bags doubled (outer bag was open)
7	TransCanada	Keystone	Salisbury to Potoka	Dig 04 Soil Sample	10/20/2012	14:30	6:48	210611				Soil	Ziplock bag
8	TransCanada	Keystone	Salisbury to Potoka	Dig 04 Deposit Sample	10/20/2012	14:30	6:48	210611				Deposit	Small food jar in Ziplock bag
9	TransCanada	Keystone	Salisbury to Potoka	Dig 05 Soil Sample	10/22/2012	17:30	12:00	207013		25000		Soil	Ziplock bag
10	TransCanada	Keystone	Salisbury to Potoka	Dig 05 Deposit Sample	10/24/2012	17:00	12:26	206998	187100		6755+32	Deposit	Small food jar in Ziplock bag
11	TransCanada	Keystone	Salisbury to Potoka	Dig 07 Soil Sample	11/9/2012	13:00	12:00			1		Soil	Ziplock bag
12	TransCanada	Keystone	Salisbury to Potoka	Dig 07 Deposit Sample	11/9/2012	13:00	12:30			1		Deposit	Small food jar in Ziplock bag
13	TransCanada	Keystone	Salisbury to Potoka	Dig 08 Soil Sample 1	11/8/2012	14:30	6:00			1		Soil	Ziplock bag
14	TransCanada	Keystone	Salisbury to Potoka	Dig 08 Soil Sample 2	11/7/2012	13:30	12:00	92591				Soil	Ziplock bag
15	TransCanada	Keystone	Salisbury to Potoka	Dig 08 Deposit Sample 1	11/8/2012	15:30	6:00			1		Deposit	Small food jar in Ziplock bag
16	TransCanada	Keystone	Salisbury to Potoka	Dig 08 Deposit Sample 2	11/8/2012	15:30	11:30	92591				Deposit	Small food jar in Ziplock bag
17	TransCanada	Keystone	Salisbury to Potoka	Dig 16 Soil Sample	11/6/2012	15:00	6:00			1		Soil	Ziplock bag
18	TransCanada	Keystone	Salisbury to Potoka	Dig 16 Deposit Sample	11/6/2012	16:30	6:15			1		Deposit	Small food jar in Ziplock bag
19	TransCanada	Keystone	Salisbury to Potoka	Dig 17 Soil Sample	11/3/2012	14:00	8:30	210553				Soil	Ziplock bag
20	TransCanada	Keystone	Salisbury to Potoka	Dig 17 Deposit Sample	11/5/2012	9:00	8:30	210553				Deposit	Small food jar in Ziplock bag
21	TransCanada	Keystone	Salisbury to Potoka	Dig 06 Soil Sample	12/14/2012	16:30	6:00					Soil (with rock)	Ziplock bag
22	TransCanada	Keystone	Salisbury to Potoka	Dig 06 Deposit Sample	12/14/2012	18:40	6:00					Deposit	Small food jar in Ziplock bag
23	TransCanada	Keystone	Salisbury to Potoka	Dig 18 Soil Sample	12/14/2012	16:00	8:00					Soil	Ziplock bags doubled

The results of the MICkit V testing are shown in Table 4 and indicate that microbially influenced corrosion may have played a role in the observed corrosion, although MIC was not deemed to be the root cause.

Table 4. MICkit V Test Results

Sample	Client Cataloged As	Date Collected	Time Collected	Clock Position	Inoculation Date	Inoculation Time	11-5-2012, 15:30					11-8-2012, 9:00					11-15-2012, 10:00				
							BTI-LNB (Purple)	BTI-IRB (White)	BTI-ANA (Blue)	BTI-APB (Red)	BTI-SRB (Green)	BTI-LNB (Purple)	BTI-IRB (White)	BTI-ANA (Blue)	BTI-APB (Red)	BTI-SRB (Green)	BTI-LNB (Purple)	BTI-IRB (White)	BTI-ANA (Blue)	BTI-APB (Red)	BTI-SRB (Green)
1	Dig 01 Soil Sample	10/19/2012	17:00	8:37	11/2/2012	15:00	2	NR	3	2	NR	2	NR	3	2	1	3	NR	3	2	2
2	Dig 01 Deposit Sample 1	10/19/2012	17:00	8:37	11/1/2012	15:00	2	NR	3	1	1	2	NR	3	1	1	3	NR	4	1	2
3	Dig 01 Deposit Sample 2	10/19/2012	17:00	7:30	11/1/2012	15:30	2	NR	2	1	2	2	NR	2	1	1	3	NR	2	1	2
4	Dig 02 Soil Sample	10/20/2012	16:30	11:30	11/2/2012	15:30	3	NR	3	2	1	4	NR	3	4	2	4	2	4	4	2
5	Dig 02 Deposit Sample	10/20/2012	16:30	11:30	11/1/2012	14:00	3	NR	2	NR	2	3	NR	2	NR	2	4	2	4	1	2
6	Dig 03 Soil Sample	10/20/2012	21:00	1:14	11/2/2012	16:00	3	NR	2	3	1	4	2	4	4	2	4	2	4	4	3
7	Dig 04 Soil Sample	10/20/2012	14:30	6:48	11/2/2012	17:00	3	NR	2	NR	1	4	NR	2	1	2	4	2	2	1	2
8	Dig 04 Deposit Sample	10/20/2012	14:30	6:48	11/1/2012	14:30	4	NR	1	2	2	4	2	2	2	2	4	2	4	2	2
9	Dig 05 Soil Sample	10/22/2012	17:30	12:00	11/2/2012	17:30	4	NR	4	4	2	4	2	4	4	3	4	2	4	4	4
10	Dig 05 Deposit Sample	10/24/2012	17:00	12:26	11/1/2012	15:00	2	NR	1	2	1	2	2	2	2	1	2	2	2	3	2

Sample	Client Cataloged As	Date Collected	Time Collected	Clock Position	Inoculation Date	Inoculation Time	11-30-2012, 15:30					12-6-2012, 10:00					12-14-2012, 15:00				
							BTI-LNB (Purple)	BTI-IRB (White)	BTI-ANA (Blue)	BTI-APB (Red)	BTI-SRB (Green)	BTI-LNB (Purple)	BTI-IRB (White)	BTI-ANA (Blue)	BTI-APB (Red)	BTI-SRB (Green)	BTI-LNB (Purple)	BTI-IRB (White)	BTI-ANA (Blue)	BTI-APB (Red)	BTI-SRB (Green)
11	Dig 07 Soil Sample	11/9/2012	13:00	12:00	11/27/2012	14:20	2	NR	3	3	NR	4	2	3	4	2	4	2	3	4	3
12	Dig 07 Deposit Sample	11/9/2012	13:00	12:30	11/27/2012	14:50	3	NR	2	4	NR	3	1	4	4	1	3	2	4	4	2
13	Dig 08 Soil Sample 1	11/8/2012	14:30	6:00	11/27/2012	16:30	4	NR	4	4	NR	4	1	4	4	1	4	2	4	4	2
14	Dig 08 Soil Sample 2	11/7/2012	13:30	12:00	11/28/2012	8:40	4	NR	3	2	1	4	2	4	3	2	4	2	4	3	3
15	Dig 08 Deposit Sample 1	11/8/2012	15:30	6:00	11/27/2012	15:15	2	NR	2	2	NR	3	NR	4	3	NR	3	1	4	3	2
16	Dig 08 Deposit Sample 2	11/8/2012	15:30	11:30	11/28/2012	9:10	3	NR	2	3	1	4	1	4	4	2	3	1	4	4	2
17	Dig 16 Soil Sample	11/6/2012	15:00	6:00	11/28/2012	10:15	4	NR	2	2	1	4	4	4	4	1	4	4	4	4	2
18	Dig 16 Deposit Sample	11/6/2012	16:30	6:15	11/28/2012	10:00	1	NR	1	1	NR	2	NR	2	2	1	2	NR	2	2	1
19	Dig 17 Soil Sample	11/3/2012	14:00	8:30	11/28/2012	15:50	2	NR	2	1	NR	3	NR	3	2	1	4	1	3	3	1
20	Dig 17 Deposit Sample	11/5/2012	9:00	8:30	11/28/2012	15:45	NR	NR	NR	NR	NR	1	NR	1	NR	NR	2	NR	2	1	NR

Sample	Client Cataloged As	Date Collected	Time Collected	Clock Position	Inoculation Date	Inoculation Time	1-5-2013, 16:00					1-10-2013, 19:50					1/20/2013				
							BTI-LNB (Purple)	BTI-IRB (White)	BTI-ANA (Blue)	BTI-APB (Red)	BTI-SRB (Green)	BTI-LNB (Purple)	BTI-IRB (White)	BTI-ANA (Blue)	BTI-APB (Red)	BTI-SRB (Green)	BTI-LNB (Purple)	BTI-IRB (White)	BTI-ANA (Blue)	BTI-APB (Red)	BTI-SRB (Green)
21	Dig 06 Soil Sample	12/14/2012	16:30	6:00	1/3/2013	12:00	4	N/R	2	3	1	4	2	4	3	2					
22	Dig 06 Deposit Sample	12/14/2012	18:40	8:00	1/3/2013	13:00	3	N/R	3	3	1	3	N/R	3	3	3					
23	Dig 18 Soil Sample	12/14/2012	16:00	6:00	1/3/2013	13:30	4	N/R	3	2	1	4	1	3	3	2					

The MICKit V testing identified viable colonies of the following bacteria in both soil samples and deposits obtained from pitted areas:

- Low Nutrient Bacteria (LNB)
- Anaerobic Bacteria (ANA)
- Acid Producing Bacteria (APB)
- Sulfate Reducing Bacteria (SRB)

LNB thrive in oxygenated environments and do not require an abundance of nutrients to sustain metabolic processes. LNB's can initiate the development of films that contribute to establishing a corrosive environment at the pipe surface.

ANA thrive in oxygen starved environments and can crest acid environments at the pipe surfaces which accelerate corrosion. Facultative anaerobes can thrive in oxygenated environments.

APB is anaerobic bacteria but also can thrive in the presence of oxygen. They derive nutrients from organic material and create localized acid conditions.

SRB are anaerobic bacteria and convert sulfate to sulfide. A byproduct of the corrosion process from SRB's is the formation of Iron Sulfide (FeS).

The serial dilution bacterial culturing identified moderate to high concentrations of viable species of bacterium ranging from 10^2 to 10^4 colonies per milliliter for the above listed species. These concentrations were identified in soil samples from the excavation sites and in deposits and products obtained from the pitted areas. It is unlikely the SRB's were a contributing factor to the observed corrosion since MICkit IV sampling did not show positive results for Sulfide which is normally detected in corrosion deposits when SRB's are mechanistically involved. Furthermore, it is considered unlikely that MIC is the root cause of the observed corrosion since the observed corrosion morphology does not appear to be consistent with MIC.

The results of the MICkit IV testing of soil samples and corrosion deposits are shown in Table 5. The testing showed positive indications for Ferrous Iron (Fe^{+2}) and Ferric iron (Fe^{+3}) in most corrosion products although some corrosion products tested positive for Ferric Iron. All samples tested positive for Calcium and negative for Carbonate, which along with pH values ranging from 7.0 to 7.5 for the corrosion deposits raises questions about the efficacy of CP in the pitted areas. All samples tested negative for Sulfide likely excluding SRB's as a contributing factor to the corrosion.

Table 5. MICKit IV Results

Sample #	Sample Description	pH	Carbonate ($CO_3^=$) Bubbles = (+) for $CO_3^=$ No Bubbles = (-) for $CO_3^=$	Sulfide ($S^=$) Black/brown color = (+) for $S^=$	Ferrous Iron (Fe^{+2}) Ferrozine Reaction: Purple color = (+) for Fe^{+2}	Ferric Iron (Fe+3) Reducing Solution Reaction: Purple color = (+) for Fe^{+3}	Calcium (Ca+2) Red color = (+) for Ca^{+2} Blue color = (-) for Ca^{+2}
1	Dig 01, Dep 1	6.0	-	-	+	+	+
2	Dig 01, Dep 2	6.5	-	-	+	+	+
3	Dig 02, Deposit	7.5	-	-	-	+	+
4	Dig 04, Deposit	7.0	-	-	+	+	+
5	Dig 05, Deposit	7.5	-	-	+	+	+
6	Dig 01, Soil	6.0	-	-	+	+	+
7	Dig 02, Soil	5.0	-	-	-	+	+
8	Dig 03, Soil	6.0	-	-	+	+	+
9	Dig 04, Soil	7.0	-	-	-	+	+
10	Dig 05, Soil	7.0	-	-	+	+	+
11	Dig 07, Soil Sample	6.5	-	-	+	+	+
12	Dig 07, Deposit Sample	7.5	-	-	+	+	+
13	Dig 08, Soil Sample 1	7.0	-	-	-	+	+
14	Dig 08, Soil Sample 2	6.0	-	-	-	+	+
15	Dig 08, Deposit Sample 1	7.0	-	-	+	+	+
16	Dig 08, Deposit Sample 2	7.0	-	-	+	+	+
17	Dig 16, Soil Sample	7.0	-	-	+	+	+
18	Dig 16, Deposit Sample	7.5	-	-	+	+	+
19	Dig 17, Soil Sample	7.0	-	-	+	+	+
20	Dig 17, Deposit Sample	7.5	-	-	-	+	+
21	Dig 06, Soil Sample	6.5	-	-	-	+	+
22	Dig 06, Deposit Sample	7.5	-	-	-	+	+
23	Dig 18, Soil Sample	7.0	-	-	-	+	+

7.0 DISCUSSION OF ANOMALY INVESTIGATIVE DIGS

The data and photographic documentation from each of the 10 ILI investigative digs covered by this report were reviewed and analyzed.

Dig Site #1 – MP 995.95 Investigated 10/19/12

This anomaly was classified as an immediate indication and was found to have six (6) anomalies caused by external corrosion with a peak depth of corrosion reported to be 96.8%. Approximately 9.0 feet of pipe was exposed from Station 597+20.0 to 597+29.0. The deepest corrosion anomaly is dish shaped and developed in an overlap area of a liquid epoxy repair. The reported CP potentials documented in the RTD Dig report ranged from -0.685 v to -0.710 v (CSE). Soil pH was reported to be between 5.5 and 6.0. The corrosion anomalies can be seen in Figures 9, 10 and 11.

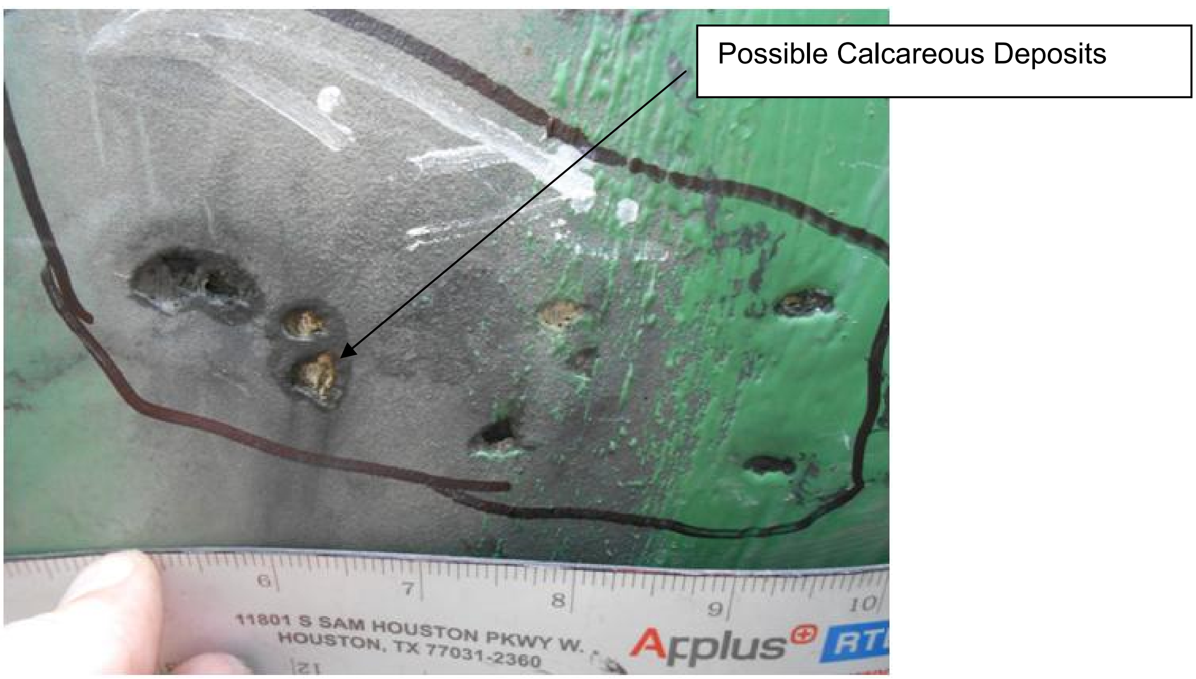

Figure 9. MP 995.95 External Corrosion Pitting

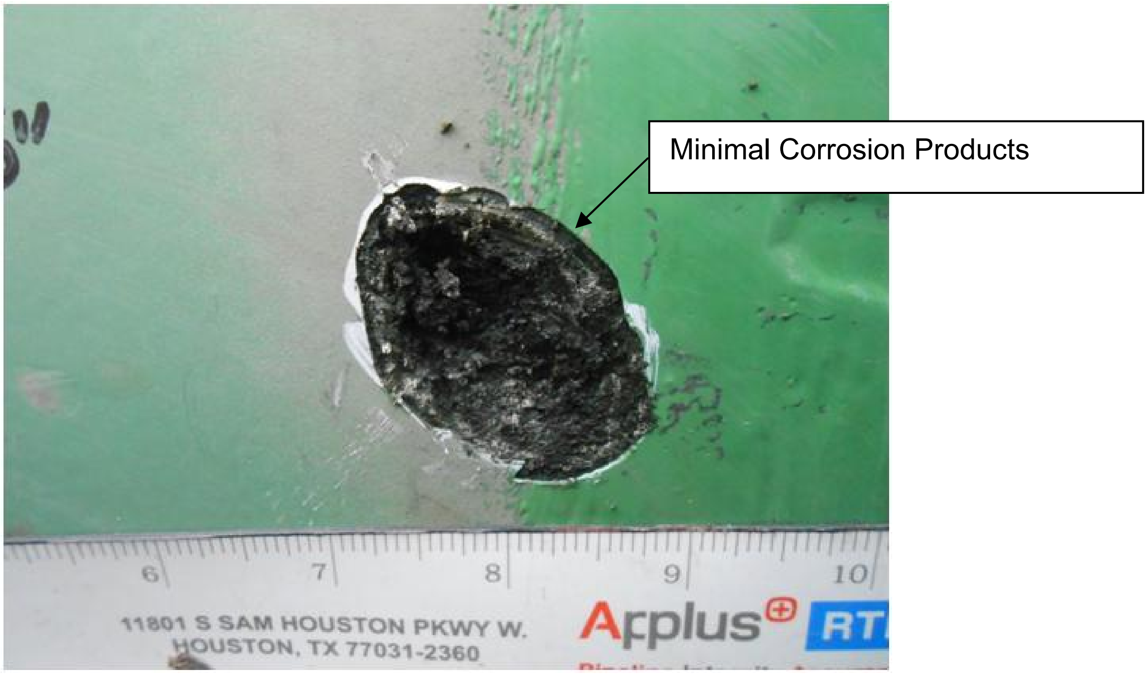

Figure 10. MP 995.95 –External Corrosion Pitting

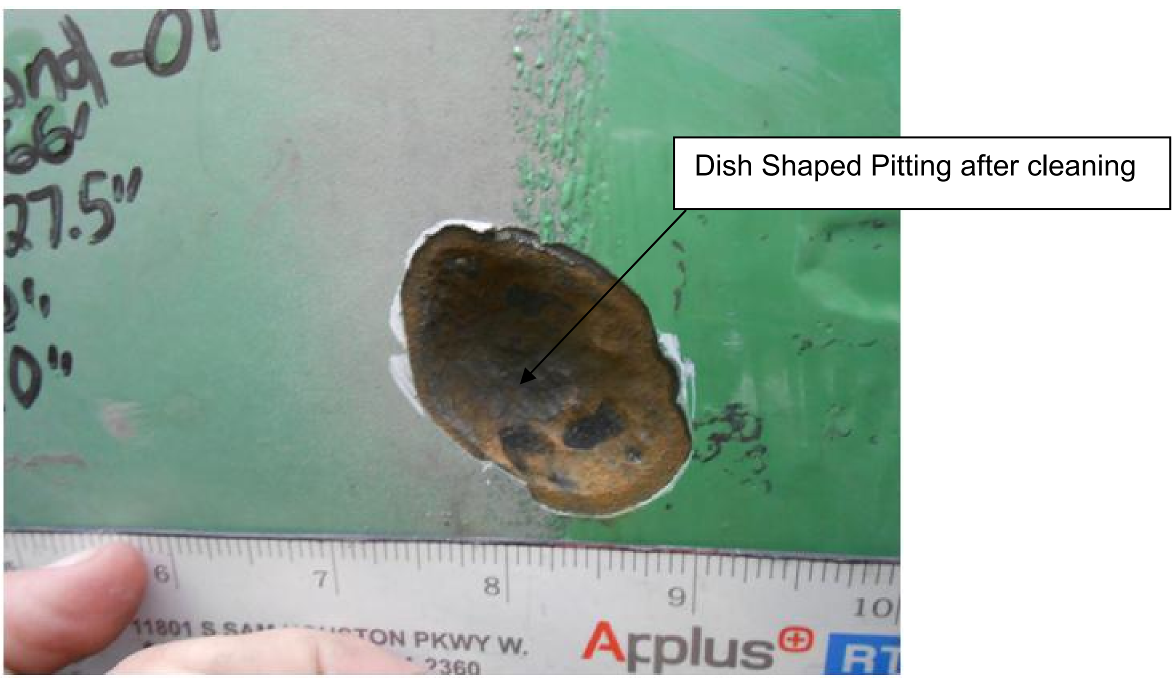

Figure 11. MP 995.95 –External Corrosion Pitting

The accelerated rate of corrosion and the observed corrosion morphology along with an absence of tubercles is consistent with D-C Stray Current Corrosion. The possibility of calcareous deposits in some pits that appear in Figure 9 suggest that CP current may have reached this site after corrosion initiated perhaps due to modifications to the CP system operating characteristics.

Dig Site #2 – MP 996.33 Investigated 10/20/12

This anomaly was classified as an immediate indication and was found to have one (1) anomaly caused by external corrosion with a peak depth of corrosion reported to be 73.9%. Approximately 9.5 feet of pipe was exposed from Station 617+30.5 to 617+40.0. The corrosion anomaly is dish shaped. The reported CP potentials documented in the RTD Dig report ranged from -0.660 v to -0.840 v (CSE). Soil pH was reported to be between 5.5 and 6.0. The corrosion anomalies can be seen in Figures 12 and 13.

Figure 12. MP 996.33 –External Corrosion Pitting

Figure 13. MP 996.33 –External Corrosion Pitting

Dig Site #3 – MP 1000.08 Investigated 10/21/12

This anomaly was classified as an immediate indication and was found to have three (3) anomalies caused by external corrosion with a peak depth of corrosion reported to be 59.9%. Approximately 11.0 feet of pipe was exposed from Station 815+72.0 to 815+83.0. The corrosion anomaly is dish shaped. The reported CP potentials documented in the RTD Dig report ranged from -0.846 v to -0.870 v (CSE). Soil pH was reported to be 6.0. The corrosion anomalies can be seen in Figures 14 and 15.

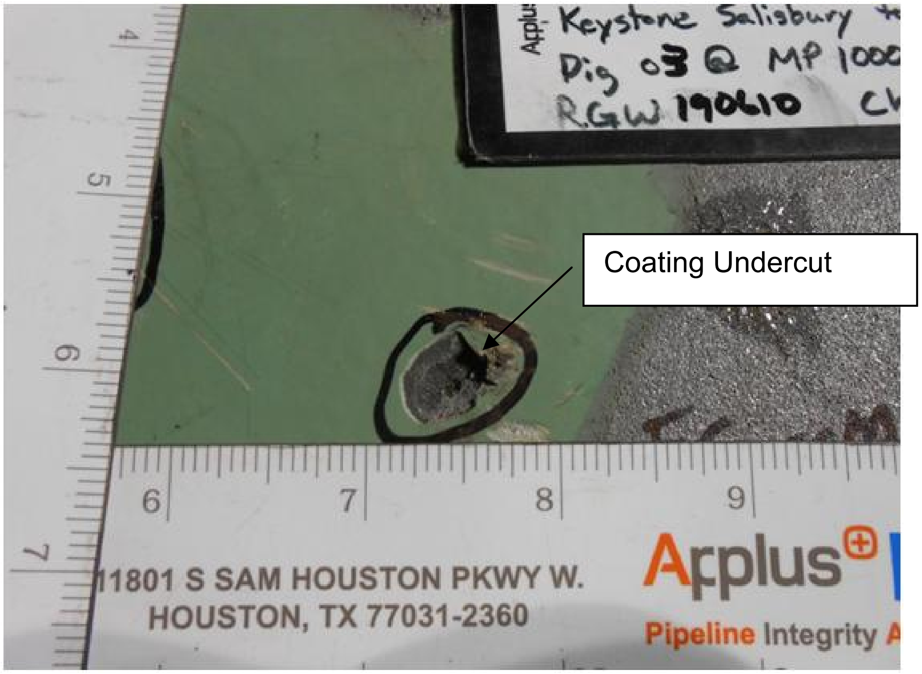

Figure 14. MP 1000.08 –External Corrosion Pitting

Figure 15. MP 1000.08 –External Corrosion Pitting

The accelerated rate of corrosion and the observed corrosion morphology along with undercutting of the FBE coating is consistent with D-C Stray Current Corrosion.

Dig Site #4 – MP 1000.38 Investigated 10/21/12

This anomaly was classified as an immediate indication and was found to have one (1) anomaly caused by external corrosion with a peak depth of corrosion reported to be 61.07%. Approximately 7.0 feet of pipe was exposed from Station 831+38.0 to 831+45.0. The corrosion anomaly is dish shaped. The reported CP potentials documented in the RTD Dig report ranged range from -0.918 v to -0.935 v (CSE). Soil pH was reported to be 6.0. The corrosion anomaly can be seen in Figure 16.

Figure 16. MP 1000.38 –External Corrosion Pitting

The available photographic documentation is not sufficient to draw conclusion regarding root cause at this site.

Dig Site #5 – MP 997.67 Investigated 10/23/12

This anomaly was classified as a 180 day indication and was reported to have eight (8) anomalies caused by external corrosion with a peak depth of corrosion reported to be 55.6%. The pipe was exposed from Station 688+18.5 to 689+30.5. Corrosion anomalies appear to be axially oriented along a length of coating damage that appears to have been caused by construction damage or third party damage. Discrete dish shaped pitting was also detected in areas related to construction damage to the coating. The reported CP potentials documented in the RTD Dig report ranged from -0.918 v to -0.935 v (CSE). Soil pH was reported to be 6.0. The corrosion anomalies can be seen in Figures 17 and 18.

Figure 17. MP 997.67 –External Corrosion at Areas of Coating Damage

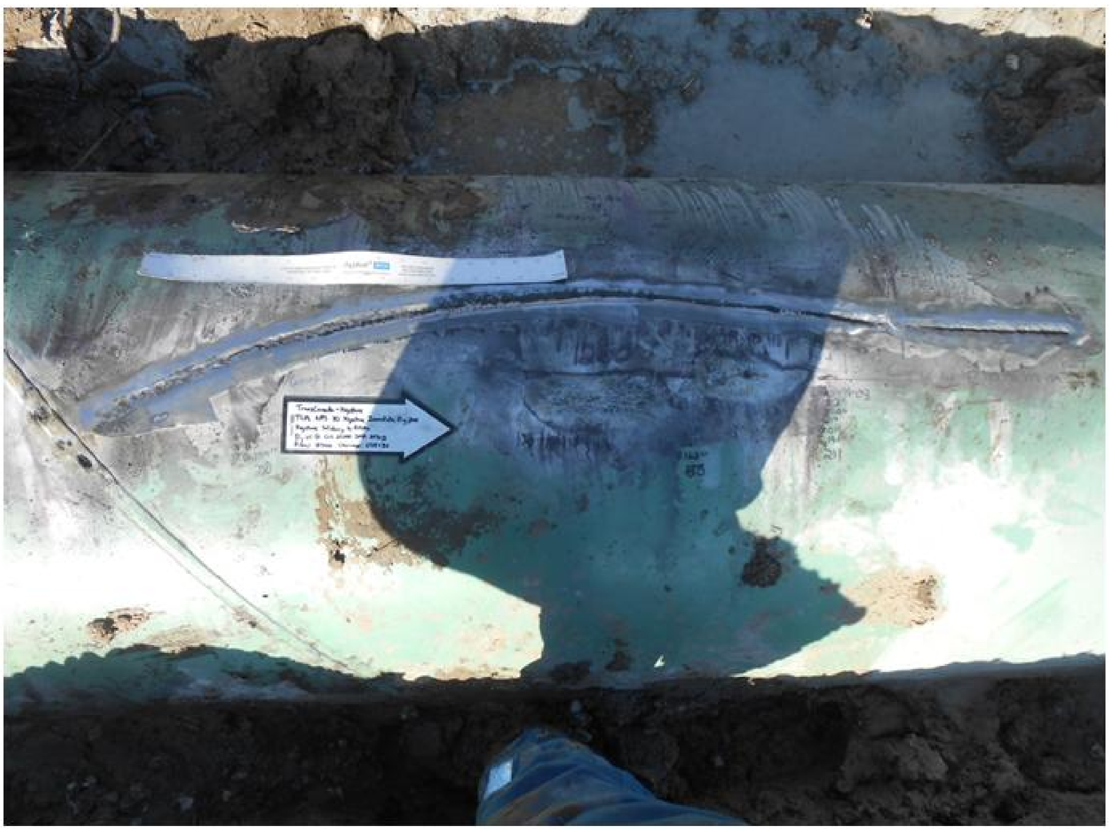

Figure 18. MP 997.67 – Axially Oriented External Corrosion at Areas of Coating Damage

The observed corrosion has an accelerating factor, but the available photographic documentation is not sufficient to draw conclusion regarding root cause at this site.

Dig Site #6 – MP 968.85 Investigated 10/21/12

This anomaly was classified as a 60 day indication and is reported as a dent with corrosion. This site investigation was not considered in the overall root cause analysis.

Dig Site #7 – MP 925.81 Investigated 11/09/12

This anomaly was classified as a 180 day indication and was found to have two (2) anomalies caused by external corrosion with a peak depth of corrosion reported to be 30.05%. Approximately 5.0 feet of pipe was exposed from Station 1153+13.4 to 1153.18.3. The corrosion anomalies are dish shaped. The reported CP potentials documented in the RTD Dig report ranged from -0.600 v to -0.666 v (CSE). Soil pH was reported to be ranging from 4.5 to 5.5. The corrosion anomalies can be seen in Figures 19 and 20.

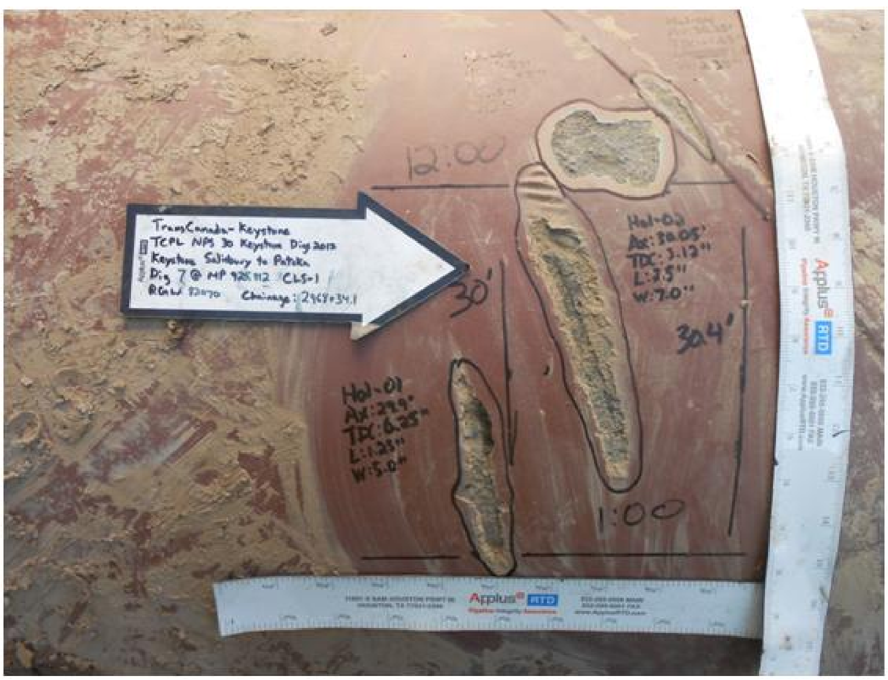

Figure 19. MP 921.81 – External Corrosion

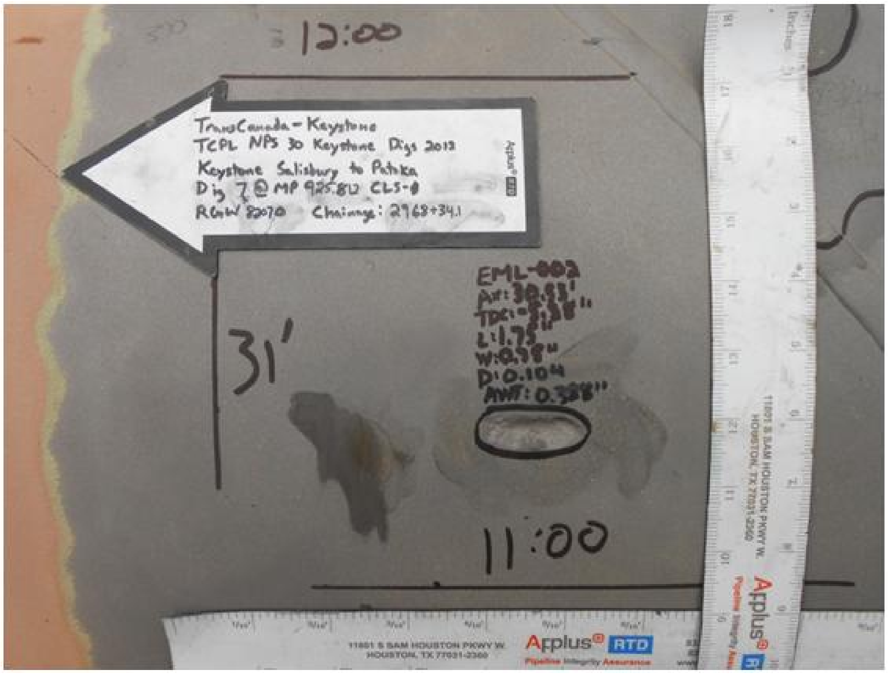

Figure 20. MP 921.81 – External Corrosion

The observed corrosion is consistent with an accelerated rate of corrosion and may be associated with D-C Stray Current Corrosion.

Dig Site #8 – MP 925.89 Investigated 11/08/12

This anomaly was classified as a 180 day indication and was found to have five (5) anomalies caused by external corrosion with a peak depth of corrosion reported to be 30.75%. Approximately 6.0 feet of pipe was exposed from Station 1156+98.8 to 1157+04.8. The corrosion anomalies are dish shaped. The reported CP potentials documented in the RTD Dig report ranged from -0.735 v to -0.745 v (CSE). Soil pH was reported to be ranging from 5.0 to 5.5. The corrosion anomalies can be seen in Figures 21 and 22.

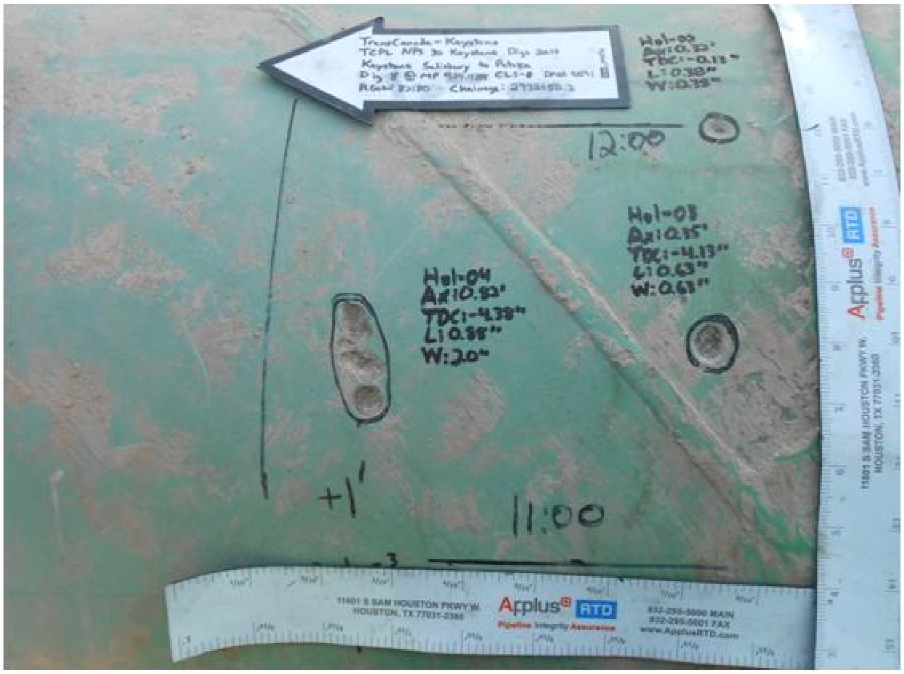

Figure 21. MP 925.89 – External Corrosion

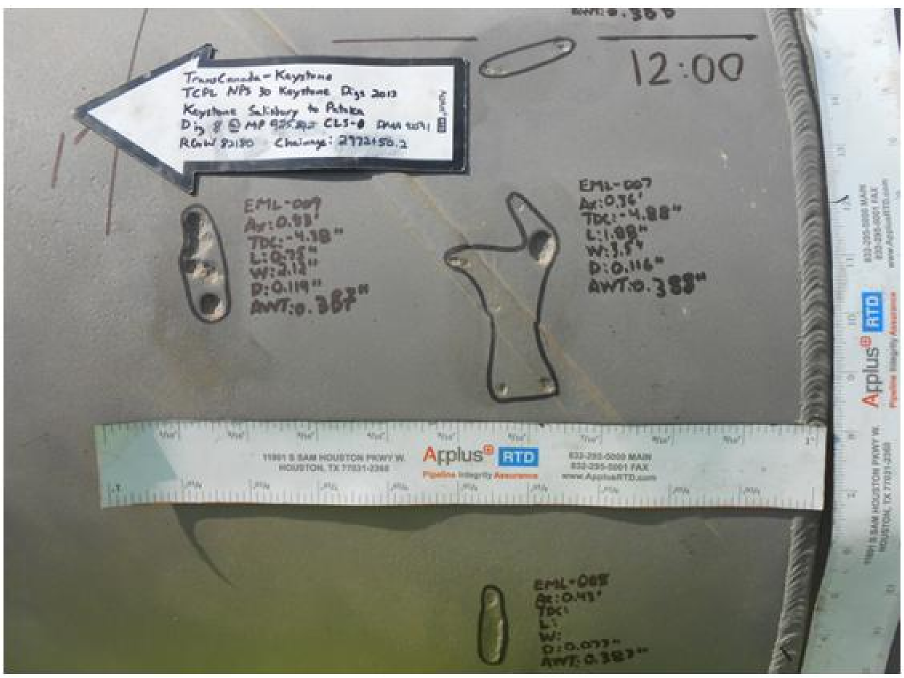

Figure 22. MP 925.89 – External Corrosion

The accelerated rate of corrosion and the observed corrosion morphology along with an absence of tubercles is consistent with D-C Stray Current Corrosion.

Dig Site #16 – MP 999.97 Investigated 11/06/12

This anomaly was classified as a 180 day indication and was found to have one (1) anomaly caused by external corrosion with a peak depth of corrosion reported to be 46.45%. Approximately 5.0 feet of pipe was exposed from Station 809+97.1 to 810+02.1. The corrosion anomalies (one large commingled area and some discrete areas of metal loss) are dish shaped and occurred in a girth weld coating area. The reported CP potentials documented in the RTD Dig report ranged from -1.489 v to -1.523 v (CSE). Soil pH was reported to be ranging from 5.0 to 6.5. The corrosion anomalies can be seen in Figures 23 and 24.

Figure 23. MP 999.97 – Coating Damage

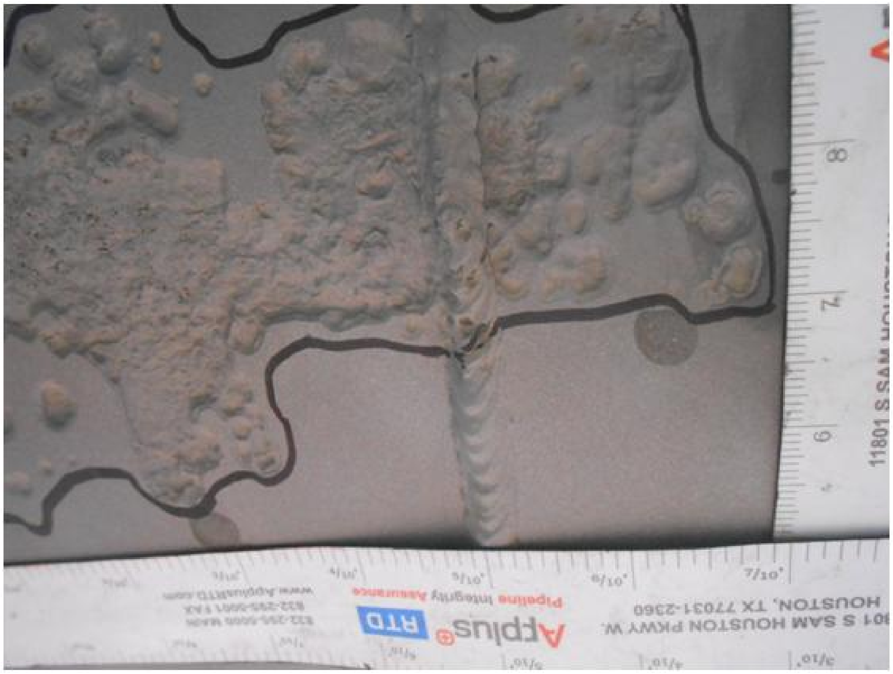

Figure 24. MP 999.97 – External Corrosion

The corrosion damage at this location occurred at an accelerated rate and the morphology is consistent with stray current corrosion due to the absence of tubercles in the corroded area. MIC may also have contributed to the observed corrosion damage.

Dig Site #17 – MP 1000.32 Investigated 11/06/12

This anomaly was a Site #4 proximity examination and was found to have three (3) anomalies caused by external corrosion with a peak depth of corrosion reported to be 41.81%. Approximately 12.0 feet of pipe was exposed from Station 828+25.3 to 828+37.3. The corrosion anomalies (one large commingled area and some discrete areas of metal loss) are dish shaped. The reported CP potentials documented in the RTD Dig report ranged from -0.830 v to -0.840 v (CSE). Soil pH was reported to be ranging from 4.5 to 5.5. The corrosion anomalies can be seen in Figures 25 and 26.

Figure 25. MP1000.32 – External Corrosion Pitting

Figure 26. MP1000.32 – External Corrosion Pitting

The corrosion damage at this location occurred at an accelerated rate and the morphology is consistent with stray current corrosion.

8.0 ASSESSMENT OF CATHODIC PROTECTION ON THE KEYSTONE PIPELINE

In the area of where the external metal loss anomalies developed along the Keystone Pipeline system cathodic protection has been provided through Impressed Current ground beds. The ground beds were installed at pump stations along the system due to the availability of AC Power and in an effort to minimize stray current interference on existing operating pipelines in the shared right-of-way with the Keystone pipeline. The systems have been supplemented and operating characteristics have been modified since the ILI results became available.

A review of operating data obtained prior to and subsequent to the discovery of the external corrosion reveals areas where the pipeline was likely not meeting industry accepted criteria for effective CP. Moreover, a review of a Close Interval Survey results has identified possible stray current interference conditions at several locations. A listing of likely sub-criterion areas and areas of possible stay current interference is shown in Table 6[5].

Table 6. Summary of Likely Sub-Criterion Areas and Possible Interference Areas

File Description				Potentials more Positive than -0.850 volts by 100mV[6]		Reversed Potentials		Least Negative OFF Potential
File #	Begin MP	End MP	Location	Start	Stop	Start	Stop	
1000	901.99	905.91	Centralia to CR 737					
1010	905.91	907.72	Centralia to CR 737					
1015	907.72	909.02	Centralia to CR 737			47927+35	47954+63	-0.447
2002	909.02	912.00	Centralia to CR 737					
2012	912.00	915.37	Centralia to CR 737	48715+68	48718+08			-0.731
				48720+68	48723+18			-0.734
				48725+93	48727+20			-0.744
				48754+25	48759+03			-0.657
1001	920.40	923.53	Centralia to CR 737	48715+68	48718+08			-0.731
				48719+55	18719+70			-0.749
				48720+68	48723+18			-0.734
				48725+78	48727+20			-0.744
				48728+48	48728+60			-0.736
				48753+45	48759+03			-0.657
1011	923.53	926.61	Centralia to CR 737	48762+27	48813+73			-0.269
				48821+63	48830+05			-0.667
				48842+35	48859+80			-0.669
				48896+30	48902+55			-0.667
1050	950.75	955.94	Middletown to Saint Paul	50230+85	50239+75			-0.680
				50240+23	50240+45			-0.745

[5] Data developed from a review of CIS profiles.
[6] Pipe-to-soil potential values less negative than -0.850v by 100 mV or more were chosen for reporting purposes since values between -0.750v and -0.850v CSE are likely experiencing beneficial CP polarization and not indicative of detrimental stray current discharge.

File Description				Potentials more Positive than -0.850 volts by 100mV[6]		Reversed Potentials		Least Negative OFF Potential
File #	Begin MP	End MP	Location	Start	Stop	Start	Stop	
				50241+20	50241+25			-0.746
				50247+75	50248+03			-0.738
				50248+50	50253+35			-0.679
				50361+75	50361+80			-0.748
				50364+32	50364+82			-0.745
				50403+60	50407+18			-0.684
1060	955.94	960.39	Middletown to Saint Paul	50481+60	50485+85			-0.684
				50489+85	50489+93			-0.748
				50490+35	50492+73			-0.723
				50493+20	50493+80			-0.740
				50541+30	50541+33			-0.748
				50541+73	50542+68			-0.735
				50543+38	50543+63			-0.746
				50544+08	50544+40			-0.748
				50545+23	50545+53			-0.746
				50546+30	50547+58			-0.744
				50548+08	50555+53			-0.714
				50562+00	50565+45			-0.726
				50595+08	50595+60			-0.740
				50596+10	50597+95			-0.720
				50599+53	50600+18			-0.726
				50600+73	50602+25			-0.742
1070	960.39	964.81	Middletown to Saint Paul	50862+68	50864+53			-0.724
				50879+08	50889+38			-0.701
				50901+20	50901+30			-0.743
				50901+95	50902+00			-0.749
				50904+80	50940+33			-0.657
				50941+00	50941+58			-0.740
1080	964.81	966.33	Middletown to Saint Paul	50977+88	50978+23			-0.741
				50980+90	50987+43			-0.712
				51008+13	51008+50			-0.724
				51010+13	51021+48			-0.662
				51022+23	51022+28			-0.749
				51022+83	51040+53			-0.663
1090	966.88	972.42	Middletown to Saint Paul	51052+28	51056+55			-0.726
				51060+65	51071+73			-0.691
				51101+50	51101+75			-0.746
				51102+35	51107+90			-0.723
				51108+85	51108+90			-0.739
				51111+30	51111+43			-0.746
				51113+95	51114+45			-0.734
				51115+90	51115+98			-0.749
				51281+85	51319+68			-0.576
				51323+13	51323+15			-0.743
				51328+68	51328+73			-0.748
				51331+13	51331+18			-0.741
				51331+70	51331+75			-0.749
				51334+13	51334+20			-0.749

File Description				Potentials more Positive than -0.850 volts by 100mV[6]		Reversed Potentials		Least Negative OFF Potential
File #	Begin MP	End MP	Location	Start	Stop	Start	Stop	
				51336+18	51336+23			-0.731
				51336+80	51343+65			-0.535
6000	972.41	974.33	Middletown to Saint Paul	51343+64	51354+60			-0.570
				51401+43	51403+70			-0.733
6010	975.62	979.49	Middletown to Saint Paul	51661+95	51717+00			-0.587
6020	979.49	981.38	Middletown to Saint Paul	51717+00	51752+73			-0.641
				51756+88	51816+56			-0.567
6025	972.41	974.33	Middletown to Saint Paul	51816+62	51831+38			-0.603
				51833+10	51833+15			-0.603
2010	1068.50	1072.05	Pierron to Patoka			56523+13	56527+55	-1.036
						56538+68	56543+83	-0.956
						56550+95	56558+60	-0.921
2020	1072.05	1074.79	Pierron to Patoka			56611+13	56611+23	-0.996
						56611+78	56611+83	-0.980
						56612+63	53312+95	-0.973
						56618+68	56632+28	-0.981
						56637+38	56643+23	-0.956
						56644+03	56644+08	-0.997
						56660+65	56664+18	-0.983
2025	1076.64	1077.79	Pierron to Patoka			56889+40	56900+43	-0.964
2030	1077.79	1080.36	Pierron to Patoka			56927+15	56930+45	-1.004
						56952+25	57041+00	-0.944
2040	1080.34	1083.45	Pierron to Patoka			57041+92	57203+85	-0.792
1000	867.57	871.84	Salisbury to Centalia	45902+50	45907+20			-0.690
				45915+93	45915+98			-0.745
1035	889.81	891.58	Salisbury to Centalia	46988+75	46992+18			-0.664
1036	990.07	992.03	St. Paul to Hartford			52344+67	52358+17	-0.913

No data was available from which to determine if locations not satisfying a -0.850 volt (CSE) Polarized Criterion were satisfying alternative criteria, but several locations showed evidence of "Instant-Off" potentials near or below the expected free corrosion potential for carbon steel raising the possibility that the Cathodic Protection in some areas was inadequate and/or interference conditions were rendering the CP system ineffective and likely accelerating corrosion.

An excerpt of a Mainline Annual Survey report is shown in Figure 27 and shows evidence of potential reversals at a crossing with Platte Pipeline.

Name	Chainage	Date	Purpose	Ref	Type	Connection	Comment	On	Off	For. On	For. Off
1185200+992.041-TS - Dalbow Rd											
2010											
	50,659.829	11/7/2010 08:00:35 PM		CuSO4	VDC	P1	P1 BLK	2701	857		
		11/7/2010 08:00:19 PM		CuSO4	VAC	P1	P1 BLK	877	824		
2011											
		9/27/2011 11:26:11 PM		CuSO4	VDC	P1	P1 BLK	3185	1114		
		9/27/2011 11:26:43 PM		CuSO4	VAC	P1	P1 BLK	0	0		
2012											
		9/15/2012 09:19:15 PM		CuSO4	VDC	P1	P1 BLK	3033	997		
		9/15/2012 09:18:59 PM		CuSO4	VAC	P1	P1 BLK	896	862		
		9/15/2012 09:22:11 PM		CuSO4	VDC		ANODE BLUE			1756	1824
1185200+994.711-TS - platte line xing											
2010											
	64,830.423	11/8/2010 06:56:15 PM	Pipe Crossing	CuSO4	VDC	P1	P1 BLK	657	777		
		11/8/2010 06:56:55 PM	Pipe Crossing	CuSO4	VDC	P1	F1 WHITE	1426	1141		
		11/8/2010 06:57:39 PM	Pipe Crossing	CuSO4	VAC	P1	P1 BLK	1385	1331		
2011											
		9/27/2011 10:40:51 PM	Pipe Crossing	CuSO4	VDC	P1	P1 VDC	1080	876		
		9/27/2011 10:38:23 PM	Pipe Crossing	CuSO4	VAC	P1	P1 VAC	0	0		
		9/27/2011 10:37:27 PM	Pipe Crossing	CuSO4	VDC	P1	F1			1327	863
2012											
		9/17/2012 03:01:23 PM	Pipe Crossing	CuSO4	VDC	P1	P1 VDC	1024	802		
		9/17/2012 03:00:55 PM	Pipe Crossing	CuSO4	VAC	P1	P1 VAC	374	271		
		9/17/2012 03:00:19 PM	Pipe Crossing	CuSO4	VDC	P1	F1			1453	882
1185200+994.884-TS - anode test station by pond											
2010											
	65,732.569	11/8/2010 07:13:03 PM		CuSO4	VAC	1	P1 AC			1381	1358
		11/8/2010 07:12:07 PM		CuSO4	VDC	1	P1 DC			788	819
		11/8/2010 07:12:27 PM		CuSO4	VDC	1	P2 DC			801	825
		11/8/2010 07:13:47 PM		CuSO4	VDC	1	ANODE DC			1734	1742
2011											
		9/27/2011 10:32:15 PM		CuSO4	VDC	P1	P1 VDC	1357	1016		
		9/27/2011 10:31:51 PM		CuSO4	VAC	P1	P1 VAC	0	0		
		9/27/2011 10:32:27 PM		CuSO4	VDC	Output Anode1	ANODE	1713	1708		
2012											
		9/17/2012 02:51:47 PM		CuSO4	VDC	P1	P1 VDC	1199	971		
		9/17/2012 02:51:27 PM		CuSO4	VAC	P1	P1 VAC	343	248		
		9/17/2012 02:52:19 PM		CuSO4	VDC	Output Anode1	ANODE	1710	1709		

Page 126 of 162

Figure 27. Annual Survey Results

A CIS profile is shown in Figure 28. where there is evidence of reversed potentials indicative of a possible interference condition. This graph shows about 5000 lineal feet of reversed potentials. TransCanada reported that they had implemented interference bonds with foreign operators that may be influencing the Keystone system, but those bonds may not have been properly sized to achieve optimum results.

Additional examples of possible issues with the CP system performance exist in the data collected at the ILI investigative dig sites.

The location of Foreign CP ground beds in relationship to the ILI anomaly digs is shown in Figures 29-31. These figures demonstrate the close proximity of possible sources of Interference.

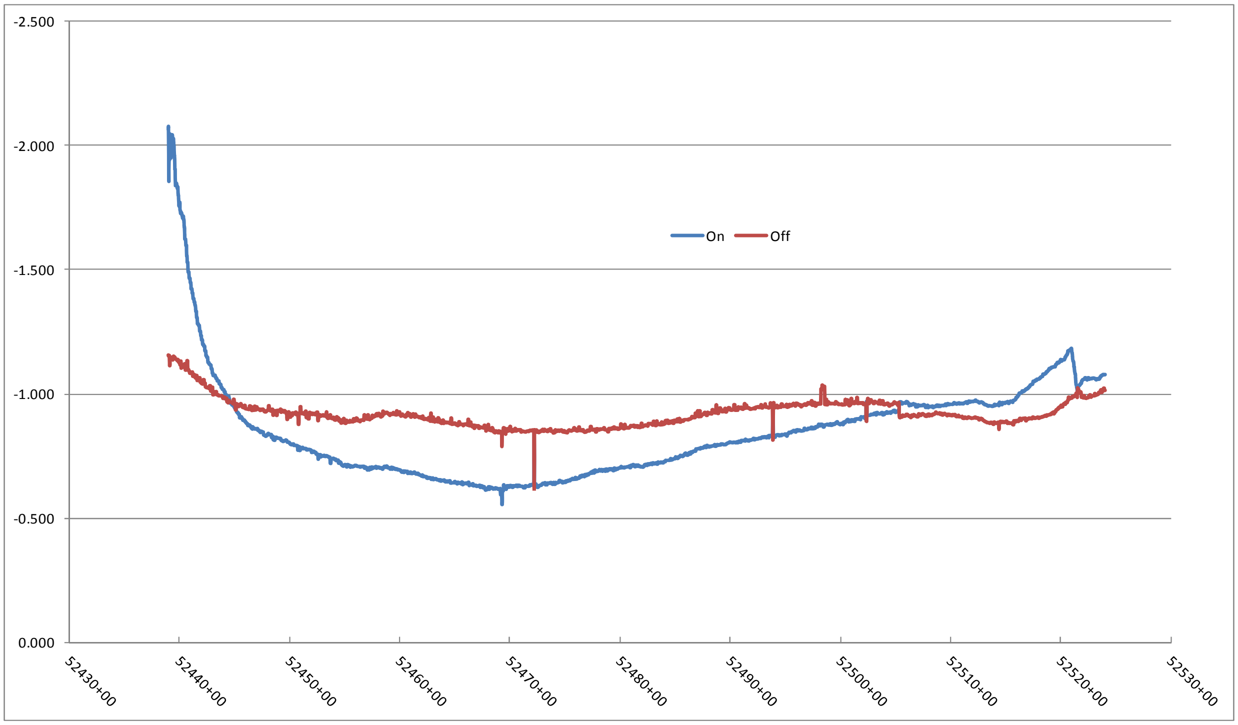

Figure 28. CIS Profile in the Area of External Metal Loss Anomalies MP 992.03-995.46[7]

Figure 29. ILI Investigative Digs 1, 2 and 5.

[7] This graph represents only a portion of the Survey

Figure 30. ILI Investigative Digs 3, 4, 16 and 17.

Figure 31. ILI Investigative Digs 7 and 8.

9.0 CONCLUSIONS AND RECOMMENDATIONS

9.1 Conclusions

Based upon the combined analysis of the documentation and material reviewed and the results testing of dig site samples, the findings of this study regarding root cause and contributing factors are:

9.1.1 Root Cause

The 30-inch Keystone Pipeline experienced localized external corrosion wall loss due to D-C stray current interference[8]. The corrosion induced wall loss occurred at an accelerated rate that can only be attributable to D-C stray current interference, microbiologically influenced corrosion (MIC), or Induced A-C corrosion. MIC may have played a role in some of the observed corrosion however it was not the primary cause. Induced A-C corrosion did not play a role in the observed corrosion. The primary supporting evidence is as follows:

1. Using a linear corrosion growth rate, the corrosion rate experienced ranged from 40 -125 mpy. Absent accelerating factors, corrosion of carbon steel in soils occurs at 2-10 mpy. The accelerated rates experienced can only be attributable to stray D-C interference, MIC or Induced A-C.
2. While the results of testing performed on soil samples and corrosion deposits showed moderate to high concentrations of viable bacteria that can contribute to MIC, the pitting morphology is not completely consistent with MIC. In most cases the pitting morphology is consistent with D-C Stray Current Interference corrosion. MIC cannot be dismissed as a contributing factor to the observed corrosion.
3. Induced A-C Corrosion can produce accelerated rates of corrosion, but because the Keystone line is not collocated with or near a source of Induced A-C, nor is the pitting morphology consistent with A-C corrosion, it is not the root cause.

9.1.2 Contributing Factors

Extensive analysis has identified problems with the application and operation of cathodic protection on the Keystone line that contributed to the observed corrosion. The primary supporting evidence is as follows:

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[8] Stray current corrosion may occur during construction as the pipeline is being installed, but has not been provided protection. PHMSA has issued an advisory bulletin to Operators offering guidance on this subject.

1. The application of CP through the installation of Impressed current ground beds at the pump stations that were electrically continuous with the mainline piping, created a condition where the applied CP current could preferentially distribute to the pump station infrastructure that represented a lower cathode to earth resistance than the mainline pipe. Piping, grounding, reinforced concrete and ancillary equipment that is electrically continuous with the mainline pipe would have more bare surface area and may have resulted in inadequate distribution of protective current to the Keystone Pipeline.

2. Analysis of the shared right-of-way configuration, the proximity to foreign CP sources in the areas of corrosion damage and the Annual Survey and Close Interval Survey data has identified locations of suspected interference and possibly inadequate CP. The primary supporting information is as follows:

    1. A review of the Annual survey data shows areas of depressed potentials and some reversals in potentials. This is also apparent in reviewing CIS survey results.
    2. Interference bonds installed to mitigate possible interference may not have been sized to achieve optimum results.

9.2 Recommendations

Based upon the findings and conclusions of the Root Cause and Contributing Factors study, we offer the following recommendations:

1. Conduct a thorough Cooperative Interference analysis along the Keystone Pipeline system to determine where there may be detrimental interference conditions that require mitigation.
    a. Evaluate all existing bonds to ensure that they are properly sized and located and necessary to mitigate harmful interference effects. This is important because the quality of protective coatings on pipelines in a shared right-of-way may not be sufficiently effective to preclude sacrificing significant amounts of protective current to foreign pipelines, which may adversely affect CP current distribution to the Keystone line.

b. If practical, consider relocating existing foreign CP sources that are deemed to be detrimental to the stray current mitigation strategy for the Keystone pipeline.

2. Consider the installation of Coupon test stations at locations of identified interference to assist in assessing the impact of interference and the success of mitigation and protection methods. The coupon stations should be utilized for future monitoring to ensure that the impact of changing environmental and operational conditions can be assessed and mitigation strategies modified accordingly. The coupons should be monitored to assess the polarized potential of the coupon in under the influence of stray current and the coupon current should be monitored to ensure that protective current is collecting on the coupon.
3. Consider a coating fault survey to identify locations where corrosion may have initiated, but may be below the ILI tool tolerance detection limit. A select number of these locations may be considered for examination to assess the success of efforts to optimize CP and interference mitigation strategies in controlling future corrosion growth.
4. Consider examining a select number of unrepaired ILI external metal loss anomalies six (6) months after implementing any necessary remedial measures to ensure that corrosion growth has been successfully controlled. Although based on a small data set, the unity plot shown in Figure 32 shows reasonable agreement with the ILI tool predicted peak depth and field measured peak depth with the ILI tool appearing slightly conservative. On that basis it would be reasonable to examine a select number of unrepaired ILI detected features to ensure a reduction in corrosion growth.

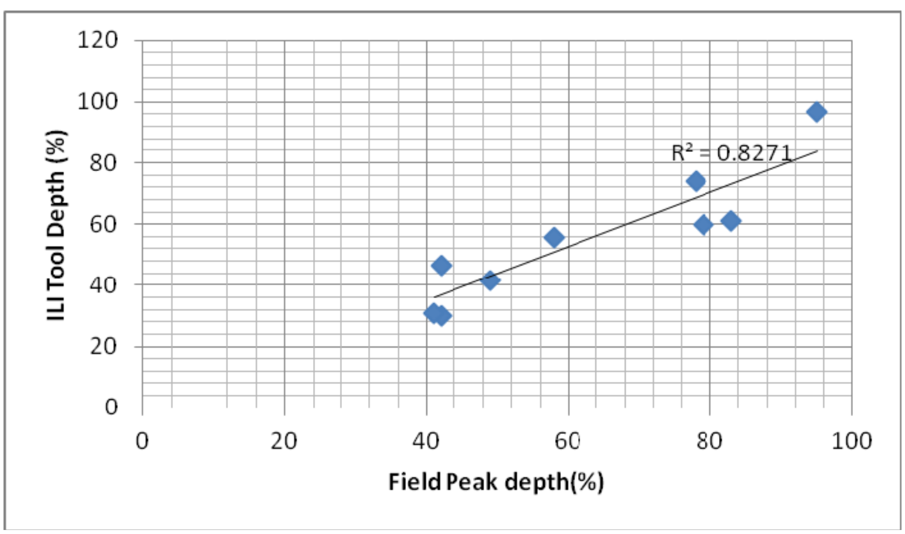

Figure 32. Unity Plot