GEOHAZARD INTEGRITY MANAGEMENT PROGRAM FOR OPERATING PIPELINES

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This paper provides an overview of a risk based Geohazards Integrity Management Program that has evolved over several years to help North American oil and gas companies manage the risk to their operating pipelines from hydrotechnical (river erosion) and geotechnical (landslides) hazards. Born from the need to systematically and efficiently identify, document, and manage thousands of geohazard sites along a pipeline system in a defensible, repeatable, and proactive manner, this paper discusses the challenges in implementing and sustaining a multi-year program that is practical and cost effective, yet sufficiently comprehensive to accurately describe the geohazard risk to the operating pipeline and surrounding environment. Based on international frameworks for geohazard risk management, and, like most risk based initiatives, the goal of the program is to focus company resources on geohazard sites that pose the greatest risk to the pipeline and the environment.

Program implementation starts on the most critical pipelines with the construction of a geohazard inventory along the pipeline using maps and information in historic reports. Follow-up baseline inspections are conducted to confirm the significance and location of the geohazard. Semi-quantitative risk assessments are then applied using the field observations to establish initial re-inspection intervals and action items for each hazard site. Over consecutive field seasons, the observations, recommendations, and photos from these baseline field inspections and follow-up re-inspections form an audit trail for each geohazard site. An internet based database houses the audit trails and provides functionality to locate, find, and display geohazards, reports, inspections, photos and to prioritize the hazard sites for future action. The database is also used to streamline the development of annual capital and operating programs and budgets. To date this Program has been implemented along 11,000 km of pipeline at approximately 3,700 sites in north western North America and through the Midwestern United States.

Keywords: database, erosion, geohazard, landslide, pipeline, probability, risk, river, slope

GEOHAZARDS

Geohazards are a subset of natural hazards and include subcategories of hydrotechnical, geotechnical, and seismic hazards. Hydrotechnical hazards include hazards caused by flowing water (river erosion) such as local scour, degradation (general scour), bank erosion, encroachment, and avulsion (channel shifting). Geotechnical hazards include ground movements driven primarily by gravity, such as landslides (earth and rock slides, rockfall), surface water and groundwater erosion, and settlement/subsidence. Seismic hazards, such as liquefaction, lateral spreading, and fault rupture, are ground movement processes triggered by earthquakes.

Classifying the geohazards using industry recognized classification schemes improves communication and helps characterize the geohazard mechanics and the assessing the affect on the pipeline and the environment. Program specific definitions of hydrotechnical and geotechnical hazard sites are employed to keep the scope of the integrity program within practical and affordable limits. These specific definitions are provided below.

Hydrotechnical Hazards

There are five classes of hydrotechnical hazards that the geohazard integrity management program addresses:

Scour

- Local deepening of channel (scour holes)
- Caused by boulders and woody debris that re-direct and concentrate water flow

Degradation

- General lowering of the channel bed
- Caused by a decrease in sediment supply or increase in flow velocity

Bank Erosion

- Horizontal channel migration at crossings
- Often occurs at the outside of river bends

Encroachment

- Horizontal channel migration where pipelines run parallel to the direction of water flow
- Often occurs at the outside of river bends

Avulsion

- Sudden abandonment of one channel and shift to another
- Caused by flooding and often occurs on debris flow fans

For the purposes of the integrity management program, a hydrotechnical hazard site is defined as a watercourse with the potential for appreciable channelized flow. Existing water flow at the geohazard site must have sufficient energy to erode soil cover and expose the pipeline. Under this definition, lakes, ponds, swamps, pools of standing water, or ephemeral gullies without evidence of appreciable past flow are not included in the program.

Geotechnical Hazards

Geotechnical hazards include ground movements driven primarily by gravity, such as landslides (earth and rock slides, rockfall), surface water and groundwater erosion, and settlement/subsidence. Longitudinal Right-of-Way (RoW) slopes steeper than 15 degrees and higher than 10 m are used to populate a geohazard integrity management program. The slope threshold is reduced to less than 15 degrees when weak geology is suspected in the region (i.e. Northeast British Columbia, Alberta, and Wyoming). All geotechnical hazards documented previous office files and geotechnical hazards identifiable in maps and airphotos provided by the client are also included.

Significance of Geohazards on Operating Pipelines

Some pipeline operators may be underestimating the density, relative frequency, or consequence of geohazards along their pipelines and RoWs. A brief analysis of the 3,700+ geohazard sites intersecting pipelines RoWs in western North America, assembled as part of an ongoing geohazards management program, reveals some useful metrics.

Geohazard Density

On average, hydrotechnical hazard sites are five times more common along pipelines than geotechnical hazards. Table 1 below shows the average hydrotechnical and geotechnical hazard density (aka spatial frequency) for select regions in western North America.

Table 1. Average geohazard densities by region

	Hydrotechnical Sites	Geotechnical Sites
Western North America	1 every 3 km	1 every 13 km
British Columbia	1 every 2 km	1 every 7 km
Alberta	1 every 6 km	1 every 20 km
Wyoming	1 every 6 km	1 every 90 km

These densities suggests that, depending on the geography, 100 to 300 hydrotechnical hazards sites and 7 to 85 geotechnical sites are likely to exist along, say, a 600 km long pipeline. Surprisingly, some pipeline operators report that their geohazard management programs are "complete" with an inventory of 10 to 20 hydrotechnical and geotechnical sites, in total. A re-assessment of the geohazard inventory along the pipeline corridor, using the geohazard definitions provided above as a guideline, is one of the first tasks in setting up a complete geohazard integrity management program. This initiative is called a baseline inspection, as described later in this paper.

Geohazard Activity

Flowing water from hydrotechnical hazards is constantly eroding pipeline cover. Average vertical erosion rates of 20 mm to 30 mm per year (1 m to 1.5 m of pipeline cover eroded in 50 years) are often observed. However, erosion rates are not a steady state process, and significant amounts of erosion can occur during large magnitude flows brought on by spring runoff, rain-on-snow events, or intense seasonal thunderstorms. Intense flow events with a 1 in 10 or lower return periods often result in a series of pipeline exposures across a system which can go undetected (if they are not visible from the air) until a thorough ground inspection is performed. Depth and effectiveness of the pipeline cover and the on-site conditions contributing to the erosion of the pipeline cover, such as the presence of debris jams, can improve or deteriorate from season to season. The point is that geohazards sites are not static - the frequency and type of action assigned by an integrity management program must be tailored annually to suit the site variability so that high risk sites receive more timely attention than lower risk sites.

Geotechnical hazards are also triggered by spring runoff, rain-on-snow events, or intense seasonal thunderstorms. Weak or unfavorable geology and uncontrolled surface and/or groundwater are also significant contributing factors to the (re)occurrence of a geotechnical hazards. Human activity such as directing water onto the RoW or pre-loading on or adjacent to the RoW are also common triggers unique to geotechnical hazards. However, for a given storm event, hydrotechnical hazards typically respond much faster and are more sensitive to the storm intensity than geotechnical hazards. Again, regular ground based inspection of the geohazards, especially hydrotechnical hazards, is required to monitor changes to depth of cover in order to proactively manage the potentially adverse changes at the site.

Estimates of Pipeline Exposure Frequency

Recording incidences of pipeline exposure and impact over the last five years across 11,000 km of pipeline and over 3,700 sites in western North America permits the annual frequency of pipeline exposure or impact to be quantitatively estimated, as shown in Table 2.

Table 2. Annual frequency of pipeline exposure/impact by geohazard type

	Hydrotechnical[1]	Geotechnical[1]	Both Geohazard Types
Events per site	0.0038	0.0025	0.0035
Events per km of pipeline	0.0012	0.0002	0.0014
Events per 5000 km of pipe	6	1	7

[1] pipeline exposure for hydrotechnical hazards; pipeline impact from geotechnical hazards

For a given geohazard site, hydrotechnical sites are 1.5 times (0.0038/0.0025) more likely to cause a pipeline exposure than a geotechnical site. The above data also suggests that, for a pipeline system on the order of 5,000 km an operator could expect, on average, to have six pipeline exposures each year from hydrotechnical hazards and one impacted pipe from geotechnical hazards. Furthermore, a 600 km pipeline should anticipate 1 exposure from a hydrotechnical hazard every 1.4 years.

To summarize the last three sections, hydrotechnical hazards are 4 times more common than geotechnical hazards and 1.5 times more likely to cause an exposed pipeline than geotechnical hazards. An effective geohazard integrity management program should focus on hydrotechnical hazards.

Estimates of Pipeline Failure Frequency

The geohazard integrity management program described in this paper currently focuses on proactively managing pipeline exposure instead of pipeline failure. Understandably, pipeline operators are more comfortable with managing for potential pipeline exposures/impacts rather than potential pipeline failures. Never the less, a comparison between pipeline exposure and pipeline failure is still needed to put the problem of pipeline exposure in context with other types of pipeline failure.

Reliable statistics for pipeline failures (leaks and ruptures) caused by geohazards are a challenge to obtain and review partly due to inaccurate reporting and the fact that pipeline failures from geohazards are so infrequent. (Porter et al. 2004) reported that United States Department of Transportation (US DOT-OPS) Gas Transmission Data 1984-2001 for onshore steel pipelines > 2” (50 mm) diameter reports pipeline failures from “natural forces” (9%) are rare in benign terrain compared to third party impact (36%) and corrosion (24%). Data from European Gas pipeline Incident data Group (EGIG) Natural Gas Transmissions Pipelines 1970-2001 are provided in Table 3. Rizkalla (2008) reports additional geohazard related failure frequencies with similar orders of magnitude.

Table 3. Annual frequencies per 1000 km by hazard type (Porter et al. 2004)

Hazard	Gas Pipeline Failure[1]
Third Party Impact	0.220
Material Defect	0.075
Corrosion	0.060
Ground Movement (geohazard)	0.025
Operator Error	0.020
Other	0.030

[1]EGIG Natural Gas Transmission Data 1970-2001

Table 4. Annual frequencies per 1000 km by region (Rizkalla, 2008)

Region	Source	Pipeline Failure
Alberta	AEUB Website 1980 to 1997	Oil: 0.0032; Gas: 0.0016
Canada	NEB Website 1984 to 2003	Oil: 0.0054; Gas: 0.0042
USA	DOT-OPS 1984 to 2001	Oil: -- ; Gas: 0.0045

By comparing Table 4 with Table 2, it appears that incidents of exposed pipeline are on the order of 260 times (1.4/0.0054) to 875 times (1.4/0.0016) more frequent than incidences of failed pipeline - at least two order of magnitude difference. This suggests that a 600 km pipeline with an average of 1 exposed pipe every 1.4 years may have a pipeline failure once every 400 years

In addition to the statistical estimates, subjective observation over the last several years indicates that pipeline exposures and subsequent (albeit rare) pipeline failures from geohazards are more likely where:

- precipitation intensities (storms) are high and more frequent,
- tributary stream gradients increase abruptly as they descend into larger river valley floors,
- watercourses are more likely to transport boulders and woody debris,
- depths of cover on watercourses are less than 0.30 m
- unfavourable geology is significant regional contributing factor to slope instability, and
- surface water and groundwater is directed onto slopes, either naturally or by human activity.

Consequences of Pipeline Failure from Geohazards

Hydrotechnical hazards deliver high consequences - not only are they root causes for pipeline ruptures but they also provide a conduit for spreading spilled product into environmentally sensitive areas. The consequences from geotechnical hazards may be slightly less because, although they have a propensity to deliver sediments into environmentally sensitive areas, spilled product tends to be absorbed by the surrounding earth, making product containment more manageable. Geotechnical consequences will be higher if the geohazard site's run-out zone is located in close proximity to a watercourse.

Guidance from Pipeline Codes

There are four major pipeline codes that discuss geohazards:

- USA (ASME B31)
  - 31.4 Hydrocarbon and Liquid Pipelines
  - 31.8 Natural Gas Pipelines
- Canada (Z-662)
- European (ISO 16708)
- Norway, Det Norske Veritas, DNV (OS-F101), Submarine Pipeline Systems

All pipeline codes recognise that geohazards exist, but only the newer codes attempt to mandate that some form of geohazard integrity management program be adopted (Leir and Baumgard 2008). Most codes require geohazards be assessed during pipeline design (in the form of loads on the pipeline) but few codes provide guidance on how to manage geohazards during pipeline operations. Some codes are more specific in that once geohazards are identified they recommend that mitigation or monitoring (inspection and re-inspection) be undertaken.

Annex N within the Canadian Z662 pipeline code provides the most explicit guidance on how to manage geohazards. Although it recommends documenting all forms of risk to a pipeline once it becomes operational, it is not prescriptive and provides the pipeline operator with considerable latitude on how to manage their geohazards. . Many jurisdictions have made *Annex N* mandatory including the British Columbia Oil and Gas Commission (BC OGC) and Alberta Energy and Utilities Board (EUB).

GEOHAZARDS INTEGRITY PROGRAM

As part of an introduction to Geohazard Integrity Management, so far this paper has provided background to geohazards by defining hydrotechnical and geotechnical hazards, commenting on their frequency and activity, and also providing insight into the frequency of pipeline exposures and pipeline failure from geohazards in Western North America. This paper will now describe the components of a geohazard integrity management program designed to manage the risk from these geohazards.

Challenges with Current Geohazard Management Programs

Most geohazard management programs consist of one or more of:

- helicopter patrols,
- depth of cover surveys,
- monitoring of on-site instruments, and
- mitigation

Larger geohazards, such as wide river crossings and higher/longer slopes, with relatively easy access, usually consume most of the operator’s attention. During baseline inspections, however, most exposed pipelines are found on smaller creeks in remote locations. Since 2003, almost every baseline inspection has discovered at least one site with an exposed/impacted pipeline.

The frequency of helicopter patrols is usually based on the Class Location (building density) and range from every week to once a year. Despite providing no information on the current protection around the pipeline, helicopter patrols are very effective in identifying third party encroachment, obvious geohazards, long sections of exposed pipe, and large pipeline failures. Timing and interest of the helicopter pilot often governs the effectiveness of the patrol. The cost per site of a helicopter patrol is usually higher than a comparable series of ground inspections. The most effective deliverable from a helicopter patrol consists of a few photos of active hazards tagged with a GPS coordinate. Lengthy reports containing several photographs are rarely read or distributed effectively.

The frequency of depth of cover surveys at river crossings is subjectively determined with little regard to the activity of the river, water depth, crossing design, or current depth of cover. Wider rivers are usually the focus of several surveys while medium creeks have never been surveyed. Bathymetry to monitor changes to bed morphology (scour holes) is rarely collected during the survey.

Long term monitoring (> 3 years) of expensive onsite instruments such as piezometers, slope inclinometers, or surface survey hubs is rare because the site falls off the priority list after movement slows. A geohazard may become inactive due to a short term change in the antecedent rainfall. Periodic monitoring and effective filing of information should be established in case the geohazard reactivates.

Mitigation is one of the most popular yet most expensive geohazard management techniques. There seems to be no shortage of enthusiastic project managers and contractors willing to “turn dirt” on site and re-establish the cover over the pipeline. Some solutions are engineered and include construction inspection while many other repairs are over-designed or not necessary because other forms of risk management could have effectively reduced the risk to the operator.

Program Goals

The components described above are rarely integrated and, despite the useful information these programs can generate, the geohazard management program continues to be guided by a reaction to seasonal storms or an individual’s risk tolerance.

Following a series of geohazard inspections operators simply want to know:

- Which sites are high risk to the pipeline?
- What needs to be done at the site to reduce/manage the risk?
- By when should we act?

Additionally, pipeline operators requested a geohazard management program that is:

- Systematic, Documented, Repeatable, and Proactive
- Helps allocate resources to geohazards that need the most attention
- Prevents geohazard sites from “falling through the cracks”

Program Methodology

The geohazard integrity management program adopts a similar framework as a corrosion integrity program. The following methodology is applied to each pipeline in an operator's system:

1. Build a preliminary geohazard inventory using a pipeline centerline with chainages, maps, and existing reports/records, and the simple definitions of hydrotechnical and geotechnical hazards.
2. Conduct baseline field inspections – Ground inspect every geohazard site in the preliminary geohazard inventory (Step 1), remove insignificant geohazards from the inventory, make observations about the hazard activity and protection around the pipeline (measure DoC), and select a recommendation from Table 5. Each ground inspection requires about 20 minutes.

Table 5. Recommendation Classes

Recommendation Class (% of sites)[1]	Description
Mitigation (1% to 9%)	General field actions typically requiring an engineering design or significant input from the engineering department such as riprap placement, slope erosion control, slope drainage control, slope stabilization, or relocate pipeline. Construction may be preceded with a detailed investigation and an engineered design.
Monitoring (0% to 1%)	Installation of instruments to quantify the progression of a hazard.
Maintenance (1% to 2%)	General field actions typically not requiring an engineering design or significant input from the engineering department. Maintenance activities can be carried out independently by pipeline districts but may require supervision by a technical specialist. Examples of maintenance include cleaning culverts, minor ditch or berm construction, replacement of swamp weights or pipeline markers, culvert installation, and access road maintenance.
Detailed Investigation (2% to 3%)	Site specific investigations to gather more information such as site surveys to determine depth of cover, stream morphology, pipe location, drilling to obtain subsurface information, or time-series airphoto interpretation. Detailed investigations are typically not performed unless they are preceded with a ground inspection.
Inspections – Ground (80% to 90%)	Site visits on foot to review the status of the hazard, elements, vulnerability, consequences, and to provide new or revised recommendations.
Inspections – Aerial (1% to 5%)	Site visits by air to review the status of the hazard, elements, vulnerability, consequences, and to provide new or revised recommendations.
Inspections – Office (1% to 5%)	An office-based assessment study such as reviewing the as-built designs, brief airphoto interpretation, or a review of monitoring data.

[1] includes the percentage of sites assigned to that type of action

3. Estimate the probability of exposure for each geohazard site using the field observations and simple measurements on hazard activity and vulnerability of the pipeline. Semi-quantitative risk based algorithms are used to convert field observations into a probability of pipe exposure. The algorithms are periodically calibrated using recorded incidences of pipe exposure. A more detailed discussion about the risk based framework used in this program can be found in AGS (2000), Leir (2004), Leir et al. (2004), Wise et al. (2004), and Leir and Baumgard (2006).

4. Automatically prioritize the sites using the probability of exposure and Table 6. High probability sites are assigned higher priority.

Table 6. Probability class and corresponding action priorities

Probability Class	Action Priority
very high	< 6 months
high	< 1 year
medium	< 2 years
medium	< 3 years
low	< 4 years
very low	< 5 years

5. Perform the action selected from Table 5.

6. Re-inspect (go back to Step 3). Re-assess geohazards sites due that year, note the changes, revise observations and recommendations, re-assess probability, and re-prioritize.

Since 2003 a systematic geohazard integrity management program has been applied to over 11,000 km of major oil and gas transmission lines across BC, Alberta, Saskatchewan, Wyoming, Montana, North Dakota, Missouri, and Washington States. Over 3,700 hazards sites have been identified, inspected, and a probability of pipe exposure has been estimated from field observations and measurement s. Each geohazard site is prioritized for future action based on the probability of pipe exposure where very high probability sites require action within 6 months and very low probability sites require action within 5 years. An Internet database is used to manage the information and status of each hazard within the pipeline system. This database system is an essential component to an effective geohazard management program (Leir et al 2004).

PROGRAM BENEFITS

There are a number of key benefits to implementing a geohazards integrity management program like this:

- The program helps pipeline operators make informed and defensible decisions. Operators will know exactly how many geohazard sites affect their system, where they are located, and how much risk they impose on the pipeline and RoW. It helps operations allocate resources to geohazards that need the most attention

- The program maintains an audit trail and assigns a due date that prevents geohazard sites from “falling through the cracks”. Employees may come and go but the program and background information lives on. The most current status of each geohazard site is stored in a centralized online database accessible anywhere by pipeline employees

- Program encourages proactive management. Geohazards are identified and managed before an incident occurs
- Program is systematic and repeatable. Inspection programs can be set up in days instead of weeks
- Program is cost effective and efficient. The program is field-based and minimizes resource intensive office analysis. Only a pipeline length or the number of geohazards sites is needed to create annual budgets. More detailed and costly studies/mitigations are reserved for a select geohazard sites
- Program currently exceeds regulatory requirements

Implementation Challenges

Despite the benefits there are some challenges that threaten initial implementation and longer term survival of the geohazard integrity management program.

- Commitment from Management – A senior employee needs to be identified in the operations department to champion the program over several years
- Communications between head and field offices – This program is usually championed from the head office. Buy-in from district offices is required to ensure the most current status of the geohazards site is known by all offices and entered into the database
- Keeping the Database Current – A commitment must be made by all users to ensure that the information in the database is current every year
- Timely Inspections – The pipeline operator needs to commit to doing inspections and mitigations before they are due. This will keep the database current and look favourable to regulators
- Maintaining Program Momentum – Program must be deliver high value, reduce the number of pipeline exposures, be affordable, receive regular funding, and be supported by a senior champion

Program Costs

The annual cost of a geohazard integrity management program depends on the size of the pipeline system. Operations departments with 2000 km to 5000 km of pipeline in their systems are allocating on the order of $100K to $300K per year to conduct baseline inspections, re-inspections, and detailed investigations. An example 2009 geohazard program budget is provided in Table 7.

Table 7. Example operational budget to manage geohazards

System	Scope	Length	Sites	2009 Budget
Pipelines B, C, and D	Baseline Inspections	600 km		$120,000
Pipeline A	Re-inspection – ground inspections	-	50	$25,000
Pipeline A	Detailed Investigations - DoC Surveys of hydrotechnical sites	-	5	$50,000
Pipeline A	Monitoring – surveying landslide movements at geotechnical sites	-	2	$25,000
Total				**$220,000**

In the above example, Pipeline A was baselined in 2008 so funds are now being allocated to re-inspect 50 geohazard sites due for a ground or aerial inspection before Dec 31, 2009. Five crossings that were too deep to wade during the ground inspections and have no recent record of past surveys have been assigned a depth of cover survey (including bathymetry) using a boat. One of the five sites needs a diver because the water depth exceeds 5 m and a pipe locator won't work. Two other sites require ground movement survey to quantify rates of surface ground movements of a landslide suspected of impacting the pipeline. This information will be used for follow-up pipe–soil interaction (detailed stress-stain) analysis. Pipelines B, C and D totaling 600 km have been scheduled for a baseline inspection. Not shown in the above table, since capital budgets is usually separate form operational budgets, is the capital budget of $150,000 to repair 3 hydrotechnical sites on Pipeline A with exposed pipeline - discovered during the baseline survey in 2008. No sites requiring installation of instruments are due in 2009.

Future Work

The geohazard integrity management program is formally evaluated internally and by pipeline operators once a year to identify improvements in areas of communications, budget management, field operations and safety, database functionality, risk estimation, and program growth. To date most efforts have been directed towards improving field efficiency, safety, and accuracy of risk estimation. Field inspection and risk estimation modules are currently being refined to estimate the probability of debris impact and failure of an exposed pipeline.

CONCLUSIONS

This paper describes a field based geohazard integrity management program that has been developed over the last several years to address the significance and high consequence of geohazards on operating oil and gas pipelines. Hydrotechnical and geotechnical geohazards are numerous, active, and sensitive to seasonal variation in precipitation intensity. Crossings and RoW slopes need to be inspected at a frequency commensurate with their activity, effectiveness of protection around the pipeline, and estimated probability of exposure/impact.

Although pipeline exposures are approximately two orders of magnitude more frequent than pipeline failures, the consequences of exposure are far less than that if pipeline failure. Nevertheless, at this time, this program elects to manage geohazards by using thresholds for the probability of exposure/impact because, understandably, pipeline operators are more comfortable managing for potential pipeline exposures/impacts than potential pipeline failures.

This program is risk based in that it assesses the presence and activity of the geohazard and the protection around the pipeline. Frameworks for incorporating probability of pipeline failure and consequences of failure are currently in place if a pipeline operator elects to manage their geohazards at this level.

The program improves on typical geohazards programs in that it integrates results of ground and aerial inspections, depth of cover surveys, monitoring, and mitigation activities. It helps guide resources to high probability sites, improves communications between head and field offices, and through an internet database, provides centralized access to current and historic site activities. The program currently exceeds code requirements and endeavors to be affordable and deliver a high level of value to pipeline operators.

ACKNOWLEDGMENTS

This program has evolved over several years and owes its success to integrity management leaders within the organizations of Kinder Morgan Canada, Terasen Gas Inc., Alliance Pipelines Ltd, Pembina Pipelines Inc., TransGas Ltd., and Plains Midstream Canada, and conscientious individuals at BGC Engineering Inc. including, Ms. Margot Ellis, Mr. Hamish Weatherly, Dr. Alex Baumgard, Mr. Gerry Ferris, Ms. Tara Coultish, Mr. Martin Zaleski, and Mr. Ashton Friesen.

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