Alberta Energy Regulator

Obsidian Energy Ltd.

Appeal of Environmental Protection Order

March 7, 2025

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Decision 2025 ABAER 002: Obsidian Energy Ltd. Appeal of Environmental Protection Order

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Decision

[1] Having carefully considered all of the evidence, the Alberta Energy Regulator (AER) confirms the decision of the AER's Compliance and Liability Management (CLM) branch, now Regulatory Compliance, to issue an environmental protection order to Obsidian Energy Ltd. (Obsidian) on March 23, 2023.

[2] In reaching this decision, the AER hearing panel presiding over this proceeding considered all relevant materials properly before us, including the record of the decision maker and new (*de novo*) evidence filed in this regulatory appeal and each party's argument. Accordingly, references in this decision to specific portions of the evidence are intended to assist the reader in understanding our reasoning on a particular matter and do not mean that we did not consider all relevant portions of the evidence.

Introduction

Background

[3] On November 29, 2022, a cluster of seismic events occurred near the Hamlet of Reno, about 40 kilometres (km) southeast of Peace River, Alberta. The first event occurred at 4:55 p.m. Mountain Standard Time. The largest event, with a local magnitude (M_L) of 5.59,[1] occurred at 5:55 p.m. Over the next 24 hours, there were 14 seismic events.

[4] On November 30, 2022, the Alberta Geological Survey (AGS) issued a public announcement about the seismic events. In the announcement, the AGS stated that while it continues to investigate the cause of the events, initial findings point to natural tectonic activity as the cause. This initial finding was based on the following factors:

- There was no active hydraulic fracturing activity in the area.
- While there were fluid disposal operations in the region, none were in the immediate vicinity of the seismic events, and there had been no changes in fluid disposal rates over the past year.

[1] Rounded to 5.6 M_L in subsequent mentions.

- The data the AGS had at the time showed the events occurring at greater depths than would be expected in the case of an induced seismic event.

[5] In early December 2022, the AGS deployed a local seismic nodal monitoring array in the vicinity of the 5.6 M_L seismic events to collect additional data.

[6] On March 16, 2023, a new cluster of seismic events occurred in the same area as the previous events, including an event with a 5.09 M_L. Given the persistence of the seismic events in the area, the AGS began to think that the seismic events were induced by human activity.

[7] On March 17, 2023, the AGS received the initial processed data from the local seismic nodal array from Nanometrics Inc. (Nanometrics).

[8] On March 20, 2023, the AER attributed the seismic events to Obsidian's disposal operations at its 14-18-82-17W5M disposal well (the Obsidian well), which is authorized for disposal of fluids into the Leduc Formation.

[9] On March 22, 2023, AER staff met with Obsidian to discuss the seismic events. At the meeting, the AER informed Obsidian that the AER attributes the seismic events to disposal operations at Obsidian's well based on data from the seismic nodal array.

[10] On March 23, 2023, the Director of Field Operations South within CLM met with Obsidian to discuss the contents of a proposed environmental protection order (the order) under sections 113 and 241 of the *Environmental Protection and Enhancement Act* (*EPEA*). Shortly after the meeting, the CLM director issued the order to Obsidian.

[11] Obsidian filed a request for a regulatory appeal of the order on April 21, 2023.

[12] On July 18, 2023, the AER granted Obsidian's request for a regulatory appeal.

Hearing

[13] A public hearing was held November 28 to December 6, 2024, to consider the regulatory appeal. Obsidian and CLM were the only participants in the regulatory appeal hearing. The hearing was adjourned on December 6, 2024, to await receipt of final argument notes and references from Obsidian and CLM. After receipt of those materials, the hearing was closed on December 10, 2024. A list of the hearing participants in included in appendix 1. A copy of the order is provided in appendix 2.

Regulatory Framework

[14] Section 113 of *EPEA* authorizes the AER to issue an environmental protection order to a person responsible for a substance when the AER is of the opinion that a release of a substance into the environment may occur, is occurring, or has occurred, and the release may cause, is causing, or has caused an adverse effect.

[15] Section 1(tt) of *EPEA* states that "person responsible," when used with reference to a substance or a thing containing a substance, means,

> (i) the owner and a previous owner of the substance or thing,
>
> (ii) every person who has or has had charge, management or control of the substance or thing, including, without limitation, the manufacture, treatment, sale, handling, use, storage, disposal, transportation, display or method of application of the substance or thing,
>
> (iii) any successor, assignee, executor, administrator, receiver, receiver-manager or trustee of a person referred to in subclause (i) or (ii), and
>
> (iv) a person who acts as the principal or agent of a person referred to in subclause (i), (ii) or (iii), but does not include…

[16] Sections 113(3) and 241(1) of *EPEA* outline the provisions that may be included in an environmental protection order. However, in this regulatory appeal, Obsidian did not take issue with any of the directions provided in the order. Obsidian testified that it had complied with the terms of the order, and CLM did not contest this.

[17] Hearing commissioners are authorized under section 12 of the *Responsible Energy Development Act* (*REDA*) to conduct regulatory appeals and make decisions in the name of and on behalf of the AER. Under section 41(2) of *REDA*, we must determine whether to confirm, vary, suspend, or revoke the CLM's decision to issue the order.

Hearing Issues

[18] The panel established the key issue for the hearing to be whether the order, including all of its content, should be confirmed, varied, suspended, or revoked.

[19] To focus the parties' submissions for the proceeding, the panel invited the parties to address the following questions:

- Were the seismic events specified in the order induced by human activity?
- Is Obsidian's disposal operation responsible for the seismic events?

The Nature of the Regulatory Appeal Proceeding

[20] Section 31.1 of the *Alberta Energy Regulator Rules of Practice* under *REDA* permits the panel to allow the submission of new information in a regulatory appeal if the information is relevant and material to the appealed decision and was unavailable to the decision maker when the decision was made.

[21] In this proceeding, we permitted Obsidian and CLM to file significant new (*de novo*) evidence that was not available to the CLM decision maker when they issued the order to Obsidian. Given the significant amount of new evidence in this proceeding, CLM and Obsidian agreed that no standard of review analysis need be applied to the decision under appeal. Obsidian argued that instead, the panel should make its decision having regard for all the evidence on the record of this proceeding, including the record of the decision maker and the new evidence. We agree with the parties that no standard of review should be applied and considered both the record of the decision maker and the new evidence in coming to our decision.

Relief Requested by Obsidian and Onus of Proof

[22] Obsidian submitted that CLM had erred in certain analyses, findings, and conclusions that formed the basis for issuing the order to Obsidian and that other disposal operations were "substantially more likely" to have caused the seismic events. Consequently, Obsidian requested that the AER revoke the order.

[23] During the oral hearing, Obsidian modified its request. While its preference was that the order be revoked, Obsidian asked that in the event we decide not to revoke the order, we vary the order in accordance with our findings in this proceeding. When we asked Obsidian what aspects of the order should be varied, Obsidian did not provide any suggestions. Obsidian's counsel said this would be addressed in final argument.

[24] In its final argument, Obsidian requested the following relief:

- The order be revoked if we conclude that the Obsidian 14-18 well was not the cause of the seismic events.
- The order be revoked and a new order issued, or the existing order be varied, naming all parties responsible if we conclude that one or more of the other industrial operations caused the seismic events and that the Obsidian 14-18 well potentially contributed "in a significant enough way." Alternatively, the order be revoked and *Directive 065: Resources Applications for Oil and Gas Reservoirs* (*Directive 065*) relied on to address those operators and operations we find caused the seismic events.
- The order be revoked and a regional order issued if we conclude that all of the industrial operations in the vicinity of the Reno, North Heart, and North Peace River clusters are or may be contributing to the induced seismicity in those clusters.

[25] In this proceeding, the onus of proof was on Obsidian, as the regulatory appeal requester, to persuade us that the order should be revoked, suspended, or varied. In a regulatory appeal, the onus is on the requester, who must provide evidence that supports their position on the balance of probabilities; that is, the requester must bring sufficiently clear, convincing, and cogent evidence to satisfy the balance of probabilities test, to succeed in the regulatory appeal.

Confidentiality Order

[26] Obsidian requested and we granted a confidentiality motion over certain scientific and technical data and related interpretations, analyses, and models that Obsidian considered confidential and commercially sensitive. This information included the following:

- proprietary 2-D and 3-D seismic data
- proprietary seismic interpretations of the Leduc Formation
- proprietary interpretations and quantitative analysis of well logs
- a proprietary geological model of the Leduc Formation
- a proprietary reservoir model of the Leduc Formation
- proprietary geological mapping of the Leduc Formation and other relevant intervals
- a proprietary geomechanical analysis of the Leduc Formation

[27] To protect the confidential information, redacted versions of documents were filed on the public record of the proceeding. During the oral hearing, those portions of direct evidence, cross-examination, and final argument involving the confidential information were held in camera. While we had access to and considered all the information on the record of this proceeding, including the confidential information, the decision has been written in a manner that does not disclose any confidential information. In some instances, this required us to leave out certain details and generalize our description of the evidence we relied on to make our decision.

CLM Witnesses

[28] During opening remarks, we confirmed, consistent with the AER’s usual practice, that we would not be qualifying expert witnesses for this proceeding. However, we indicated each party could argue what weight we should give to a witness's evidence based on that witness's qualifications and other relevant factors.

[29] CLM witnesses included the following:

- Mr. Erik Kuleba, Director of Field Operations South of the AER’s Regulatory Compliance Branch (formerly CLM). Mr. Kuleba is the statutory decision maker who issued the order.

- Dr. Mauricio Canales, Senior Geophysicist in the AGS, focused on induced seismicity.
- Dr. Todd Shipman, Senior Advisor for induced seismicity and geohazards in the AER's Regulatory Compliance Branch.
- Mr. Claudio Virues, Senior Reservoir Engineer at the AER.
- Mr. Elwyn Galloway, Senior Geophysicist at the AGS.

[30] Obsidian argued the panel should afford materially less weight to the opinion evidence of the CLM witnesses Dr. Canales and Dr. Shipman, given their extensive involvement in the events leading up to the issuance of the order. Obsidian argued their involvement would make it difficult for them to have the necessary degree of detachment or impartiality. Obsidian submitted that because Drs. Canales and Shipman cannot be considered impartial, they would not have properly qualified as expert witnesses. Therefore, their opinion evidence should garner materially less weight than any competing evidence.

[31] Obsidian also argued that the testimony of Mr. Virues consisted largely of unsupported assertions and should be given no weight.

[32] CLM submitted that in deciding what weight should be afforded to the opinion evidence of witnesses, we should have regard for more than just who the witness works for, but also their behaviour during the hearing. This includes whether witnesses appeared dispassionate and objective during their testimony, whether they responded to questions reasonably, and whether their opinion evidence was consistent with other evidence.

[33] We recognize that when presenting evidence, it is common for parties to present evidence that supports their views and ignore or downplay contrary information and interpret ambiguous evidence in a way that supports their position. This is a form of confirmation bias, and it can be pervasive even among well-intentioned experts or decision makers. We must therefore be cognizant of the potential for bias by each party as we weigh the evidence before us.

[34] In determining what weight to apply to the opinion evidence of each party, we had regard for Section 47 of *REDA* which states:

> The Regulator in conducting its hearings is not bound by the rules of law concerning evidence applicable to judicial proceedings.

[35] We considered the reliability, relevance, and objectivity of the evidence and the methodology used by each witness to reach their conclusions. Rigorous methods that are scientifically sound, transparent, and generally accepted within the relevant field tend to mitigate the influence of bias. We also considered whether the witness's findings or opinions were consistent with other evidence presented in this proceeding and whether those conclusions disproportionately favour one side or marginalize other interpretations, which may indicate confirmation bias. Similarly, we considered whether inconsistent

answers, defensiveness, or an unwillingness to acknowledge alternative viewpoints during cross-examination may indicate a potential bias.

Seismic Events Specified in the Order Were Induced by Human Activity

[36] Induced seismicity refers to seismic events caused by human activities. A variety of industrial activities, including geothermal energy production, hydraulic fracturing for oil and natural gas, and wastewater injection and disposal, may cause seismic activity.

[37] During wastewater injection and disposal, critically stressed subsurface faults may be activated (slip) near the disposal operations, resulting in seismic activity. Failure of existing faults may be due to

- an increase in shear stress,
- a decrease in normal stress, or
- a pore-pressure increase.

[38] Injection of fluids into the subsurface normally increases pore pressures in the reservoir, potentially lubricating and triggering slip on existing planes of rock weakness.

Seismic Activity in the Peace River Region

[39] CLM and Obsidian identified three clusters of seismic activity in the Peace River region as shown in appendix 3.

[40] The North Peace River cluster is northeast of the Town of Peace River about 40 km northwest of the Obsidian well. Seismic activity in this cluster was first recorded in 2014. Over 90 events of up to 4.04 M_L have been detected in this cluster as of March 2023. The AGS has historically considered the North Peace River cluster to be the result of natural seismic activity; however, recent and ongoing evaluations by the AGS and others indicate the potential for induced seismicity in this area. There is a series of high-volume Leduc disposal wells located about 18 to 20 km to the east of the North Peace River cluster.

[41] The North Heart cluster is about 20 km north of the Obsidian well. Active seismicity was identified in this cluster starting in 2016. Over 30 events up to 3.2 M_L have been detected in this cluster until November 2022. A surge in seismicity occurred between April and May 2019. The two largest seismic events, both occurring in May 2019, had a 3.2 M_L. Preliminary analysis has linked these seismic events to a Canadian Natural Resources Limited well at 13-11-084-17W5 (the 13-11 Leduc well), disposing of wastewater into the Leduc Formation at an approximate depth of 1828 metres (m).

[42] The Reno cluster is located further south in the Reno area. Seismicity was first recorded in this area in 2017 (two events). A small burst of seismic activity was recorded in 2021, followed by a significant increase in activity in late 2022, including the two major (greater than 5 M_L) seismic events in

November 2022 and March 2023 that led to the issuance of the order to Obsidian. Between November 2022 and March 2023, the AGS recorded over 245 seismic events in the Reno area.

[43] Seismic activity may have occurred earlier in these clusters and not recognized because of the sparse regional seismic monitoring arrays in place and the limitations of the monitoring data available at that time.

CLM Determination that Obsidian's Disposal Operations Caused the Seismic Events

[44] The AGS initially attributed the seismic events to natural tectonic causes. However, the continuing nature of aftershocks from the November 29, 2022, 5.6 M_L event and the second significant seismic event on March 16, 2023, suggested that the events had a pattern of recurrent seismic activity like other observed instances of induced seismicity.

[45] By March 17, 2023, the AGS had received from Nanometrics the initial processed data from the seismic nodal array AGS had deployed in the vicinity of the seismic events. This data helped refine the location of the seismic events. The nodal array data showed two clusters of seismic events relatively close to the Obsidian well, and the events were shallower than originally determined from the regional seismic station data. While most events were observed to occur in the Precambrian basement rocks, the shallower events extended up to the Leduc Formation at a depth of about 2 km. The Obsidian well is authorized to dispose of water into the Leduc Formation at a depth of about 1920 m and has been operational since December 2012. Based on these observations, the AGS believed there was a spatial and temporal correlation between the seismic events and Obsidian's disposal activities. The seismic events were below and close to the Obsidian well and occurred during disposal operations at the Obsidian well. This caused the AGS to revise its opinion on March 20, 2023, and attribute the seismic events to human activities.

[46] Before issuing the order, CLM considered the potential for other disposal operations in the area to have caused the seismic events. This included a nearby Baytex Energy Corporation disposal well at 6-14-82-18 W5M (the 6-14 Belloy well) authorized to dispose into the Belloy Formation at a depth of about 790 m and the 13-11 Leduc well.

[47] CLM eliminated the 6-14 Belloy well as a possible cause of the seismic events because it was disposing into the Belloy Formation at a much shallower depth than the seismic events, and there was no observed seismicity between the depth of disposal and the deeper seismic events. While the 13-11 Leduc well was disposing into the Leduc Formation at a comparable depth to the seismic events and was considered the cause of the induced seismicity in the North Heart cluster, this well was eliminated by CLM as a possible cause of the seismic events because it was about 20 km away from the Reno seismic cluster. Also, there had been no seismic activity between the13-11 Leduc well and the seismic events in the Reno area.

[48] Based on its view that the seismic events were induced and that the Obsidian well was the cause of the seismic events, CLM issued the order to Obsidian.

Obsidian's Views About the Cause of the Seismic Events

[49] Obsidian retained consultants in the areas of geology, geomatics, geophysics, petrophysics, and reservoir modelling to assess the geological and geophysical conditions in the vicinity of the Obsidian 14-18, 13-11 Leduc, and 6-14 Belloy wells and to provide independent analysis and conclusions regarding the causation of the events referenced in the order. The consultant's retained by Obsidian and who appeared as witnesses at the hearing are listed in table 1.

Table 1. Obsidian consultants who appeared as witnesses

Consultant/witness	Company	Scope
Dr. Mehran Pooladi-Darvish	MPD Reservoir Engineers Ltd. (MDP)	Modelled and simulated the temporal and spatial increase in pressure in the Leduc Formation from water disposal injection in the vicinity of the Obsidian 14-18, 13-11 Leduc and 6-14 Belloy wells (the MPD evidence).
Ms. Fiona Marshall	2228260 Alberta Ltd.	Developed a static geological model of the Leduc reef complex (the Marshall Evidence).
Dr. Amy Fox Mr. Neil Watson	Enlighten Geoscience Ltd. (Enlighten)	Performed geological mapping of the Leduc Formation and other relevant intervals to assist in developing the geological model and reservoir model contained in the Marshall evidence and the MPD evidence. Conducted a geological and geomechanical analysis to assess the state of the in situ stress in the area around the Obsidian well.
Dr. James Verdon	Outer Limits Geophysics LLP (Outer Limits)	Reanalyzed the data and conclusions relied on by CLM in issuing the order. Applied a seismicity attribution framework to the Peace River Alberta seismic event sequences, including the seismic events, to evaluate whether the seismic events could be induced, and if so, what activities could be the potential cause. (the Outer Limits evidence).
Mr. Derek Boeckx	DAB Energy	Provided 2D and 3D seismic and fault interpretation in the vicinity of the Obsidian 14-18 and 6-14 Belloy wells.

[50] Based on the analyses of its consultants, Obsidian was critical of the CLM's approach in determining that the Obsidian well caused the seismic events. Obsidian concluded that the evidence linking the Obsidian well to the seismic events is ambiguous and that other industrial activities in the area are "substantially more likely" to be the cause of the seismic events. However, despite its concerns about how CLM determined that the Obsidian well was responsible for the seismic events, Obsidian concluded that the seismic events "were more likely induced than natural seismicity, but that this conclusion is not definitive."

CLM and Obsidian Assessments of Induced Seismicity

[51] CLM and Obsidian both used previously published seismicity attribution frameworks to assess the cause of the seismic events. Seismicity attribution frameworks are often used to evaluate whether a sequence of seismic events might have been induced by human activities. A range of frameworks have been published in the academic literature. These frameworks typically pose a series of questions pertaining to the locations of the events relative to the proposed industrial cause, the timing of the events relative to the timing of industrial activities, and other questions as to whether the proposed activities could have created the seismic events.

[52] The earliest such framework is that of Davis and Frohlich 1993[2] (the Davis and Frolich framework). This framework poses seven questions:

1) Are these the first known earthquakes of this character in the region?
2) Is there a clear temporal correlation between injection and seismicity?
3) Are epicentres near wells (within 5 km)?
4) Do some earthquakes occur at or near injection depths?
5) If not, are there known geologic structures that may channel flow to sites of earthquakes?
6) Are changes in fluid pressure at well bottoms sufficient to encourage seismicity?
7) Are changes in fluid pressure at hypocentral locations sufficient to encourage seismicity?

[53] If the answer to most of these questions is "yes," then the seismicity is likely induced.

[54] Verdon et al. 2019[3] produced an updated framework for induced seismicity determination (the Verdon framework). The Verdon framework defines a series of questions about the seismicity and industrial activities of interest. The answer to each question is assigned a score, with negative values for answers that indicate natural seismicity, and positive values for answers that indicate induced seismicity.

[2] Davis, S. D., and C. Frohlich (1993). Did (or will) fluid injection cause earthquakes?-criteria for a rational assessment, Seismol. Res. Lett. 64, nos. 3/4, 207–224, doi: 10.1785/gssrl.64.3-4.207.

[3] Verdon, J.P., B.J. Baptie, J.J. Bommer, 2019. An improved framework for discriminating seismicity induced by industrial activities from natural earthquakes: Seismological Research Letters 90, 1592-1611.

The different scores assigned to different answers reflects their differing degrees of importance in determining potential induced seismicity causation. The questions and possible responses comprising the Verdon framework are included in appendix 4.

[55] Before answering the questions in the Verdon framework, the user must appraise the quality of evidence available and whether sufficient evidence is available to answer the question. Where robust evidence is available, such that a question can be fully answered, the question is given an evidence weighting (EW) of 100%. If no evidence is available, such that a question cannot be answered, then the EW is set to 0%. In cases where some evidence is available but is poorly constrained or limited in some way, an intermediate EW value may be assigned (e.g., EW = 50%), indicating that the question is answered with limited confidence. The choice of EW value is at the user's discretion, but Verdon et al. 2019 provide examples showing how this might be assigned. The answer scores are weighted by the respective EW values for that question. The EW values are then used to determine the evidence strength ratio (ESR), which is computed from the maximum score that could be assigned given the available data (i.e., when the scores are weighted by the EW values) relative to the total score that could be assigned if all the questions could be fully answered.

[56] Having evaluated the quality of the available evidence via the ESR, the induced seismicity causation is then assessed. Each question is answered, and the combined positive and negative scores are summed to give the induced assessment ratio (IAR). A positive IAR implies that events are likely induced, whereas a negative IAR implies events are likely natural. An IAR close to zero implies an ambiguous result, with different elements of the evidence pointing to different causation. The larger the IAR, either positive or negative, the stronger the conclusion in the given direction.

[57] The framework developed by Foulger et al. 2023[4] (the Folger framework) consists of nine questions, each with four possible responses: (a) insufficient information available, (b) evidence supporting a natural origin, (c) equivocal information, and (d) evidence supporting an induced origin. The user selects a response for each question. Questions are assigned weights (10 points or 100 points) to yield a total score of 360. The term "equivocal" does not imply partial support for either a natural or induced origin but rather that the data is inconclusive.

[58] Initially, the AGS used a modified version of the Davis and Frolich framework to conclude that the seismic events were likely induced by human activity. The AGS answered "yes" to four of the five questions in the modified framework. However, two yes responses were qualified to reflect uncertainties or limitations of the data available at the time.

[4] Foulger, G., M. Wilkinson, M. Wilson, N. Mhana, T. Tezel, and J. Gluyas (2023). Human induced earthquakes: E-PIE—A generic tool for evaluating proposals of induced earthquakes, J. Seismol. 27, 21–44, doi: 10.1007/s10950-022-10122-8.

[59] The induced seismicity assessment conducted by Outer Limits for Obsidian used the Verdon framework to assess the potential for the Obsidian well, 6-14 Belloy well, and the high-volume Leduc wells (including 13-11 Leduc well) to have caused the seismic events. Dr. Verdon is a principal with Outer Limits and the lead author of the Verdon et al. 2019 paper. The results of the Outer Limits assessment are summarized in table 2.

Table 2. Obsidian's induced seismicity assessment results using the Verdon framework

Cause	Evidence strength ratio (ESR)	Induced assessment ratio (IAR)
Obsidian 14-18 well	92%	+31%
6-14 Belloy well	87%	+49%
Leduc high-volume wells	92%	+55%

[60] The ESR is high and the IAR positive for each well or group of wells, indicating a potential linkage between the disposal operations in these wells and the seismic events.

[61] In its hearing submission, CLM applied both the Verdon and Foulger frameworks to the Reno seismic event sequence, using only the information available up to March 2023, when the order was issued. Using the Verdon framework, CLM obtained an ESR of 80% and an IAR of 50%. These scores indicate a significant amount of data with relatively good confidence, suggesting an induced seismicity origin for the seismic events. Using the Foulger framework, CLM found that 61% of the points were inclined towards an induced origin, 33% were equivocal, and 0% were inclined towards a natural tectonic origin. For six points, there was not enough data.

[62] In response to Obsidian's evidence, CLM also used the Verdon framework to reassess all the available data as of July 2024 for the Obsidian 14-18 well, 6-14 Belloy well, and the high-volume Leduc wells. The CLM assessment results are summarized in table 3.

Table 3. CLM reassessment results for all data up to July 2024 using the Verdon framework

Cause	Evidence strength ratio (ESR)	Induced assessment ratio (IAR)
Obsidian 14-18 well	100%	+51%
6-14 Belloy well	91% to 100%	+21% to +48%
Leduc high-volume wells	85% to 100%	-12% to +35%

[63] For some questions in the framework, CLM evaluated two possible scenarios and provided ESRs and IARs for each scenario. It explained that these variations were intended to capture different scenarios where some key assumptions have not been proven. For most scenarios assessed by CLM, the IAR is positive, indicating an induced origin. The only exception was the scenario for the high-volume Leduc

disposal wells, where the assessment score was slightly negative, suggesting an ambiguous or possible natural cause for the seismic events. In all cases, the ESR was high, suggesting the evidence used in the assessment was robust.

[64] As an alternative to the Verdon framework, CLM also applied the Foulger framework to the three potential causes described in Obsidian's evidence. The results are summarized in table 4.

Table 4. CLM assessment results for all data up to July 2024 using the Foulger framework

Result category	Obsidian 14-18 well	6-14 Belloy well	Leduc high-volume wells
Evidence supporting an induced origin	64%	36%	36%
Equivocal information	31%	58%	33%
Evidence supporting a natural origin	0%	0%	28%
Not enough data	5%	6%	3%

[65] Based on the assessment results, CLM and Obsidian both concluded that the seismic events were likely induced, although they disagree on the specific cause of the events.

Importance of the North Peace River Cluster

[66] In the induced seismicity assessment conducted for Obsidian, Outer Limits assumed that the cluster of seismicity associated with the North Peace River cluster was induced. Outer Limits acknowledged that this has been debated since the nearest injection wells are about 20 km from the seismic events in that cluster. Outer Limits submitted that if the North Peace River cluster were instead treated as a natural seismic event sequence, the conclusion that the Reno seismicity is induced becomes much harder to support. This would affect the answer to question 1 in the Verdon framework, as Outer Limits would conclude that natural seismicity has recently occurred at similar rates and magnitudes. This would alter the IAR calculated for the Obsidian well, as it would have an IAR of only +9%. This low IAR value, close to zero, would imply that the evidence is very ambiguous as to whether the events were induced by the Obsidian well, with no clear outcome either way. Furthermore, if the North Peace River cluster is believed to be natural and not induced, then it becomes reasonable to assume that the Reno cluster is also not induced.

[67] CLM confirmed that when the order was issued, they assumed that the North Peace River cluster was a case of natural seismicity. However, they acknowledged some academic publications have concluded that the North Peace River cluster is induced by wastewater disposal activities (Anderson and

Eaton,[5] 2016 and Schultz et al. 2023[6]). Consequently, studies are underway by the AGS to further evaluate the origin of this cluster.

Independent Academic Research Supports an Induced Origin for the Seismic Events

[68] CLM reported that all relevant literature published after the occurrence of the November 2022 mainshock seismic event suggests that the Reno sequence has an anthropogenic (human-caused) origin. CLM referenced studies by Schultz et al. 2023, Vasyura-Bathke et al. 2023,[7] and Salvage et al. 2023.[8]

[69] Schultz et al. 2023 attribute the seismicity in the Reno cluster to disposal injection activities. They found a statistical relationship between seismic events and disposal operations in the area. They relocated some initial events in November and December 2022 to improve the depth estimate of the seismic events, suggesting seismic event depths ranging between 1 and 6 km and matching the target injection depth from the disposal activities in the Leduc Formation. Schultz et al. also use surface deformation measurements from interferometric synthetic aperture radar (InSAR) to improve the location of the mainshock event and expanded the analysis to include the other clusters in the Peace River region, concluding that they are also associated with disposal activities.

[70] Vasyura-Bathke et al. 2023 used a combination of InSAR, seismic waveform data, and Bayesian inference methods to reduce uncertainty in the mainshock source parameters. They showed that the mainshock originated at about 5 km depth, propagating updip towards the injection source, arresting at about 2 km depth. They interpreted the seismic events to have involved the reactivation of four subparallel faults, which they believed were likely part of a regional, basement-rooted graben system. They found a statistically significant correlation between monthly disposal volumes and three disposal wells close to the seismic events.

[71] Salvage et al. 2023 conducted a questionnaire survey to assess the November 2022 mainshock event in Reno. They presented the Reno case study to a panel of experts, which evaluated the sequence using both the Verdon and Foulger frameworks with seismic event details up to March 1, 2023. The results of both frameworks indicate that the experts believe the Reno seismic event sequence was likely induced. Using the Verdon framework, the average ESR was 64.8%, suggesting good data availability.

[5] Anderson, Z. and D. Eaton, 2016. Induced seismicity due to wastewater injection near Peace River, Alberta: Geoconvention Conference, Calgary AB.

[6] Schultz, R., J.-U. Woo, K. Pepin, W. L. Ellsworth, H. Zebkar, P. Segall, Y. J. Gu, and S. Samsonov (2023). Disposal from in situ bitumen recovery induced the ML 5.6 Peace River earthquake, Geophys. Res. Lett. 50, no. 6, e2023GL102940, doi: 10.1029/2023GL102940.

[7] Vasyura-Bathke, H., J. Dettmer, K. Biegel, R. O. Salvage, D. Eaton, N. Ackerley, S. Samsonov, and T. Dahm (2023). Bayesian inference elucidates fault-system anatomy and resurgent earthquakes induced by continuing saltwater disposal, Nature Comm. Earth Environ. 4, 407, doi: 10.1038/s43247-023-01064-1.

[8] Salvage, R., Eaton, D., Furlong, C., Dettmer, J., Pedersen, P. (2023). Induced or Natural? Toward Rapid Expert Assessment, with Application to the Mw 5.2 Peace River Earthquake Sequence, Seismological Research Letters, 10.1785/0220230289, 95, 2A, (758-772).

The average IAR was 15%, suggesting that the origin of the sequence is ambiguous, though slightly inclined towards an induced origin.

[72] CLM submitted that the results from the panel in the Salvage et al. study differ from the analysis conducted by the AGS (ESR = 80% and IAR = 50%) because the AGS had access to additional data that the Salvage panel would not have considered. This includes the AGS nodal array data, which dramatically increases event depth certainty, facilitating the identification of the cluster as induced. The Salvage panel also likely did not have access to detailed operational data, such as disposal volumes, which improves the certainty of the volumetric correlation question. Additionally, the AGS considered the second large seismic event on March 16, 2023, which provided additional information regarding background seismicity. The Salvage panel of experts would not have considered this event.

[73] The AGS and the panel from the Salvage et al. study reached similar results when answering the questions in the Foulger framework. On average, the panel from the Salvage study allocated 61% of the points towards an induced seismicity origin, 30% towards equivocal data, 8% towards insufficient or not available data, and 2% towards natural origin.

Analysis and Findings

[74] We find on a balance of probabilities that the seismic events in November 2022 and March 2023 specified in the order were induced by human activities.

[75] The recurring nature of the seismic events since November 2022 in an area which previously experienced little seismic activity is consistent with the pattern observed for other induced seismic events. Additionally, the induced seismicity assessments completed by CLM, Obsidian's independent consultant, and several independent researchers all indicate an induced origin for the seismic events. While the strength of the association between different disposal wells and seismic events varies depending on the assessment framework used and the evaluator's judgement, the results are consistent across all assessments. This increases our confidence that the seismic events were caused by human activity and are not natural.

[76] Having determined that the seismic events were induced by human activities, we now consider whether disposal operations at the Obsidian well were responsible for the seismic events.

The Obsidian Well May Have Caused or Contributed to Causing the Seismic Events

[77] Obsidian was critical of the approach used by CLM in determining that the Obsidian well caused the seismic events. Obsidian alleged that Nanometrics and the AGS made several errors in the initial processing and interpretation of nodal seismic array data, which formed the basis for issuing the order to Obsidian. Based on the analyses of its consultants, Obsidian argued that the evidence linking the Obsidian well to the seismic events is ambiguous and the 6-14 Belloy well and the high-volume Leduc wells,

which include the 13-11 Leduc well, are "substantially more likely" to have caused the seismic events than Obsidian's well. The locations of the Obsidian 14-18 well, Belloy 6-14 well, and the high-volume Leduc wells north of the Reno area are shown in appendix 5, which also shows the outline of the Leduc fringing reef on the flanks of the Peace River Arch.

[78] We start this section with a discussion of the seismic nodal array data collected by the AGS and used to attribute the cause of the seismic events to the Obsidian well. We then consider each possible cause of the seismic events identified by CLM and Obsidian. To assist us in evaluating the different potential causes, we make use of the Verdon framework and the induced seismicity assessment results provided by CLM and Obsidian.

[79] We chose the Verdon framework for several reasons. First, it is a more recent and robust framework than the Davis and Frolich framework. It allows for quantification of the assessment results (the IAR) and the strength of the evidence used in the assessment (the ESR) rather than relying on yes/no answers. This framework was also applied by both CLM and Obsidian to the evidence for each of the possible causes of interest, allowing us to compare areas of agreement and disagreement. In contrast, the Foulger framework was only applied to the evidence by CLM, making comparisons more difficult.

Nodal Array Data Collection and Processing

[80] Shortly after the November 29, 2022, 5.6 M_L event, the AGS deployed ten seismic nodes around the mainshock event area. The purpose of using local seismic nodes is to improve the seismic event monitoring capacity and record the subsequent aftershocks associated with the mainshock event with a higher location certainty than provided by the regional seismic monitoring arrays. The AGS deployed three rounds of seismic nodes, as described in table 5.

Table 5. AGS seismic nodal array deployment

Round	Date deployed	Active until	Date collected
1	December 6, 2022	January 13, 2023	January 26, 2023
2	January 26, 2023	March 3, 2023	March 10, 2023
3	March 10, 2023	April 14, 2023	Not reported

[81] In early February 2023, round 1 nodal array data was sent to Nanometrics for processing as soon as possible. Together with waveform data and sensor information, the AGS provided a velocity model designed for the Reno area in the Peace River region. Before the November 29, 2022, seismic event, the AGS used a velocity model adjusted to the Fox Creek region to analyze of the Reno events. As this could have led to inaccuracies in the event locations, the AGS used sonic travel time well logs from wells in the Reno area to build the velocity model of the sedimentary strata over which the logs were run. The velocity model for the Reno area was developed to improve the accuracy of the seismic event location.

[82] The AGS received the processed round 1 nodal array data from Nanometrics on March 17, 2023. Nanometrics provided four earthquake catalogues (event locations) that corresponded to the use of different velocity models (Fox Creek and Reno velocity models) and different location algorithms (inversion and grid search methods). From these four earthquake catalogues, the AGS prioritized the catalogue resulting from the Reno velocity model and the grid search location method.

[83] The AGS interpreted the round 1 data to show two subclusters of seismic events (the eastern and western subclusters) near the Obsidian 14-18 well and 6-14 Belloy well. The AGS observed the presence of two rough lineaments outlined by the seismic events, which were interpreted as two activated faults with depths ranging between 1.5 and 6 km below sea level. The AGS noted that the seismic events reached depths as shallow as 1900 m from surface level. This was shallower than previously observed from the regional seismic data, reaching the same levels as disposal operations into the Leduc Formation in the Obsidian well. The AGS did not observe the interpreted activated faults reaching the levels of the Belloy Formation, making the association between the seismic events and the 6-14 Belloy well disposing into the Belloy Formation unclear. The AGS also observed some "horizontal lineaments" in the depth plots for the events, which they considered to be processing artifacts produced by rapid changes in the velocity model.

[84] The only event location data available to the AGS and CLM before issuing the order to Obsidian were from the regional seismic monitoring network and the initial processed data from round 1 of the nodal array. The other two rounds of nodal array data were delivered and processed later. Although potential processing artifacts had been observed in the round 1 processed data, the AGS considered the data of sufficient reliability, in conjunction with other data, to demonstrate a connection between the Obsidian well and the seismic events.

[85] After issuing the order to Obsidian, the AGS continued to refine the processing of the round 1 nodal array data to improve event location accuracy and address the cause of the linear artifacts. Two key issues related to the initial processing—a low-velocity zone in the velocity model and the velocity datum used—were identified and addressed, and a comprehensive reprocessing of the round 1 nodal data was completed. The AGS also collected and processed the two additional rounds of nodal array data using the corrected velocity model and datum and refined processing workflow. An independent third party also processed these later two rounds of nodal array data. In addition, the AGS reprocessed and relocated data from the regional seismic monitoring array. This work continued until mid-2024, resulting in the AGS issuing updated earthquake catalogues in July 2024.

[86] Obsidian's consultant, Outer Limits, identified several issues with the processing workflow that produced the initial AGS seismic event locations:

- Low-quality picks of event arrival times associated with the use of an artificial intelligence algorithm or poor quality control during manual review of the picks.

- The presence of a low-velocity zone at a depth of 1600 to 2000 m in the Reno velocity model.
- The use of an incorrect velocity model datum.

[87] Outer Limits reprocessed the AGS nodal array data to compute an updated earthquake catalogue. It also computed a new earthquake catalogue for the monitoring array installed by Obsidian in April 2023 in response to the order. Outer Limits reported that these two catalogues are consistent with each other, and the results are broadly consistent with the updated catalogue produced by the AGS in 2024, although some differences remain. For example, the main planar structure on which the seismic events are located is about 500 m shallower in the updated catalogue produced by the AGS in 2024 than the events in the Outer Limits catalogue. Outer Limits attributed this to differences in the velocity models used by the AGS and Outer Limits. Outer Limits also observed that the AGS locations appear to show significant vertical "smearing" at the upper edge of the fault plane. Outer Limits suggested this may indicate there are still some issues remaining in the AGS processing, possibly associated with the quality of the event picks by the AI algorithm.

[88] In addition to the noted processing errors, Outer Limits observed that the map projections used by CLM in their figures use unequal axes, which distort the positions of the mapped features. In the CLM plots, 1° of latitude is set equal to 1° of longitude, whereas at this geographical position, 1° of latitude is equal in distance to nearly 2° of longitude. The CLM plots are therefore horizontally exaggerated, and they distort features laterally. Outer Limits submitted that this distortion means that the AER's figures cannot be relied upon for any "by eye" visual analysis or interpretation of the nodal array datasets.

Analysis and Findings

[89] We find that the initial round 1 nodal array data CLM relied on to issue the order to Obsidian suffered from several processing issues that affected the accuracy of the initial seismic event locations. However, Obsidian did not present its critique of the Nanometrics and AGS processing methodology and catalogues of seismic event locations until it filed its hearing submission in July 2024. This was nearly 16 months after the order was issued to Obsidian. During this time, the AGS continued to collect additional data and refine its processing and interpretation of the local nodal array and regional network data, independently identifying and correcting the processing issues observed by Obsidian and refining the seismic event locations. By the time of the oral hearing, the earthquake catalogues produced by CLM and Obsidian were broadly consistent.

[90] We observe that plots using the revised 2024 AGS catalogue for the round 1 nodal array data continue to show two subclusters of events near and below the Obsidian 14-18 and 6-14 Belloy wells. However, the linear artifacts have been removed, and there is less scatter in event locations as locations with high uncertainty have been removed. Events are still observed up to the depth of the Leduc Formation in the eastern subcluster below the Obsidian well and the western subcluster below the 6-14 Belloy well. However, there are still some shallow events above the base of the Leduc Formation that

may represent poorly located events. In the plots for the round 2 and 3 nodal array data, the events are deeper and do not reach the level of the Leduc Formation. Differences in event locations between nodal array datasets are expected, given the timing of data collection. Rounds 1 and 2 of the AGS nodal array data would have primarily captured aftershocks of the November 22, 2022, mainshock event. Round 3 of the AGS nodal array data would have captured the March 16, 2023, mainshock event and its aftershocks.

[91] A comparison of the event location plots created from the updated 2024 AGS catalogue with those produced by Outer Limits shows similar patterns in the event locations, although differences are evident. Most importantly, many of the shallower events in the Outer Limits plots are gone, and the cluster of events observed immediately adjacent to the toe of the Obsidian well in the AGS plots of round 1 nodal array data is no longer apparent.

[92] Several factors may explain the observed differences in the event location plots presented by CLM and Obsidian. First, as noted by Obsidian, the event locations associated with the 2024 AGS earthquake catalogue are consistently shallower than those in the Outer Limits catalogues. We accept that this may be due to differences in the velocity models. Second, there may be some remaining issues with the AGS processing, as indicated by the apparent vertical "smearing" of event locations near the upper edge of the fault plane. The differences in depth observed in plots of the AGS nodal array data and data from the Obsidian array may be related to data collection timing. The Obsidian array would have captured the March 16, 2023, event aftershocks. As critically stressed faults in one area slip and release stress, the stress and movement may shift to other areas of higher stress.

[93] Given that the parties have filed new evidence in this proceeding, we have relied on the updated earthquake catalogues provided by CLM and Obsidian when considering the different potential causes of the seismic events. We also used caution when reviewing the CLM map projections due to the distortion issue identified by Obsidian.

Interpretation of the Mainshock Fault Mechanism From the Nodal Array Data

[94] CLM noted that two subclusters of seismic events are visible in the data from the updated earthquake catalogues (an eastern subcluster and a western subcluster). It interprets the two subclusters as associated with two separate parallel fault structures. CLM submitted that the two structures are visible in all three rounds of nodal array data (although the depth increases from 1.5 and 6 km below the surface in the reprocessed round 1 nodal array data to 2 and 8 km in the round 3 data). It noted that while the round 2 nodal array data show a considerably lower number of events when compared with the rounds 1 and 3 data, two structures are still apparent, although relatively deeper than the ones observed in the round 1 data. The round 3 nodal array data show a reactivation of the seismicity, recording the March 16, 2023, 5.09 M_L event and subsequent aftershocks. Two structures are still apparent but show an increasing depth. However, the earthquakes still reach depths proximal to the disposal injection targets in the Leduc Formation.

[95] CLM suggested that the deeper events in round 3 might indicate the activation of an additional set of faults adjacent to the planes observed in the round 1 data. It submitted that it is possible that the deeper adjacent faults observed in round 3 were activated by a combination of increasing pressure from the disposal activity plus stress re-accommodation resulting from the November 2022 mainshock. It submitted that in cases of induced seismicity from disposal, it is common for shallow activities to trigger faults rooted in the basement, leading to earthquakes deeper than the injection target.

[96] Obsidian submitted that the CLM's two-fault-plane interpretation is inconsistent with the rupture dynamics of the 5.6 M_L mainshock event or with the locations of the aftershocks recorded by the nodal seismic array. According to Obsidian, the dimensions of the western or eastern subclusters are, when considered individually, not sufficiently large to have hosted a 5.6 M_L event. A 5.6 M_L event requires a rupture area of 10 to 100 km^2 or a fault length of at least 3 to 10 km. Furthermore, the orientations of each subcluster, when considered individually, do not match the orientation of the 5.6 M_L mainshock rupture as inferred from the InSAR and regional seismological observations identified in Schultz et al. 2023 and Vasyura-Bathke et al. 2023.

[97] Obsidian interpreted the seismic events in both subclusters to lie along a single planar structure. Obsidian used a simple geometric fitting algorithm to fit a single plane to the entire earthquake population and found a good fit between this single fault plane and the event locations. In support of its interpretation of a single-planar-fault structure, Obsidian noted the following:

- The position and orientation of this structure are consistent with the mainshock fault plane that has been inverted from the InSAR and regional seismic observations, and the size of this fault plane is consistent with the rupture dimensions of an event with greater than 5.0 M_L.
- The InSAR inversions and the nodal seismic observations both show that the uppermost edge of this fault, where it may reach the basement-sediment interface, is located directly below the 6-14 Belloy well and is 3 to 4 km from the Obsidian well.
- The regional seismic and InSAR observations for the mainshock show no clear evidence for complex multifault or multistrand rupture. So, a single fault plane between 3 to 10 km long must exist in the subsurface. This fault plane must have a roughly northwest-southeast strike, dipping obliquely to the northeast.
- The observed seismicity recorded by the nodal arrays for the eastern and western subclusters, when treated jointly, align onto a single fault structure with dimensions and orientation that provide an excellent match to the observed mainshock rupture (as estimated by Schultz et al. 2023 and Vasyura-Bathke et al. 2023).

[98] Obsidian acknowledged a region of quiescence in the middle of the mapped plane that separates the western and eastern subclusters. Obsidian suggested that a reasonable interpretation of this zone is that it represents the area in which the 5.6 M_L mainshock nucleated. In this area, the stresses will have been

released entirely by the mainshock, leaving no aftershocks. The events in the western and eastern subclusters represent events at either end of the fault, where stresses will have become concentrated after the mainshock.

[99] Obsidian and CLM agree that due to the absence of reflectors in the Precambrian basement, it is not possible to image the mainshock fault plane (or planes) using reflection seismic.

Analysis and Findings

[100] We note that in addition to the two fault planes interpreted by CLM and the single fault plane interpreted by Obsidian, Vasyura-Bathke et al. 2023 interpret the mainshock and aftershock events to have involved the reactivation of four steeply dipping subparallel faults that may be part of a regional, basement-rooted graben system. Vasyura-Bathke et al. 2023 also conclude that the mainshock for the November 2022 event nucleated at a depth of about 5 km, propagating updip towards the injection source, arresting at about 2 km depth.

[101] We accept that the mainshock fault planes in the Precambrian basement cannot be mapped using reflection seismic. While the location of the mainshock fault planes can be determined by plotting the seismic event locations, this approach is limited by the resolution of the regional and local seismic monitoring arrays and the associated data processing. Therefore, we cannot determine with any degree of certainty which of the interpreted fault mechanisms is responsible for the seismic events specified in the order.

[102] Although CLM and Obsidian have different interpretations related to the mainshock and aftershock earthquake mechanism, some facts are not in dispute:

- The fault (or faults) that slipped and resulted in the mainshock seismic events are oriented northwest-southeast, dipping to the northeast and occur in the Precambrian basement below the Leduc Formation.
- The stress in the Leduc Formation is strike-slip, and this stress regime is inconsistent with the reverse fault seismicity of the Reno cluster.
- There are faults at the top of the basement that can be assumed to extend into the Leduc Formation and downward into the Precambrian.
- The mechanism that can cause induced seismicity in the basement is pore-pressure propagation either through faults or permeable formations.

[103] What is in dispute is the specific disposal activity that caused the pore-pressure increase and the mechanism that allowed it to be transmitted to the critically stressed faults in the basement rocks to trigger the seismic events.

The Obsidian 14-18 Well

[104] The CLM's determination in March 2023 that the Obsidian well was responsible for the seismic events was based on an observed temporal and spatial correlation between the seismic events and disposal operations at the Obsidian well. Disposal operations at the Obsidian well started in December 2012 and were going before and during the November 2022 seismic event, continuing until the March 2023 seismic event. In 2017, two seismic events corresponded to the peak disposal rates at the Obsidian well. The observed spatial correlation was based on the initial processed round 1 nodal array data, which showed seismic events near the Obsidian well and events up to the depth of the Leduc Formation into which disposal was occurring.

[105] Obsidian submitted that there is no statistically significant temporal correlation between disposal rates at the Obsidian well and seismicity in the Reno area. Furthermore, the apparent cluster of seismic events close to the Obsidian well observed in the initial round 1 processed nodal data was a processing artifact generated by errors in the initial data processing and was not real. Obsidian observed that the updated earthquake catalogues do not show any seismicity near the Obsidian well and place the seismic events closer to the 6-14 Belloy well.

Application of the Verdon Framework to the Obsidian 14-18 Well

[106] Applying the Verdon framework to the Obsidian well, Obsidian assessed the ESR to be 92% and the IAR to be +31%.

[107] In reevaluating the Obsidian well based on Obsidian's hearing submission, CLM determined the ESR to be 100% and the IAR to be +51%.

[108] In response to questions about how significant the 20% difference in score was, Dr. Verdon testified that when doing an induced seismicity assessment involving a single potential cause, he would consider an IAR of 20% to 25% or below as sufficiently low to be ambiguous. He stated that when an induced event is caused by one thing, and another thing is nearby, it causes the assessor to answer more of the questions in the positive, which starts to pull up the score for the thing that did not cause it. He went on to suggest that if this pull-up effect were removed from the assessment for the Obsidian well in the Outer Limits assessment, its score would drop to below 20%.

[109] CLM and Obsidian selected the same response and arrived at the same score for five of the seven questions in the Verdon framework. They differed only in their responses to question 3 (temporal correlation) and question 4 (depth of events), as shown in table 6.

Table 6. CLM and Obsidian responses to Verdon framework questions 3 and 4 for the Obsidian 14-18 well

Questions and possible responses	Score	Obsidian response	CLM response
Q3. Are the observed seismic events temporally correlated with the injection activities?	Score	Evidence weight 100%	Evidence weight 100%
a. The earthquakes are coincident with the injection, but there is minimal correlation.	-4	Yes	No
b. There is some temporal correlation between the seismicity and the industrial activity.	+4	No	Yes
c. There is strong temporal correlation between the seismicity and the industrial activity.	+15	No	No
Q4. Do the earthquakes occur at similar depths to the activities?	Score	Evidence weight 80%	Evidence weight 100%
a. Earthquakes do not occur at the same depth, and there is no plausible mechanism by which stress or pressure changes could be transferred to the earthquake depths.	-4	No	No
b. Earthquakes do not occur at the same depth, but plausible mechanisms exist by which stress or pressure changes could be transferred to these depths.	+2	Yes	No
c. Earthquakes occur at similar depths to the injection.	+3	No	Yes

Temporal Correlation

[110] Obsidian's response suggests that while the seismic events are coincidental with the disposal activity in the Obsidian well, there is minimal correlation. Obsidian assigned an EW of 100% for the Obsidian well, 6-14 Belloy well, and the high-volume Leduc wells for this question, reflecting the availability of a full time series of disposal volumes and enough observed seismic events with which detailed assessments of temporal correlation can be made.

[111] Dr. Verdon noted that the Verdon framework differentiates between “co-incidence” (question 2), where events occur at the same time and place as an injection well, and “correlation” (question 3), where there is an ongoing relationship between injection rates and seismicity. He noted that in various places in the record of the decision maker and supplemental materials, CLM asserted a temporal correlation between injection rates and seismicity; however, he was unaware of any attempts by CLM to quantify the degree of correlation by computing correlation coefficients between injection rates and seismicity.

[112] Obsidian computed the temporal correlation between wastewater disposal rates and seismicity for the Obsidian well, 6-14 Belloy well, and the high-volume Leduc wells. Only events detected by the Alberta RAVEN regional seismic monitoring network were used to avoid any biases in event detection introduced by deploying the local nodal seismic arrays after the November 2022 seismic events.

[113] Obsidian submitted that a high, statistically significant cross-correlation coefficient at relatively short time lags would indicate a causal factor for induced seismicity. For the Obsidian well, cross-correlation coefficients were found to be low, less than 0.25 for all lags less than four years. Obsidian tested the statistical significance of these correlations by computing the probability of attaining such values with random, uncorrelated time series of equivalent length. It found that the P-value for the Obsidian well is 0.71, implying a high chance that the two time series are not correlated.

[114] The CLM’s response reflects its view that there is some temporal correlation between seismicity and disposal activities in the Obsidian well. It relied on the observation that disposal operations at the Obsidian well started in December 2012 and continued during the November 2022 and March 2023 events, as described above. It noted that the two previous seismic events in 2017 occurred during a period corresponding to peak disposal rates at the Obsidian well, when disposal rates were much higher than those leading up to the November 2022 seismic event.

[115] In its hearing submission, CLM referenced the Vasyura-Bathe et al. 2023 paper to support its claim of a correlation between disposal activities in the Obsidian 14-18 well and the Reno seismic events. However, Obsidian noted that the correlation identified in the Vasyura-Bathke et al. 2023 paper did not concern the Obsidian well alone, but rather the combined monthly disposal volumes for the Obsidian 14-18 well, 6-14 Belloy well, and another well disposing into the Paddy Cadotte Formation. Obsidian, therefore, submitted that the Vasyura-Bathke paper does not support a significant correlation between disposal volumes in the Obsidian 14-18 well and the seismic events specified in the order. Rather, Vasyura-Bathke et al. found a significant correlation between the Obsidian well, 6-14 Belloy well, and Paddy Cadotte wells combined. Obsidian submitted that the implication is that Vasyura-Bathke et al. assumed that the Reno seismicity is jointly driven by injection in multiple wells.

[116] CLM acknowledged that there was not a strong observed correlation between disposal and seismic event rates but disagreed with Obsidian’s assessment of minimal or no temporal correlation for the Obsidian well. CLM inferred some temporal correlation for time lags of 50 to 60 months in the cross-

correlation coefficient figure prepared by Outer Limits and in the plots between operational activities (injection rates) and seismicity. CLM noted that the two seismic events in 2017 had occurred after a long time lag. CLM submitted that this was consistent with the idea that "a long time is required to build up the pressure in the reservoir." Based on these observations, CLM believed a finding of some level of correlation was appropriate.

[117] Obsidian submitted that the CLM's conclusions regarding temporal correlation appear to be based on a "by eye" visual comparison of the seismic event and disposal volume time series without any quantitative assessment, which is not an appropriate approach to assessing correlation. While some correlation coefficients between the Obsidian well and the Reno seismicity increase with larger time lags, they do not generally achieve statistical significance at the threshold of 5%. There are only two time lags for the Obsidian time series that produced statistically significant ($P < 0.05$) correlations: at time lags of 68 and 84 months. Obsidian submitted that it would be remarkable to claim that time lags of 68 or 84 months, and only these values (i.e., no intervening values), are relevant in establishing a connection between the Obsidian well and the Reno seismicity. Obsidian further submitted that the two seismic events in 2017 coincided with peak disposal volumes for both the Obsidian 14-18 well and the 6-14 Belloy well.

Depth of Events

[118] Obsidian's response reflects its interpretation that while the seismic events do not occur at the same depth as the disposal activities, plausible mechanisms exist by which stress or pressure changes could be transmitted to these depths.

[119] Obsidian assessed the EW to be 80% for the Obsidian well, 6-14 Belloy well, and the high-volume Leduc wells. This EW recognizes that the regional seismic monitoring for the mainshocks does not provide tightly bounded depths for the mainshock events. However, InSAR monitoring of static surface deformation has been used to better define event depths. In addition, local seismic arrays provide an improved definition of aftershock locations; although there is some disagreement between the depths produced in the Outer Limits analysis and those produced in the reprocessed 2024 AGS catalogue. Also, as aftershocks, these events do not necessarily define the positions of the mainshock events.

[120] Obsidian noted that responses a and b to question 4 of the Verdon framework refer to structures such as faults that could transfer pressures or stresses to a greater depth. Obsidian used a combination of 2-D and 3-D seismic data to map faults in the area and identify basement-rooted faults crossing relevant strata. The Enlighten evidence also provides geological observations and interpretations that have been used to identify additional faulting in the area. Obsidian also presented a Precambrian time-structure map for a portion of the Reno area. However, since this analysis relies on 2-D seismic coverage and geological interpretations, Obsidian acknowledged that other structures could have been missed. Overall, Obsidian considered there is good quality data for this question but recognized that some uncertainties remain.

[121] Obsidian observed that in the updated earthquake catalogues, the western subcluster is directly below and north of the 6-14 Belloy well, about 3 to 4 km laterally from the Obsidian well. The eastern subcluster is below and southeast of the Obsidian well. Obsidian submitted that regardless of whether the AGS or Outer Limits event locations are preferred, the events in the eastern subcluster do not extend upward into the Leduc Formation as claimed by CLM. For the AGS locations, the shallowest events in the eastern subcluster reach around 2500 m below sea level, more than 1 km below the depth of the Leduc Formation. For the Outer Limits locations, there is as much as 2 km between the depth of disposal and the seismic events. Obsidian submitted that the events in the eastern subcluster only reach the depth of the Leduc Formation if the original (erroneous) Nanometrics locations are used. Events in the western subcluster may reach the depth of the Leduc Formation (using the AGS locations) or be located over 1 km below the Leduc (using the Outer Limits locations). Obsidian, therefore, submitted there are no events immediately proximal to the Obsidian well.

[122] The CLM's response reflects its view that seismic events occur at similar depths to disposal in the Obsidian well. Based on the nodal array data, it identified seismic events reaching the depths of the Leduc Formation. Because the event locations are based on the reprocessed AGS nodal array data, there is high confidence in the evidence, and an evidenced weighting of 100% is appropriate.

[123] Dr. Canales submitted that the Obsidian well provides the clearest causation path to fault activation. The Reno area overlies the Peace River Arch, which contains numerous basement-rooted faults. In its hearing submission, CLM incorporated 2-D seismic into its analysis to identify potential basement-rooted faults and their association with the sedimentary strata above. The CLM's 2-D reflection seismic interpretation, when coupled with Obsidian's 3-D seismic Precambrian time-structure mapping, shows horst and graben features with basement-rooted faults near the Obsidian well. The faults are at the top of the basement and extend into the Leduc Formation, providing a pathway for fluids or pressure from the Obsidian well to be transmitted to deeper and critically stressed faults in the Precambrian basement.

[124] In response to Obsidian's claim of no seismic events proximal to the Obsidian well, CLM noted that in the case of the western subcluster, it is clear in the round 1 nodal data that the seismicity reaches the levels of the Leduc Formation. This situation suggests the possibility of a direct hydraulic connection and pore-pressure increase at the fault location from the Obsidian well. In the case of the eastern subcluster, which is more proximal to the Obsidian well, it is possible to infer the interpolation of the basement faults towards the Leduc Formation. CLM submitted that even if this is not the case because the Leduc Formation directly overlies the Precambrian basement, it is possible to assume pore-pressure increases in the Leduc Formation propagate downwards into the basement to activate the fault. CLM submitted that such assumptions of hydraulic connectivity can be argued since there is seismicity in these faults: pore-pressure diffusion occurs along the fault, causing it to slip and generate seismicity.

[125] Mr. Boeckx, Obsidian's geophysicist, expressed concerns about the quality and accuracy of the CLM's interpretation of the 2-D reflection seismic and related conclusions. Obsidian also disputed the exact locations of the basement-rooted faults identified by CLM near the Obsidian well and how far into the Leduc they extended.

Analysis and Findings

[126] Obsidian has not convinced us on a balance of probabilities that the Obsidian 14-18 well did not cause or contribute to causing the seismic events specified in the order.

[127] The IARs computed for the Obsidian well by Obsidian and CLM using the Verdon framework are both positive, suggesting that the Obsidian well may have caused or contributed to causing the seismic events. The ESR for both assessments is high (92% and 100%), suggesting the data supporting the assessment is robust. We were not persuaded by Dr. Verdon's testimony that the IAR of +31 for the Obsidian well arrived at in the Outer Limits assessment is low enough to be considered ambiguous as to whether the Obsidian well may have caused the seismic events. The extent to which positive responses to other possible causes result in a false positive or pull-up effect for the induced assessment ratio for the Obsidian well is difficult to assess.

[128] In applying the Verdon framework, Obsidian and CLM differed only in their responses to two questions. The first is related to the degree of temporal correlation between disposal activities in the Obsidian well and the seismic events. The difference in the IAR determined by CLM and Obsidian is driven predominantly by their differing responses to this question. Where Obsidian found minimal evidence of correlation for the Obsidian well, CLM submitted that there was some correlation. We agree that quantitative methods, such as the calculation of cross-correlation coefficients, provide a more robust approach to assessing correlation than a "by eye" visual examination of plotted data. However, we recognize that natural systems do not always behave predictably. In cases of induced seismicity, there may be long and irregular time lags between disposal operations and induced seismic events. This situation complicates the assessment of correlation. Given the observed coincidence between the peak disposal rates in the Obsidian well and the seismic events in 2017 and the statistically significant cross-correlation coefficients computed by Outer Limits for time lags of 68 and 84 months, we cannot rule out the possibility of some correlation. However, we agree that the correlation between the disposal activities in the Obsidian well and the seismic events is ambiguous.

[129] We agree with Obsidian that the Schultz et al. 2023, Vasyura-Bathke et al. 2023, and Salvage et al. 2023 papers did not find a correlation between disposal volumes in the Obsidian well and the seismic events. Rather, they found a possible correlation between the disposal volumes from several wells, disposing into different zones, and the seismic events. While this supports an induced origin for the seismic events, it does not support the CLM's contention that the Obsidian well alone caused the seismic events.

[130] The second question concerns the depth of the events regarding disposal activities and whether there is a plausible mechanism to connect the activities with the seismic events. CLM interprets the seismic events and disposal operations in the Obsidian well to occur at similar depths, while Obsidian interprets the seismic events and disposal operations at different depths. However, both agree there is a plausible mechanism (faulting) to connect the disposal activities and seismic events.

[131] We acknowledge that the cluster of events at the toe of the Obsidian well in the initial processed data from the round 1 nodal array is no longer present in the reprocessed data. However, we do not agree with Obsidian's assertion that there are no event locations near the Obsidian well. In the plots of reprocessed round 1 nodal array data presented by CLM, we observe seismic events in both the eastern and western subclusters occurring up to the depth of the Leduc Formation. However, as noted by Obsidian, some "smearing" of event locations may be occurring. The western subcluster contains the highest concentration of events and is situated closest to the 6-14 Belloy well in both plan and depth views. Meanwhile, the eastern subcluster is positioned nearest and beneath the Obsidian well. Both subclusters occur within 3 to 4 km of the Obsidian well in an area that could reasonably be influenced by disposal operations.

[132] Seismic events are also detected below the Obsidian well in the CLM's plots for the reprocessed round 2 and round 3 nodal array data, though at depths ranging from 1000 to over 2000 m beneath the well. The AGS nodal array data reprocessed by Outer Limits also indicates the presence of seismic events below the Obsidian well but at greater depths, between 2000 and 3000 m below the base of the well.

[133] Regardless of whether the seismic events reach the level of the Leduc, we find there are plausible mechanisms connecting disposal in the Leduc to deeper faults in the basement. The 2-D and 3-D seismic evidence presented by both Obsidian and CLM show basement-rooted faults and horst and graben structures present near the Obsidian well. These faults provide a potential pathway for increased pressures from the Obsidian well to be transmitted to the deeper faults in the Precambrian basement that slipped and caused the seismic events.

[134] Given that CLM and Obsidian induced seismicity assessments both indicate a possible linkage between disposal operations in the Obsidian well and the seismic events specified in the order, a plausible mechanism exists to connect disposal operations at the Obsidian 14-18 well to the mainshock fault plane in the Precambrian basement, and that some degree of temporal correlation between the disposal operations and the seismic events cannot be ruled out, we are not persuaded on the balance of probabilities that the Obsidian well did not cause the seismic events specified in the order.

The 6-14 Belloy Well

[135] Before issuing the order to Obsidian, CLM considered the 6-14 Belloy well as a possible cause of the seismic events. The 6-14 Belloy well exhibited the strongest observed temporal correlation between injection volumes and seismic events, with a significant increase in disposal volumes occurring shortly before the November 2022 seismic event. There was also a strong spatial correlation—the 6-14 Belloy well was closest to the November 2022 mainshock event. However, the disposal operations occurred at a depth of only 790 m, and the observed seismic events were much deeper. Furthermore, the initial processed round 1 nodal array data did not show events reaching up to the level of the Belloy Formation. Consequently, CLM concluded that the 6-14 Belloy well did not cause the seismic events.

[136] Obsidian submitted that the 6-14 Belloy well has a "moderate likelihood" of having caused the seismic events and is "substantially more likely" to have caused the events than the Obsidian well. Obsidian's conclusions are based on an observed temporal correlation between the seismic events and the disposal rates in this well and by the identification of a fault near the 6-14 Belloy well that extends from the Precambrian to the Belloy Formation. Obsidian interprets this fault to connect the Belloy Formation to the uppermost part of the mainshock fault plane identified by the nodal array analysis. Obsidian also observed that most events located by the nodal array are closest to this well.

[137] Regarding temporal correlation, Obsidian's geological consultants, Enlighten, reported that disposal volumes in the 6-14 Belloy well increased from an average of 75 cubic metres per day (m^3/d) during 2020 and 2021 to an average of 208 m^3/d in early 2022, just before the seismic events in November 2022. This is an increase of 177% compared with the years immediately prior and an increase of 20% compared with the previous peak injection volumes in 2016-2017. In the cross-correlation coefficients calculated for the 6-14 Belloy well, Outer Limits observed a clear peak in cross-correlation for disposal volumes in the Belloy well, with values of 0.36 and 0.39 for lags in seismicity rate of zero or four months. The P-value for the Belloy well with a four-month time lag is 0.035, suggesting a statistically significant correlation between the injection rates in the 6-14 Belloy well and the seismicity in the southern cluster at the 5% threshold level.

Application of the Verdon Framework to the 6-14 Belloy Well

[138] Applying the Verdon framework to the 6-14 Belloy well, Obsidian determined the ESR to be 87% and the IAR to be +49%. In reassessing the data, CLM determined the ESR to be 91% to 100% and the IAR to be +21% to +48%.

[139] CLM explained that the lowest ESR (91%) and IAR (+21%) were obtained for the scenario where the fault conditions between the Belloy Formation and the Precambrian basement proved unfavourable for stress transfer. The highest ESR (100%) and IAR (+48%) are for scenarios where fault conditions between the Belloy Formation and the basement might favour stress transfer; however, the evidence strength is properly calibrated to capture uncertainty in the multiple assumptions.

[140] CLM and Obsidian selected the same response and arrived at the same score for five of the seven questions in the Verdon framework. They agree that there is some temporal correlation between the disposal rates in the 6-14 Belloy well and the seismic events. They differed in their responses to question 4 (depth of events) and question 6 (earthquake mechanism), as shown in table 7.

Table 7. CLM and Obsidian responses to Verdon framework questions 4 and 6 for the Belloy 6-14 well

Questions and possible responses	Score	Obsidian response	CLM response	CLM response
Q4 Do the earthquakes occur at similar depths to the activities?	Score	Evidence weight 80%	Evidence weight 100%	Evidence weight 50%
a. Earthquakes do not occur at the same depth, and there is no plausible mechanism by which stress or pressure changes could be transferred to the earthquake depths.	-4	No	Yes	No
b. Earthquakes do not occur at the same depth, but plausible mechanisms exist by which stress or pressure changes could be transferred to these depths.	+2	Yes	No	Yes
c. Earthquakes occur at similar depths to the injection.	+3	No	No	No
Q6. Is there a plausible mechanism to have caused the events?	Score	Evidence Weight 50%	Evidence Weight 100%	Evidence Weight 50%
a. No significant pore pressure increase occurred that can be linked in a plausible manner to the hypocentral positions.	-5	No	Yes	No
b. Some significant pore pressure increase occurred that can be linked in a plausible manner to the hypocentral positions.	+2	Yes	No	Yes
c. A large pore pressure increase (or stress perturbation) occurred that can be linked in a plausible manner to the hypocentral positions.	+5	No	No	No

Depth of Events

[141] Obsidian's response reflects its interpretation that while disposal operations at the 6-14 Belloy well occur at a much shallower depth than the observed seismic events, there is a plausible mechanism that allows pressure changes or stress to transfer to faults in the Precambrian basement.

[142] Obsidian has mapped a fault near the 6-14 Belloy well that is rooted in the basement and is observed to cut strata across the Palaeozoic section and into the Belloy Formation. The EW of 80% reflects uncertainties associated with the depth of the mainshock and aftershock events and the characteristics of faults or other structures capable of transferring pressures or stress to greater depth, as discussed above for the Obsidian well assessment.

[143] CLM provided two responses to reflect different scenarios. CLM prefers response a) as reflected in the higher EW (100%) assigned to this response. This response is consistent with its view that the disposal operations in the 6-14 Belloy well occur at a much shallower depth than the seismic events. There is insufficient evidence to confirm that the fault connecting the Belloy Formation to the faults in the basement relied on by Obsidian has the necessary properties to act as a conduit for pressure/stress transfer between the Belloy Formation and the mainshock fault planes.

[144] The lower EW provided for response b) (50%) reflects the CLM's view that the properties of the fault interpreted by Obsidian to connect the Belloy Formation to the faults in the basement require multiple assumptions and are considered highly speculative.

[145] CLM acknowledged the presence of the fault mapped by Obsidian near the 6-14 Belloy well but considered Obsidian's claim that this fault has acted as a conduit to transfer pressure or deformation from the 6-14 Belloy well into the basement as "speculative," "improbable," and "unlikely to be achieved." CLM maintained that there is no concrete evidence that the interpreted fault extends all the way to the activated basement-rooted faults, acts as a conduit and not as a sealing fault, or slips seismically or aseismically. CLM suggested the absence of seismicity in this fault could indicate nonexistent hydraulic conductivity.

[146] To understand the cause of the seismic sequence, Obsidian suggested it is necessary to understand how pressure changes from the disposal wells could have reached the mainshock fault plane in the Precambrian basement. Relying in part on the confidential evidence, Obsidian described how the interpreted fault from the Belloy Formation to the Precambrian basement connects the 6-14 Belloy well to the mainshock fault plane. Obsidian noted that when considering the gap in depth between the Leduc Formation and the seismicity in the eastern subcluster related to the Obsidian well, CLM assumes that pore-pressure increases in the Leduc Formation can propagate downwards into the basement to activate the faults in the Precambrian basement to induce seismicity. Obsidian submitted that its interpretation for the 6-14 Belloy well relies on the same assumption made by CLM about fault transmissibility through the basement.

[147] CLM submitted that it is unlikely that, at any point, there is no sealing component along the interpreted fault, especially when the distance between the Belloy Formation and the Leduc Formation is almost 1.2 km.

[148] Obsidian explained that its view that a fault extending downwards from the Belloy Formation could provide a hydraulic or geomechanical connection to trigger seismicity in the basement was not based on speculation. It was based on observational evidence from cases of induced seismicity from across the Western Canadian Sedimentary Basin. Obsidian provided several analogue examples of such cases, including a case of induced seismicity described by Peña-Castro et al. 2020[9] within the Peace River Arch, where a fault was identified that extended from the Triassic section across 1.5 km of Palaeozoic strata to intersect a larger fault in the basement. Hydraulic fracturing in the Triassic strata caused pressure or stress transfer along this fault to trigger a 4.5 M_L seismic event in the Precambrian basement. Although there was some microseismicity at the formation level (Triassic) associated with hydraulic fracturing, the transfer of pressure or stress downwards through 1.5 km of Palaeozoic strata was aseismic. Obsidian submitted that this case was not unique as induced seismicity caused by the downward transfer of pressure and deformation from operations in Triassic-age formations into basement strata is commonly observed in the Western Canadian Sedimentary Basin. Obsidian provided several examples from the academic literature of similar cases, including cases involving the Belloy Formation.

[149] Enlighten also provided evidence of non-sealing faults open to the transmission of fluids at the depths of the Belloy Formation. This evidence includes reports of lost circulation events and geomechanical borehole issues described in some wells in the Peace River Arch when drilling through these strata, including in the 100/01-01-082-18W5/00 well, which is within 5 km of the 6-14 Belloy well.

[150] CLM asserted that if the 6-14 Belloy well had caused the induced seismicity, then "one would expect to see significant earthquake activity up to the Belloy well injection depth" and that "in all instances of shallow operations causing induced seismicity there is direct evidence of induced earthquakes originating at that injection depth and deeper."

[151] Obsidian submitted that the CLM's claim regarding "all instances" is factually incorrect and inconsistent with observations from induced seismicity cases globally. Obsidian referenced what it considered to be a seminal paper on injection-induced seismicity by Ellsworth 2013[10] that stated, "[I]nduced earthquakes sometimes occur at the source of the stress or pressure perturbation; at other times, these events take place deep below and kilometres away from the source." Obsidian also noted that Schultz et al. 2023 recognize that "depth differentials of ~2-4 km between the sedimentary injection interval and basement induced earthquakes have been documented before." Obsidian stated that numerous

[9] Peña-Castro, A.F., M.P. Roth, A. Verdecchia, J. Onwuemeka, Y. Liu, R.M. Harrington, Y. Zhang, H. Kao, 2020. Stress chatter via fluid flow and fault slip in a hydraulic fracturing induced earthquake sequence in the Montney formation, British Columbia: Geophysical Research Letters 47, e2020GL087254.

[10] Ellsworth, W.L., 2013. Injection-induced earthquakes: Science 341, 1225942.

cases can be identified where induced seismicity has occurred at greater depths than the industrial cause, with minimal or no seismicity at the depth of the operation or along connecting fault structures and provided several examples.

[152] Obsidian submitted that there are also sound geomechanical reasons that explain the absence of observed seismicity within the sedimentary strata for the Reno cluster. Based on the analysis of stress conditions Enlighten completed for the Leduc Formation, faults in the sedimentary layers in this area are unlikely to be critically stressed and, therefore, would not be capable of hosting earthquakes. However, an absence of critical stress conditions would not preclude such faults from serving as conduits for fluid flow, resulting in structures capable of providing a hydraulic connection from the Belloy Formation on which observed seismicity would not be expected.

[153] Obsidian submitted that its evidence shows a clear precedent for industrial operations in the Permo-Triassic formations in the Peace River Arch causing induced seismicity and, therefore, no basis for assuming that activities in the Reno area are not capable of causing induced seismicity. Detailed analyses of hydraulic fracturing datasets have revealed faults that extend from the Precambrian basement into the Triassic strata, with these faults providing conduits for fluid pressure or stress transfer that has nucleated large seismic events in the basement.

Earthquake Mechanism

[154] Obsidian's response reflects its interpretation that pore pressure or poroelastic stress change associated with disposal operations at the 6-14 Belloy well can be plausibly linked to the hypocentral position of the seismic events. The EW of 50% recognizes that no full-field reservoir simulation for the Belloy Formation has been developed. However, Enlighten has performed a geological and hydrodynamic analysis of this formation, which provides some indication as to how pore pressures would be expected to respond to wastewater disposal in this area.

[155] The geological and hydrodynamic analyses conducted by Enlighten of the area near the 6-14 Belloy well indicate that the Belloy reservoir is thinner and more limited in extent than originally indicated in the mapping provided by the well operator to support the proposal to convert the well into a water injector. This would minimize the ability of the Belloy well to transmit pressure increases laterally within the Belloy Formation. An inability to transmit pressures away implies that pore pressures would increase near the 6-14 Belloy well, which is close to the mapped fault extending into the Precambrian basement. Obsidian submitted that it is reasonable to assume, given the proximity of the mapped fault connecting the Belloy Formation to the basement, that injection in the 6-14 Belloy well would create a pore-pressure increase of sufficient magnitude to cause induced seismicity.

[156] Consistent with its response to question 4, CLM selected two different responses reflecting different scenarios. CLM prefers response a) as indicated by the higher EW (100%) provided for this response. This response reflects its view, as discussed above, that there is insufficient evidence to

demonstrate that the fault connecting the Belloy Formation to the basement has the necessary properties to transmit pressure or stress increases from the Belloy Formation to the mainshock fault planes.

[157] Response b) reflects the CLM's acknowledgement of the potential presence of a fault or faults that could connect the Belloy Formation and the Precambrian basement as described in the Obsidian evidence. However, given the speculative nature of the properties of the faults and that no reservoir model has been generated for the Belloy Formation, CLM submitted the degree of pore-pressure increase resulting from the 6-14 Belloy well cannot be determined. Therefore, CLM considered an evidence weight of 50% to be appropriate.

[158] CLM was not convinced the interpreted fault from the Belloy Formation to the Precambrian basement explained the causation of the seismicity in the eastern cluster. Obsidian submitted that this comment was without basis as Obsidian interprets all the seismic events to have occurred on a single fault plane. The eastern subcluster represents aftershocks occurring at the far end of the mainshock fault plane, driven by stress transfer and earthquake processes that are common in the aftermath of larger events.

Analysis and Findings

[159] The IARs computed by Obsidian and CLM for the 6-14 Belloy well using the Verdon framework are all positive, suggesting a possible linkage between the 6-14 Belloy well and the seismic events specified in the order. The ESR for both assessments is high, suggesting the assessment data was robust.

[160] CLM and Obsidian agree there is some correlation between disposal rates in the 6-14 Belloy well and the seismic events. The cross-correlation coefficients computed by Outer Limits for disposal volumes in the 6-14 Belloy well were found to be statistically significant for lags in seismicity of zero to four months. While we find the evidence supports some temporal correlation between disposal rates in the 6-14 Belloy well and the seismic events, we are mindful that correlation alone does not prove causation.

[161] The only issue in dispute between CLM and Obsidian regarding the 6-14 Belloy well concerns the characteristics of the fault that Obsidian has identified from the Belloy Formation to the Precambrian and whether it acts as a conduit to the mainshock fault planes in the Precambrian basement that caused the seismic events.

[162] We accept Obsidian's evidence that the transfer of pressure or stress along faults from Triassic, Permian, or upper Mississippian Formations, including the Belloy Formation, through significant thicknesses of Lower Palaeozoic strata to nucleate earthquakes in the basement is commonly observed in the Western Canadian Sedimentary Basin. We also accept Obsidian's evidence that there are examples of induced seismicity occurring deep below or kilometres away from sources without observed seismicity between the source and the events. Therefore, we find that the fault mapped by Obsidian provides a plausible mechanism connecting the 6-14 Belloy well to the seismic events observed in the Reno area. By plausible, we use Dr. Verdon's definition that plausible means possible, not disproven.

[163] However, there is no direct evidence that this fault provides a hydraulic conduit from the Belloy Formation to the Leduc Formation or the basement seismogenic fault. While the evidence presented by Enlighten from petrophysical logs and other analogue data supports Obsidian's view that faults in the Belloy Formation may provide hydraulic conductivity to other formations, it comes from other wells in the region and not specifically from the 6-14 Belloy well. So, while this mechanism is plausible, it has not been demonstrated to be more likely than other mechanisms.

[164] While we accept that the 6-14 Belloy well may have contributed to causing the seismic events specified in the order, given uncertainties associated with the characteristics of the fault connecting the Belloy Formation to the Precambrian basement, we have insufficient information to conclude on a balance of probabilities that the 6-14 Belloy well caused the seismic events.

High-Volume Leduc Disposal Wells

[165] Before issuing the order to Obsidian, the AGS and CLM considered whether the 13-11 Leduc well may have been responsible for the seismic events. The 13-11 Leduc well had previously been linked to a series of seismic events near the well within the North Heart cluster and is considered by the AER to be seismogenic (having the ability to cause seismic events). However, the 13-11 Leduc well is located about 20 km north of the seismic events in the Reno area, and there was no observed seismicity between the seismic events and the 13-11 Leduc well. On this basis, the AGS and CLM concluded that the 13-11 Leduc well was not responsible for the November 2022 and March 2023 seismic events.

[166] Obsidian submitted that a group of high-volume Leduc disposal wells north of the Reno area, including the 13-11 Leduc well (collectively the high-volume Leduc wells), were "substantially more likely" to have caused the seismic events than the Obsidian well. Obsidian's assessment relies on the analyses completed by its consultants, specifically the geological and reservoir analysis and modelling completed by Enlighten and MPD and the subsequent induced seismicity assessment by Outer Limits.

[167] During the oral hearing, CLM confirmed that the operator of the 13-11 Leduc well has voluntarily implemented a monitoring, mitigation, and response plan and taken steps to mitigate the seismic activities induced by the well's operation. However, it did not agree that the 13-11 Leduc well or other high-volume Leduc disposal wells north of the Reno area contributed to the seismic events specified in the order given the greater distance (>20 km) between those wells and the seismicity in the Reno cluster and the absence of observed seismicity between those wells and the seismic events in the Reno area. CLM assumed that any pore-pressure increases in the Reno area resulting from the high-volume Leduc wells are minimal compared with the pressure changes from the Obsidian well.

The MPD Evidence

[168] Obsidian's consultant, MPD, studied pressure and production data in the Leduc fringing reef in Townships 80 to 85, Ranges 17 to 21, West of the 5th Meridian to examine the effect of water disposal wells on reservoir pressure. The study area includes the Obsidian well and the high-volume Leduc wells north of the Obsidian well, including the 13-11 Leduc well.

[169] Ten Leduc water disposal wells are identified (nine with disposal volumes) and divided into three geographical groups. There is a significant difference in the length of disposal operations and cumulative volume of water disposed by these three groups of wells:

- The southern wells in Township 82: These wells include the Obsidian well with a total disposal volume of 1.3 million m^3
- The central wells in Township 84: A group of four disposal wells, including the 13-11 Leduc well, with a total disposal volume of 7.8 million m^3
- The northern wells in Township 85: A group of four disposal wells with a total disposal volume of 69.8 million m^3

[170] The cumulative disposal volume for the northern wells in Township 85 represents 88% of the total water disposed of in the Leduc fringing reef in the study area since 1986.

[171] Based on a study of pressure since the start of disposal in 1986, MPD determined that the maximum pressure rises around the northern wells, where most of the water has been disposed of, was less than expected. MPD also found that pressure in areas away from the northern wells, and specifically in the area around the Obsidian well, had increased before disposal operations started in those areas. Based on these observations, MPD concluded that the pressure rise in those areas was due to disposal in the wells north of the Obsidian well and the movement of fluids to the south towards the Obsidian well.

[172] A fall-off test was conducted on the Obsidian well in October 2023. The bottomhole pressure data gathered during the fall-off test was analyzed using pressure-transient analysis techniques. This analysis suggests the presence of a constant pressure boundary condition near the wellbore. MPD submitted that this supports the finding that there is communication with the wells north of the Obsidian well and that pressure near the Obsidian well is affected by disposal from the wells to the north.

[173] MPD built a reservoir simulation model using the Fine-Faulted Geomodel described in the Marshall evidence. Initially, a base case was run using mid-case properties (including permeability). This resulted in a predicted pressure rise near the northern wells that was much larger than observed by measurements. The base-case model also underpredicted the pressures in the south. When a high-permeability case was used, a larger portion of the injected fluid was allowed to leave the northern part of the study area, and the model pressures agreed much better with the measurements in the north. A better pressure match is also obtained for the two other groups of wells, including the Obsidian well.

[174] MPD selected an observation point 2.3 km west of the Obsidian well to correspond to the location of the November 2022 mainshock event. When the pressure changes at that location were investigated, it was found that in November 2022, when all wells were included, the pressure rise at that location was much greater than if only the effects of the Obsidian well were included.

[175] Based on the analysis and modelling completed, MPD concluded the following:

- Since 1986, there has been a significant flow of water from the northern and central wells towards the south, including the area around the Obsidian well.
- The communication from the northern and central wells led to a measurable increase in pressure in the area around the Obsidian well before this well was put into disposal service in 2012.
- The contribution of the Obsidian well in increasing the pressure at the observation point near the mainshock seismic event is far less (<10%) than the pressure increase caused by the other disposal wells.

[176] Mr. Virues, AER's senior reservoir engineer, submitted that MDP's conclusions that the high-volume Leduc wells caused the seismic events rely on a reservoir model that involves many assumptions and constraints and was speculative. Specifically, Mr. Virus expressed the following concerns:

- The reservoir model is based on limited data and relies too much on a single fall-off test from the Obsidian well in 2023 to support the presence of a constant pressure boundary near the well.
- Existing bottomhole static gradients and fall-off reservoir pressures are not used, and there is no history matching of pressures between 1986 and 2012 (26 years).
- Different choices for modelling parameters, such as permeability and fault transmissibility, would make a difference in the model results.
- The model uses the results from step rate tests even though such tests are not intended to measure reservoir pressures.
- The model relies on drillstem test interpretation, which can be difficult, and the results unreliable.

[177] Dr. Pooladi-Darvish clarified that his analyses and conclusions were not speculative but "based on basic scientific principles, which are then tested with the use of established engineering models and workflows." In response to the CLM's comments, he demonstrated the following:

- His conclusions were based on the reservoir engineering model and observed pressure data.
- The application of first principles to the pressure data led him to his conclusion that pressure in the Leduc Formation has increased because of the disposal in wells that are at large distances (more than 20 km) and, in particular, because of the northern disposal wells.

- The reservoir engineering model allows the application of the scientific method to test the validity of the conclusion arrived at using the first principles.
- The use of pressure data from different types of tests (drillstem tests, step rate tests) in the model is consistent with AER regulatory requirements and recommendations and accepted engineering best practices.
- The use of modelling provided advantages in assessing formation pressure in the study area and in determining that the contribution of the Obsidian well in increasing pressure in the Leduc Formation in the area of the seismic events was much smaller than for other wells.
- The modelling workflow allowed for integration with other information (geological/geophysical and petrophysical), quantification of the results, accounting for uncertainties, and testing the validity of the conclusions.

Application of the Verdon Framework to the High-Volume Leduc Wells

[178] Applying the Verdon framework to the high-volume Leduc disposal wells, Obsidian assessed the ESR to be 92% and the IAR to be + 55%. Based on its assessment, Obsidian concluded that the high-volume Leduc wells north of the Reno area have a “moderate likelihood” of having caused the seismic events.

[179] In the CLM’s reassessment of the evidence using the Verdon framework, it determined that the evidence strength for the high-volume Leduc wells ranges between 85% and 100%, and the IAR ranges between −12% and +35%. The lowest ESR and IAR are for the scenario where a reservoir model does not support a large pore-pressure increase at the Reno location from distant disposal wells. The highest ESR and IAR are for scenarios where reservoir models show large pore-pressure increases at the Reno location from distant disposal wells; however, the evidence strength is properly calibrated to capture the multiple assumptions in the reservoir model.

[180] CLM and Obsidian selected the same response and arrived at the same score for three of the seven questions in the Verdon framework. They differed in their responses to questions 3 (temporal correlation), question 4 (depth of events), question 5 (spatial correlation), and question 6 (earthquake mechanism), as shown in table 8.

Table 8. CLM and Obsidian responses to Verdon framework questions 3, 4, 5 and 6 for the high-volume Leduc wells

Questions and possible responses	Score	Obsidian response	CLM response	CLM response
Q3. Are the observed seismic events temporally correlated with the injection activities.	Score	Evidence weight 100%	Evidence weight 100%	
a. The earthquakes are coincident with the injection, but there is minimal correlation.	-4	No	Yes	
b. There is some temporal correlation between the seismicity and the industrial activity.	+4	Yes	No	
c. There is strong temporal correlation between the seismicity and the industrial activity.	+15	No	No	
Q4 Do the earthquakes occur at similar depths to the activities?	Score	Evidence weight 80%	Evidence weight 100%	
a. Earthquakes do not occur at the same depth, and there is no plausible mechanism by which stress or pressure changes could be transferred to the earthquake depths.	-4	No	No	
b. Earthquakes do not occur at the same depth, but plausible mechanisms exist by which stress or pressure changes could be transferred to these depths.	+2	Yes	No	
c. Earthquakes occur at similar depths to the injection.	+3	No	Yes	
Q5 Is there spatial collocation between events and the injection?	Score	Evidence Weight 100%	Evidence Weight 100%	Evidence Weight 50%
a. Earthquakes are distant to the activities, given the putative causative mechanism.	-10	No	Yes	No
b. Earthquakes are sufficiently close to the activities, given the	+5	Yes	No	Yes

Questions and possible responses	Score	Obsidian response	CLM response	CLM response
putative causative mechanism.				
c. If earthquake loci change with time, this change is consistent with the industrial activity, for example, growing radially from a well or shifting in response to the start of a new well.	+10	No	No	No
6. Is there a plausible mechanism to have caused the events?	Score	Evidence Weight 100%	Evidence Weight 100%	Evidence Weight 50%
a. No significant pore pressure increase occurred that can be linked in a plausible manner to the hypocentral positions.	-5	No	Yes	No
b. Some significant pore pressure increase occurred that can be linked in a plausible manner to the hypocentral positions.	+2	No	No	No
c. A large pore pressure increase (or stress perturbation) occurred that can be linked in a plausible manner to the hypocentral positions.	+5	Yes	No	Yes

Temporal Correlation

[181] Obsidian's response reflects its interpretation that there is some temporal correlation between the seismic events and disposal operations in the high-volume Leduc wells. Obsidian considered an evidence strength of 100% appropriate given the availability of a full time series of disposal volumes and enough observed seismic events with which detailed assessments of temporal correlation can be made.

[182] Obsidian calculated cross-correlation coefficients for the high-volume Leduc wells using the combined injection volume for the high-volume Leduc wells and the total seismicity in the North Peace River, North Heart, and Reno clusters. Given the lateral extent of the pressure pulse as modelled by MPD, Outer Limits considered it reasonable to compute the correlation between injection in the high-volume Leduc wells and the overall seismicity sequence.

[183] Obsidian observed that the cross-correlation coefficients for the high-volume Leduc wells were "elevated" at short time lags higher than 0.3 for all lags less than two years. The P-values for the high-volume Leduc disposal wells with an 8-month time lag is 0.038, and for a 12-month time lag, 0.025. Hence, at the 5% threshold, there is a statistically significant correlation between injection rates in the high-volume Leduc wells and the overall seismicity (including the southern cluster).

[184] The CLM's response reflects its view that there is minimal correlation between the seismic events and disposal operations in the high-volume Leduc wells. CLM disagrees with Obsidian's approach to assessing temporal correlation. As the Obsidian well is injecting into the same formation as the high-volume Leduc wells and is very close to the seismicity, CLM did not see a reason to exclude the Obsidian well in the analysis when all Leduc Formation disposal wells in the Peace River region are considered. CLM acknowledged the apparent correlation between the high-volume Leduc wells and the entirety of seismicity in the Peace River region but suggested it is a product of the correlation between the different clusters and the nearby associated disposal activity. In other words, the low-resolution assessment conducted by Obsidian obscures the correlation between seismogenic disposal wells and nearby seismicity. CLM submitted that this explains why there are no significant variations in the cross-correlation coefficient observed for the high-volume Leduc wells in the plot of cross-correlation coefficients presented by Obsidian.

[185] CLM reported that correlations between disposal activities and each of the seismic clusters in the Peace River region have been described in the analysis conducted by Schultz et al. 2023. For instance, the North Heart cluster shows a strong correlation with the disposal activity nearby, with temporal confidence between 89% and 97% (Schultz et al., 2023). Consequently, CLM argued that a score of +4 points would be appropriate for seismogenic disposal activities in the Leduc Formation with their associated seismic cluster, and −4 points would be appropriate for the correlation between disposal activities in the Leduc Formation with distant seismic clusters.

[186] In response, Dr. Verdon noted that only the North Heart cluster is near the high-volume Leduc wells. As it is the smallest cluster in terms of the number of seismic events, he submitted it was unlikely that short-term effects associated with this cluster could have a significant influence on the cross-correlation coefficient for the bulk of the seismicity, which is associated with other clusters that are far away from the disposal activities.

Depth of Events

[187] Obsidian's response reflects its interpretation that the seismic events do not originate in the Leduc Formation, the depth at which disposal operations are occurring, but that plausible mechanisms exist connecting the disposal operations to deeper faults in the Precambrian basement. These mechanisms include the fault that Obsidian has mapped from the Belloy Formation to the Precambrian basement or other similar faults cutting through the Leduc Formation and into the Precambrian basement, such as

those proposed by CLM to connect the disposal operations associated with the Obsidian well to the basement. The evidence strength of 80% reflects uncertainties related to the location and properties of these faults.

[188] The CLM's response is consistent with its interpretation that seismic events occur at similar depths to disposal operations in the Leduc Formation. Based on the AGS seismic nodal array data, CLM identifies seismic events reaching the depths of the Leduc Formation. CLM also finds evidence of ample faulting of the Precambrian basement near the Obsidian well in the 2-D seismic lines presented in the additional evidence filed in its hearing submission. CLM submitted that this faulting supports the concept that deep disposal operations injecting into the Leduc Formation that overlies the Precambrian basement can interact with faults, causing them to slip. Thus, +3 points is a reasonable allocation for both the Obsidian well and the high-volume Leduc wells. CLM believes that an evidence weight of 100% is reasonable, given that the information includes high-resolution seismic data and 2-D seismic images.

Spatial Correlation

[189] Obsidian's response reflects its view that the seismic events are sufficiently close to the high-volume Leduc disposal wells to have caused the events. Obsidian noted that the locations of the injection wells are well defined. Furthermore, the regional seismic data provides sufficient precision to assess the proximity of the events relative to the wells, and this precision is enhanced by the availability of the local seismic nodal array data, recognizing that the local arrays record aftershock locations rather than the locations of the mainshocks. Consequently, Obsidian considered an EW of 100% to be appropriate.

[190] Obsidian submitted that there is no basis for CLM to have discounted the high-volume Leduc wells as a possible cause of the seismic events due to their distance from the Reno cluster. There are numerous examples of wastewater disposal inducing seismicity elsewhere, where seismic events have been triggered at large distances without seismicity in the intervening gaps. Obsidian identified examples from Oklahoma, Kansas, and Ohio.

[191] Obsidian acknowledged that the local nodal seismic array datasets provide the highest resolution event locations and that the Reno cluster is 20 km from the nearest high-volume Leduc wells. However, the analysis and reservoir modelling completed by MPD shows that, given the volumes of fluid injected in the high-volume Leduc wells, significant pore-pressure changes can be expected to have reached the location of the Reno cluster.

[192] As discussed earlier, when conducting the induced seismicity assessment for Obsidian, Outer Limits assumed that the seismicity cluster associated with the North Peace River cluster was induced. Outer Limits submitted that if this cluster is induced, it demonstrates that the high-volume Leduc wastewater disposal wells can trigger seismicity at distances of up to 20 or 30 km without seismicity occurring between the disposal wells and the seismic events. This phenomenon is consistent with the stress conditions observed by Enlighten, where faults in the Leduc Formation are unlikely to be critically

stressed. Seismicity only occurs where faults exist that allow elevated pressures in the Leduc Formation to propagate downwards into the Precambrian basement. Outer Limits submitted that if the high-volume Leduc wells can trigger seismicity at distances of 20 to 30 km for the North Peace River cluster, then they are also capable of causing seismicity in the Reno cluster.

[193] CLM selected two different responses to reflect different scenarios. CLM disagrees with the Obsidian assessment and prefers response a) as the high-volume Leduc wells are more than 20 km and, in some cases, almost 40 km, from the Reno cluster. Furthermore, there is no observed seismicity between these distant high-volume Leduc wells and the Reno cluster. CLM suggested this either indicates that there are no faults prone to slip between the Reno seismicity and the distant wells or that the actual pore-pressure increase from the distant wells is not as significant as proposed by the reservoir modelling by MPD. Therefore, CLM considered the allocation of −10 points to be appropriate.

[194] Given its concerns about the many assumptions and constraints involved in the MPD reservoir modelling and the speculative nature of the model results, CLM submitted that if a positive spatial colocation were assigned, an EW of 50% would be more appropriate to reflect the uncertainties associated with the model inputs.

Earthquake Mechanism

[195] Obsidian's response is consistent with its evidence:

- The Leduc reservoir simulations conducted by MDP show that the pore-pressure perturbations from the high-volume Leduc wells can propagate 20 km or more through the Leduc Formation to the location of the Reno cluster.
- The pressure increase at the location of the November 2022 Reno mainshock event due to the high-volume Leduc wells is much greater than the pressure increase attributable to the Obsidian well alone.
- The observed pressure increase is large enough to trigger slippage of a critically stressed fault.
- The absence of seismicity between the northern and central high-volume Leduc wells and the seismic events in the Reno area is consistent with the stress conditions observed by Enlighten.

[196] Obsidian submitted that the assessment and simulations of pressure changes created by wastewater disposal in the Leduc developed by MPD provide the basis for evaluating whether the injection activities in the Leduc could have created sufficient pressure change to cause induced seismicity. An EW of 100% is therefore appropriate.

[197] Obsidian submitted that the three seismicity clusters in the area (North Peace River, North Heart, and Reno) all occur in the same structural setting and display similar behaviours, magnitudes, rates of seismicity, and ongoing durations. Therefore, it is reasonable to assume that the same mechanism for fault activation is involved.

[198] CLM selected responses for two different scenarios. For question 6, CLM prefers response a) for similar reasons to those provided for its response to question 5. The high-volume Leduc wells are located more than 20 km from the seismic events, and no seismicity is observed between these wells and the Reno cluster. Additionally, CLM considers MPD's interpretation that these wells caused a large pore pressure or poroelastic stress change in the Reno area debatable since it relies on a model based on many assumptions, constraints, and limited data. CLM submitted that if answer c) to question 6 is chosen, an evidence weight of 50% would be more appropriate given the highly speculative inputs of the reservoir model.

Analysis and Findings

[199] The IAR determined by Obsidian is moderately positive, and the ESR is high, indicating a possible linkage between the disposal activities in the high-volume Leduc wells and the seismic events specified in the order. While CLM calculated a range of IARs and ESRs, we find the evidence supports the scenarios with the higher IAR (+35%). The pressure analysis and reservoir modelling conducted by MPD is robust. It used established engineering modelling and workflow processes, evaluated the data quality used in the model, and used sensitivity analyses and other techniques to account for uncertainties to test the validity of the results and conclusions from the model. Recognizing that all reservoir models involve some assumptions and uncertainty, we find that the model results can be relied on for assessing the contribution of the high-volume Leduc wells to pressure increases in the Leduc Formation near the Obsidian well and the Reno cluster.

[200] Based on the reservoir analysis and modelling, we accept that disposal in the high-volume Leduc wells has resulted in a pressure increase in the Leduc Formation in the Reno area that is much larger than what would be expected from the Obsidian well alone and that this pressure increase began before the Obsidian well commenced operations. Therefore, we find it plausible that this pressure increase may have contributed to causing the seismic events.

[201] Regarding temporal correlation, we are not persuaded by Obsidian's assessment. While Outer Limits observed statistically significant correlations for periods under two years, we share the CLM's concern that the apparent correlation may be a product of the correlation between the different clusters and the nearby associated disposal activity. It is curious that the most significant correlations are for short periods under two years, which leads us to question whether the correlations are being driven by nearby seismicity rather than effects over significant distances. Therefore, we are not convinced that the observed correlation demonstrates a correlation between disposal rates in the high-volume Leduc wells and the seismic events in the Reno area.

[202] As discussed for the 6-14 Belloy well, we accept Obsidian's evidence that there are examples of induced seismicity occurring deep below or kilometres away from sources without observed seismicity between the source and the events. Furthermore, we find the absence of induced seismicity within the

Leduc Formation is consistent with the assessment of stress conditions in the formation performed by Enlighten, which demonstrated that most faults in the Leduc Formation are not critically stressed. Seismic events would only be triggered where increased pressure in the Leduc Formation can propagate downwards via faults to deeper critically stressed faults in the Precambrian basement. Therefore, we find that the absence of seismicity between the high-volume Leduc wells and the Reno cluster and the distance between these wells and the seismic events is not a sufficient reason to discount these wells as a possible cause or contributor to the seismic events in the Reno area.

[203] As discussed in the assessment for the Obsidian well, Obsidian and CLM have each mapped multiple fault systems around the Obsidian well and Reno cluster. These basement-rooted faults extend into the Leduc Formation and provide a plausible pathway for increased pressures from the Leduc Formation to be transmitted to the deeper faults in the Precambrian basement that slipped and caused the seismic events.

[204] Based on our review of the evidence, we find that the high-volume Leduc wells may have contributed to causing the seismic events referred to in the order. However, given the evidence available, we cannot conclude on a balance of probabilities that the high-volume Leduc disposal wells caused the seismic events.

Summary and Conclusions Related to the Cause of the Seismic Events

[205] We accept that induced seismicity assessment frameworks help assess whether seismicity may be natural or induced. The frameworks can be applied rapidly after seismic events occur and be updated as more information becomes available, providing a systematic approach that can improve the consistency of the approach and assessment results.

[206] However, applying the frameworks requires significant subjective judgement by the assessor. Different assessors, using the same framework and the same evidence, may arrive at different scores and conclusions. We observed this in comparing the results of CLM and Obsidian induced seismicity assessments using the Verdon framework and in the results of the Salvage et al. 2023 study. While the use of a robust assessment framework helps improve the consistency of approach and results, how different assessors deal with uncertainties in the data can have a significant impact on the assessment results.

[207] We disagree with Dr. Verdon's suggestion that the Verdon framework must be applied strictly as presented in the Verdon et al. 2019 paper without "significant amendment or change." As CLM pointed out, this is inconsistent with the contents of the Verdon et al. paper, which includes the following statements:

- "However, we stress that the specific details of the framework are only a suggestion and others may wish to adapt and adjust those features."

- "We wish to emphasize two particular points, the first being that both the criteria and the associated scores presented herein are our own best judgement put forward as a suggestion. These are not intended as a prescription."
- "We provide these suggestions to illustrate the practical application of our proposed framework, but we would expect users to make their own choices regarding the details, both with regards to questions asked and scores assigned to them."

[208] Dr. Verdon suggested that where multiple different activities have been invoked as potential causes of an earthquake, the IAR for each activity can be used to determine the more likely cause. For example, in a case of induced seismicity where one activity produces a significantly higher positive IAR than another, then the conclusion of the assessment should be that the activity with the higher score was the dominant or more likely cause. Where two different activities produce similar positive IAR scores, then the conclusion of the assessment should be that both activities are equally likely to have caused or contributed to the induced seismicity.

[209] Dr. Verdon considers a difference of 5 to 10 points or more between assessment ratios as meaningful. In the assessment completed for Obsidian, Outer Limits concluded that the high-volume Leduc wells (+55%) and the 6-14 Belloy well (+49%) are "substantially more likely" to have caused the seismic events than the Obsidian well (+31%). In contrast, CLM submits that the Obsidian well (+51%) is the most likely cause, while the 6-14 Belloy well (+21% to +48%) and high-volume Leduc wells (−12% to +35%) are significantly less likely to be the cause. As discussed earlier, we consider the higher induced assessment score developed by CLM for the high-pressure Leduc wells (+35%) to be more reasonable. Disregarding the −12% score, all the other scores are moderately positive, ranging from +21% to +55%. These scores indicate a potential link between each of the disposal operations and the seismic events.

[210] We are not persuaded that we can or should rely primarily on the observed differences in induced assessment scores to determine the relative likelihood that the Obsidian 14-18 well, 6-14 Belloy well, or the high-volume Leduc disposal wells caused the seismic events. Assessing the causes of induced seismicity is complex, and it can be challenging to quantify the contribution of different disposal activities to fault activation. While the induced seismicity scores help identify potential causes for consideration, as Dr. Canales and Dr. Verdon acknowledged, understanding the geology and physics associated with the potential pressure transfer and failure mechanisms is key.

[211] The observed differences in induced assessment scores are the result of differences in interpretations related to two factors: the degree of temporal correlation between disposal rates and seismicity and differing hypotheses by Obsidian and CLM as to how pressure could have been transferred from different disposal wells to the mainshock fault in the basement.

[212] Regarding temporal correlation, the strongest observed correlation is for the 6-14 Belloy well, and it was assessed only as demonstrating "some" correlation. For the Obsidian well and the high-volume Leduc wells, the correlation was assessed as either "minimal" or "some," depending on the assessor. Hence, we find that the degree of differentiation regarding the temporal correlation between the seismic events and the different disposal operations is not strong.

[213] Regarding the earthquake mechanism, Dr. Verdon summed it up well with the following statements:

- "You've heard now several different hypotheses of mechanisms for how pressure could have been transferred from different wells to the mainshock fault in the basement. Some are clearly more plausible than others; however, none can be definitively proven or definitively ruled out given the evidence that we have."
- "Geophysical observations can tell us where faults are, but they cannot tell us whether pressure actually was transferred along the faults or not."

[214] We concur with Dr. Verdon. While Obsidian and CLM have both proposed plausible hypotheses on how pressure from the different disposal operations could have reached the mainshock fault plane in the Precambrian basement, there are key uncertainties associated with each hypothesis. Given the evidence available, none are clearly superior or more likely compared with the others.

[215] In summary, Obsidian has not persuaded us that the Obsidian 14-18 well did not cause or contribute to causing the seismic events specified in the order. While we find that it is plausible that the 6-14 Belloy well and the high-volume Leduc wells may have contributed to causing the seismic events, based on the evidence available, we cannot conclude on a balance of probabilities that these operations caused the seismic events.

Revoking, Varying, or Suspending the Order Is Not Justified or Necessary

[216] Obsidian alleged that CLM conducted and relied on certain analyses and made certain findings and conclusions that were erroneous and used those erroneous findings and conclusions as the basis for issuing the order. Obsidian submitted that after considering and adjudicating this appeal, we should conclude that CLM erred in the facts and analyses and that the order should be revoked or varied.

[217] Obsidian alleged that CLM erred for the following reasons:

- The order states that between January 2023 and March 16, 2023, the AGS analysis started to indicate there may be a connection between the seismic events and disposal operations at the Obsidian well. However, the record of the decision maker does not include any analysis indicating that as of March 16, 2023, CLM had conducted any analysis indicating a connection between the Obsidian well and the November 2022 seismic event.

- The order states that on March 17, 2023, the AGS reviewed new information from the seismic nodal array and determined the seismic events were spatially and temporally correlated to the Obsidian well. However, the Outer Limits evidence shows no spatial or temporal correlation between the seismic events and the Obsidian well. Instead, there is a temporal correlation between the seismic events and the 6-14 Belloy well and the 13-11 Leduc well.
- The order states that the Obsidian well induced the seismic events, but the Outer Limits evidence shows that the 6-14 Belloy well and a group of high-volume disposal wells north of the Obsidian well, including the 13-11 Leduc well, are substantially more likely than the Obsidian well to have caused the seismic events.
- The order states that the director is of the opinion that a release of the substances has occurred and that the substances have caused, are causing, or may cause adverse effects. However, the order states that the AER was unaware of any adverse effects to date.
- The order names Obsidian as a "person responsible" for the substances which is erroneous given the errors identified above.

[218] We address each of these issues below.

Analysis was Completed by the AGS and CLM Before Issuing the Order to Obsidian

[219] After the November 29, 2022, mainshock event and before issuing the order to Obsidian on March 23, 2023, the AGS and CLM undertook several tasks and analyses to better understand the possible causes of the November 29, 2022, mainshock event. This included using a local nodal array to gather information on aftershock locations, processing and interpreting data from the regional seismic array and identifying disposal operations that might have caused or contributed to the seismic events. On March 17, 2023, the AGS obtained the initial processed data from round 1 of the nodal array and used it in its analysis. This data and analysis were used to inform the CLM's decision to issue the order to Obsidian.

[220] Not all the analysis appears in the records of the decision maker. Some of it appears in the supplemental information that reflects information used by staff (including AGS staff) to develop recommendations to be considered by the CLM decision maker. It appears in a variety of formats, including emails and PowerPoint presentations. It does not generally appear in formal reports.

Analysis and Findings

[221] The November 2022 and March 2023 seismic events were among the largest recorded in Alberta. When faced with such a significant seismic event, the decision makers responsible for ensuring the protection of the environment and public safety must decide when they have sufficient information to act. Decision makers do not always have the luxury of time to collect more data and complete further analyses before acting. We believe that is the case here. While taking additional time to reprocess the nodal array

data would have improved the accuracy of the event locations and provided further insights about the cause, the potential for another significant seismic event was a possibility. Therefore, we find it was appropriate for the decision maker to have acted when he did.

[222] As noted earlier, after issuing the order, the AGS continued to collect, process, and interpret data to better understand the cause of the seismic events. Obsidian also collected data and conducted analyses and modelling to understand the cause. However, even with the benefit of 16 months of additional data collection and analysis, significant uncertainties remain about the possible cause of the seismic events.

[223] Regarding the above, we find that the activities and analysis completed by the AGS and CLM before issuing the order were reasonable and made use of the information available at the time. Furthermore, the CLM director's decision to issue the order was consistent with the director's discretion under section 113(1) of *EPEA*. To issue an environmental protection order to a responsible person, the decision maker only needs to "be of the opinion" that a release of a substance into the environment may occur, is occurring, or has occurred, and (b) the release may cause, is causing, or has caused an adverse effect.

[224] As Obsidian did not take issue with the director's finding that there was a release into the environment, we are therefore left to consider Obsidian's concerns that it was not a responsible person and the release did not cause an adverse effect.

The Evidence Supports a Connection Between the Seismic Events and the Obsidian Well

[225] Obsidian submitted that CLM erred because there is no spatial or temporal correlation between the Obsidian well and the seismic events, and there are other disposal operations "substantially more likely" to have caused the seismic events.

Analysis and Findings

[226] The initial nodal array data relied on by CLM to issue the order suffered from processing issues that affected the accuracy of the event locations. However, these issues were corrected in the revised AGS and Outer Limits earthquake catalogues presented in the Obsidian and CLM evidence and used in our analysis. CLM and Obsidian were also allowed to present significant new evidence on other matters, including the degree of spatial and temporal correlation between the Obsidian 14-18 well, 6-14 Belloy well, and the high-volume Leduc wells.

[227] Having reviewed the record of the decision maker and the new evidence filed in this proceeding, we are not persuaded on the balance of probabilities that the Obsidian 14-18 well did not cause or contribute to causing the seismic events. Important in this regard is Obsidian's evidence. Obsidian did not argue that the Obsidian well did not or could not have caused the seismic events. It argued there were other disposal operations that were "substantially more likely" to have caused the seismic events. This is

consistent with Obsidian's evidence, including the induced seismicity assessment completed by Outer Limits, which indicated a possible link between the Obsidian well and the seismic events.

[228] To confirm the order, it is not necessary for us to find that Obsidian caused the seismic events. Finding that Obsidian *may have caused* the seismic events is sufficient to confirm the order. The onus was on Obsidian as the regulatory appeal requester to demonstrate that the Obsidian well was not responsible for causing the seismic activity.

Occurrence of Adverse Effects and Issuance of an Environmental Protection Order

[229] Obsidian submitted that CLM erred in issuing the order because the order stated that "a release of the substances has occurred, and that the substances have caused, are causing, or may cause adverse effects" but that no adverse effect had been observed. Obsidian requested that if the order is upheld, it be amended to reflect this fact.

[230] Mr. Kuleba confirmed that at the time the order was issued, he was concerned about the potential for a larger, more damaging seismic event to occur should mitigation measures not be taken. He believed that a future release may cause an adverse effect, and an order was required to prevent or minimize the potential for this occurring.

Analysis and Findings

[231] We find that the language used in the order reflects the wording in *EPEA* that the release may cause, is causing, or has caused an adverse effect. Mr. Kuleba confirmed that at the time the order was issued, he was concerned about the potential for a larger, more damaging seismic event to occur should mitigation measures not be taken. He believed that a future release may cause an adverse effect, and an order was required to prevent or minimize the potential for this occurring.

[232] Given that seismic events greater than 5.0 M_L had occurred in November 2022 and in March 2023, before issuing the order, Mr. Kuleba's concern about the potential for future, larger magnitude events was reasonable. We accept that at the time the order was issued, Mr. Kuleba was of the opinion that a future release may occur and that it may cause an adverse effect. We also accept that he was of the opinion that Obsidian was the "person responsible" for the seismic events. This was sufficient for him to issue the order. We find no error here nor reason to revoke or vary the order.

Director's Discretion About Who to Name in an Environmental Protection Order

[233] Obsidian argued that CLM erred because the order named Obsidian as the responsible person and did not name other parties that were "substantially more likely" to have caused the seismic events. Initially, Obsidian submitted this as a basis on which the order should be revoked. However, in its final argument, Obsidian requested that if the order were not revoked, it be revoked and reissued or varied to name other persons responsible for the seismic events, consistent with our findings in this proceeding.

Analysis and Findings

[234] Under *EPEA*, the director has significant discretion about who to name in an order. It is not necessary for the director to name every person responsible for a release. Although out of fairness, it is desirable that the decision maker name everyone they believe caused or contributed to the release[11]. At the time the order was issued, the CLM director was of the opinion that the Obsidian well and no other operation were responsible for causing the seismic events. This was sufficient for him to name Obsidian in the order as the person responsible. Obsidian, as operator of the well, had management and control over the substance released (the vibrations and release of energy associated with the seismic events). This meets the definition of "person responsible" under sections 113 and 1(tt) of *EPEA*. We find no error in the CLM's initial decision to issue the order only to Obsidian.

[235] Because of the new evidence filed in this proceeding, we find that it is plausible that the 6-14 Belloy well and the high-volume Leduc wells may have also contributed to causing the seismic events specified in the order, but as discussed earlier, we do not have enough information to make any conclusive findings regarding the other operators.

Directive 065 Provides New Regulatory Tools for Seismogenic Wells

[236] Clause 12 of the order states:

> This Order will remain in effect until such time as a permanent regulatory instrument is in place or the induced seismic hazard from the Disposal Operation has reduced to the satisfaction of the Director.

[237] On November 12, 2024, shortly before the hearing, the AER released a revised edition of *Directive 065*. Section 4.1.8 of *Directive 065* is new and outlines regulatory requirements for induced seismicity potentially related to disposal wells. Section 4.1.8 recommends and requires steps and actions to reduce the hazard of induced seismicity from fluid disposal operations. If seismicity is associated with a fluid disposal operation, *Directive 065* allows the AER to designate an operating disposal well to be "seismogenic" and to amend the disposal scheme approval.

[238] Key requirements of *Directive 065* include:

- If the AER determines the disposal well to be seismogenic, the disposal scheme approval holder must submit a seismic risk assessment and a monitoring, mitigation, and response (MMR) plan.
- If the AER determines the disposal well to be seismogenic, the disposal scheme approval holder must provide operational data, passive seismic monitoring information (including waveform data), and data required under the scheme approval to the AER upon request.

[11] Imperial Oil Ltd. and Devon Estates Ltd. v. Director, Enforcement and Monitoring, Bow Region, Regional Services, Alberta Environment, 2002 ABEAB 23(CanLII), at paras. 196-197.

- All applications for new fluid disposal wells must include an induced seismic hazard assessment. A seismic risk assessment and an MMR plan are also required if the seismic hazard assessment shows that the area is prone to induced seismic events.
- Applications to amend the operating conditions of an existing fluid disposal well must include a seismic hazard assessment. A seismic risk assessment and MMR plan must also be included if the seismic hazard assessment shows that the area is prone to induced seismic events.
- A disposal scheme approval holder with an MMR plan must follow the traffic light protocol described in the directive should seismicity occur within ten kilometres of their disposal well, or a greater distance if directed by the AER).

[239] Section 4.1.8.2 of *Directive 065* outlines requirements for conducting seismic hazard assessments for disposal wells, and section 4.1.8.3 of the directive specifies requirements for MMR plans.

[240] On August 21, 2024, before the release of the revised *Directive 065*, Obsidian submitted a motion requesting that we stay clause 12 of the order pending completion of the regulatory appeal proceeding and issuance of our decision on the appeal. Obsidian anticipated that when the new directive came into force, CLM would choose to invoke clause 12 of the order. In response to the motion, CLM confirmed that it would not seek to rely on clause 12 of the order to adjourn the proceeding and would allow us to hear Obsidian's regulatory appeal and issue a decision. Considering the CLM's commitment, no decision was required on the motion.

[241] CLM confirmed that the licensee of the 13-11 Leduc well has voluntarily implemented an MMR plan and taken steps to mitigate the seismic activity observed in the North Heart cluster believed to have been induced by that well's operation.

[242] Mr. Kuleba confirmed that the AER intends to use the new requirements in *Directive 065* to address disposal wells that the AER considers to be seismogenic, including the Obsidian 14-18 well and the 13-11 Leduc well.

[243] While the evidence suggests the 6-14 Belloy well and high-volume Leduc wells may have contributed to causing the seismic events, based on the evidence available, we cannot conclude that these wells caused the seismic events. Therefore, there is no justification for us to vary the order to name the operators of these wells in the order.

The Nature and Impacts of the Order

[244] During the March 23 due process meeting, CLM indicated to Obsidian that the order was meant to be remedial and not punitive. Obsidian submitted that while that may have been the CLM's intent when issuing the order, the reputational and other impacts to Obsidian because of the order and the CLM's findings contained in the order have been real and material.

[245] Obsidian noted that shortly following the AER announcing the order on its website on March 23, 2023, media stories were published naming Obsidian as the recipient of the order. These media stories were published by media outlets across Alberta and nationally. Because of the order and the associated media articles, on March 24, 2023, Obsidian's publicly traded shares fell as much as 4% in premarket trading.

[246] Furthermore, Obsidian reported that in February 2024, the Woodland Cree First Nation took the following actions:

- Issued a press release citing the order and calling it "unprecedented."
- Filed a blanket statement of concern with the AER opposing any development by Obsidian in the vicinity of the Woodland Cree First Nation traditional lands based in part on concerns with the "potential for continued induced seismicity."
- Filed with the AER a request for regulatory appeal relating to well licences issued by the AER to Obsidian based in part on concerns with "seismicity," which it called "especially relevant due to ongoing issues with Obsidian's disposal practices."
- Commenced blockading Obsidian's ongoing operations, preventing Obsidian from gaining access to producing wells and operating facilities.

[247] Obsidian reported that the blockade lasted about 30 days and led Obsidian to shut in production during this time.

[248] CLM confirmed that the order was only remedial and required Obsidian to

- take immediate actions to reduce the frequency and magnitude of induced seismic events caused by Obsidian's disposal operation;
- meet with AER subject matter experts to determine the appropriateness of those immediate actions;
- establish real-time passive seismic monitoring in the area surrounding Obsidian's disposal operation;
- install accelerometers at strategic locations within a 10 km radius of the disposal operation;
- submit and implement a mitigation plan to reduce the magnitude and frequency of induced seismic events caused by the Obsidian's disposal operation; and
- submit to the director various information as specified in the order.

[249] CLM noted that the order does not impose a fine or other penalty or sanction on Obsidian and does not amount to a charge of breaching *EPEA*. The order also does not direct the Obsidian disposal operation to be discontinued or to shut in the Obsidian well. CLM submitted that the terms of the order were crafted to permit Obsidian's disposal operation to continue while preventing the operation from inducing seismic events of magnitudes that may cause adverse effects.

[250] CLM acknowledged that the order has resulted in Obsidian bearing certain burdens but noted that publicly available information indicates that any impact on Obsidian's share price was, at most, short term and transient and minimal compared to whatever other factors were affecting the market price of Obsidian shares as of March 2023. Similarly, while induced seismic activity was identified as a concern voiced by the Woodland Cree First Nation, it was only one of numerous concerns related to Obsidian's activities raised by the Woodland Cree First Nation.

[251] CLM submitted that whatever the true extent of any cost or prejudice to Obsidian resulting from the order was, any such cost or prejudice is irrelevant to the issues in this regulatory appeal. If the panel concludes that disposal operations at the Obsidian well induced the seismic events specified in the order, the order was issued properly pursuant to *EPEA*.

[252] CLM reported that since the order was issued to Obsidian, the traffic light protocol required by the order has been triggered twice. The first time was on April 29, 2023, after an event of 3.28 M_L. The second time was on May 19, 2023, after an event of 3.4 M_L. Both were yellow-light events that required a reduction in disposal rates. Since then, no other yellow-light events have been reported, even though the seismicity continues. CLM submitted that it could be inferred from this that it "got it right" because after implementing the traffic light protocol for the Obsidian well, seismicity has not returned to the level seen in the November 2022 and March 2023 events.

[253] Obsidian disagreed that the reduction in seismic events observed since the order was issued to Obsidian was evidence that CLM "got it right." Obsidian noted that the 13-11 Leduc well also injects into the Leduc Formation and implemented a voluntary mitigation plan around the same time as the order was issued. Obsidian suggested that the CLM's inference could just as easily be applied to the voluntary mitigation plan for the 13-11 Leduc well. Obsidian also suggested there may be other reasons why large seismic events have not been observed since the order was issued. They did not elaborate on what those other reasons might be.

Analysis and Findings

[254] We find that the order is only remedial and not punitive. The order requires Obsidian to take actions to reduce the magnitude and frequency of potential future seismic events. It does not impose fines or other penalties on Obsidian and is designed to allow Obsidian to continue its disposal operations within limits designed to mitigate the consequence of any future seismic events.

[255] While the order may be responsible for reducing the magnitude of seismic events in the Reno area, we accept that there may be other reasons why the magnitude of seismic events has declined. As Obsidian suggests, the voluntary mitigation plan implemented for the 13-11 Leduc well may have contributed to the reduction in events. However, no evidence was presented as to whether the traffic light system was triggered for the 13-11 Leduc well under the voluntary mitigation plan. It is also possible that

the November 2022 and March 2023 mainshock events and associated aftershocks relieved the existing stress on critically stressed faults in the area. Increased pressures resulting from disposal operations may not have yet reached other critically stressed faults in the area or increased to the level required to cause these faults to slip.

[256] The evidence provided by Obsidian in support of its alleged reputational impacts was limited. We had planned to ask Obsidian questions about its evidence related to reputational impacts but were advised by Obsidian's counsel that Obsidian did not intend to rely on those submissions, so we did not ask our questions. However, in its final argument, Obsidian reiterated its claims about reputational impacts, so we will briefly address those claims here.

[257] Based on the evidence on the record, we find that any impacts to Obsidian's share price because of the order were likely short term and transient. The observed decline in share price was in premarket trading, and the share price had largely recovered by the end of the trading session. Obsidian did not present any evidence related to the longer-term effects of the order on its share price. Regarding the concerns expressed by the Woodland Cree First Nation about Obsidian's operations, we find that most of those concerns were not related to induced seismicity or the order. While concerns about induced seismicity may have been a factor that contributed to the blockade, it appears to have been only one of many factors. Furthermore, the blockade ended after 30 days, so the effects on Obsidian appear to have been short term. Obsidian did not present any evidence suggesting longer-term effects.

[258] However, we acknowledge that the order has resulted in costs for Obsidian to comply with the terms of the order. For example, Mr. McGilvary reported that initiating the yellow traffic light protocol in response to events in April and May 2023 required a 15% reduction in disposal volumes. There were also costs associated with installing and operating the Obsidian seismic monitoring array. We see these costs as distinct from the costs associated with appealing the order. However, if the order was properly issued, which we find it was, then the costs to comply with the order are justified and not a basis for revoking or varying the order.

Need for a Regional Approach to Induced Seismicity in the Area of the Peace River Arch

[259] The Peace River Arch has a complex structural history with episodic structural deformation dominated by faulting during the Precambrian uplift of the arch, faulting during the Carboniferous period collapse of the arch, and a possible overprint of faulting and reactivation of these faults through the Cretaceous period. There are numerous disposal operations in the area and several clusters of significant induced seismicity, including the North Peace River, North Heart, and Reno clusters.

[260] Identifying which disposal operation or operations are responsible for specific seismic events is challenging. Historically, various regulatory tools have been applied to operations suspected of causing seismicity, including enforcement orders and voluntary MMR plans. However, these tools were generally

applied reactively on a case-by-case basis rather than comprehensively. The new regulatory requirements for seismogenic wells in *Directive 065* provide an opportunity to take a more comprehensive and consistent approach to assessing and mitigating induced seismicity in the Peace River region.

[261] CLM and Obsidian acknowledged that wastewater disposal in the Peace River Arch is associated with an increased risk for induced seismicity, and they agreed that a more holistic and consistent approach to assessing and mitigating induced seismicity associated with disposal operations would be beneficial. Dr. Canales noted that in addition to the North Peace River, North Heart, and Reno clusters associated with disposal into the Leduc Formation, other disposal-related seismicity clusters were present in the Gold Creek and Kakwa clusters south of Grande Prairie and the Musreau Lake cluster. He said disposal-induced seismicity has become a recurrent issue in the last five years. Dr. Verdon remarked that it was notable that seismicity has continued in the region and that there are what appear to be new clusters starting to develop. Dr. Shipman confirmed that requirements in *Directive 065* were developed to provide such an approach.

[262] Ms. Fox described her experience working on other areas of induced seismicity in British Columbia and Alberta, where there has been more of a cooperative approach between operators and much scientific rigour applied to understand induced seismicity in those areas. She suggested Fox Creek was an excellent example of where the AER and AGS did rigorous work. She also believed that a more cooperative approach between operators is helpful. Mr. Watson concurred and suggested there were benefits of looking at the entire sedimentary section, including the basement, on a regional basis to understand the problem and mitigate it.

[263] We encourage the AER to actively incorporate the observations and findings in this decision, ongoing AGS studies, and the new tools provided in Directive 065 to provide a comprehensive and regionally coordinated approach to understanding the causes and mitigating the effects of induced seismicity associated with disposal operations in the Peace River Arch area.

Conclusion

[264] In summary, we find that CLM did not err in issuing the order to Obsidian. The CLM director's decision to issue the order to Obsidian on March 23, 2023, was a prudent exercise of judgement based on the information available at the time. While the CLM director had incomplete information at the time the order was issued, issuing the order was consistent with the director's discretion under *EPEA* and appropriate to ensure the protection of public safety and the environment.

[265] Having reviewed all the evidence on the record of this proceeding, including the record of the decision maker and the additional evidence filed by CLM and Obsidian, we find on a balance of probabilities that the seismic events were caused by human activities. We are not persuaded that the

disposal operations at the Obsidian well did not cause or contribute to causing the seismic events specified in the order.

[266] Although we find it plausible that the 6-14 Belloy well and the high-volume Leduc wells may have contributed to causing the seismic events, based on the evidence presented, we cannot conclude that they caused the seismic events.

[267] On a balance of probabilities, we find that Obsidian was the person responsible for the release of a substance into the environment, and the release may cause an adverse effect. Therefore, there is no basis to revoke or vary the order.

[268] While Obsidian did not ask us to suspend the order, we considered whether suspending the order would be appropriate in the circumstances. However, given the potential for future seismic events and the potential that a larger event may cause an adverse effect, we determined that maintaining the order was appropriate until such time as the CLM director is satisfied that the requirements of *Directive 065* have been met for the Obsidian well and the order no longer required, as provided for in clause 12 of the order.

[269] For the reasons above, we find no basis to revoke, vary, or suspend the order. The order is confirmed.

Dated in Calgary, Alberta, on March 7, 2025.

Alberta Energy Regulator

Alex Bolton, MMSc, PGeo
Presiding Hearing Commissioner

Brian A. Zaitlin, PhD, PGeol, CPG
Hearing Commissioner

Tracey Stock, KC, FEC, FGC (Hon), PEng, PhD
Hearing Commissioner

Appendix 1 Hearing Participants

Principals and Representatives (Abbreviations used in report)	Witnesses
Obsidian Energy Ltd. (Obsidian) D. Langen, Legal Counsel A. Barrington, Legal Counsel	D. Boeckx S. Charbonneau A. Fox F. Marshall J. McGilvary M. Pooladi-Darvish J. Verdon N. Watson
AER Compliance and Liability Management (CLM) P. Fitzpatrick, Legal Counsel J. Allison, Legal Counsel A. Hall, Legal Counsel	M. Canales E. Galloway E. Kuleba T. Shipman C. Virues
Alberta Energy Regulator staff B. Kapel Holden, AER Counsel A. Huxley, AER Counsel O. Chijioke, AER Counsel A. Lung D. Parsons A. Stanislavski T. Wheaton E. Arruda N. Hymers M. Rahimabadi F. Hamdan	

Appendix 2 Environmental Protection Order

Made at Edmonton, in the Province of Alberta, on March 23, 2023	ALBERTA ENERGY REGULATOR

Under Sections 113 and 241 of the *Environmental Protection and Enhancement Act* (*EPEA*)

Obsidian Energy Ltd.
200 – 207 9 Avenue SW
Calgary, AB T2P 1K3

WHEREAS Obsidian Energy Ltd. (Obsidian) is the holder of well licence W0443668 issued by the Alberta Energy Regulator (AER) under the *Oil and Gas Conservation Act* at Surface Location 14-18-082-17 W5M, approximately 40 kilometres (km) SE of the Town of Peace River*;*

WHEREAS the well is authorized for disposal of water via injection into the Leduc formation (the Disposal Operation);

WHEREAS as reported on the Alberta Geological Survey (AGS) Earthquake Dashboard, seismic events occurred on November 29, 2022, approximately 40 km SE of the Town of Peace River, AB, including one event with local magnitude of M_L= 5.59;

WHEREAS after the November 29, 2022, seismic events, AGS requested and received operational data from Obsidian for the Disposal Operation;

WHEREAS AGS analysis of the seismic events on November 29, 2022, and the Disposal Operation data did not show a clear correlation between the seismic events and operational changes at the Disposal Operation;

WHEREAS in December 2022, AGS set up a seismic nodal array around the epicentre of the November 29, 2022, seismic events;

WHEREAS between January 2023 and March 16, 2023, AGS analysis started to indicate there may be a connection between the Disposal Operation and seismic events in the area of the Disposal Operation;

WHEREAS as reported on the AGS Earthquake Dashboard, seismic events occurred on March 16, 2023, approximately 42 km SE of the Town of Peace River, AB, including one event with local magnitude of M_L= 5.09;

WHEREAS on March 17, 2023, AGS received new information from the seismic nodal array and determined the seismic events that occurred approximately 40 – 42 kms SE of the Town of Peace River between November 29, 2022, and March 16, 2023, were spatially and temporally correlated to the Disposal Operation;

WHEREAS the AER concluded that the Disposal Operation induced the seismic events that occurred approximately 40 – 42 kms SE of the Town of Peace River between November 29, 2022, and March 16, 2023;

WHEREAS the AER is not aware of any adverse effects resulting from the induced seismic events to date;

WHEREAS seismic activity and seismic events are vibrations and/or the release of energy into the environment, and vibrations and the release of energy are defined as substances in section 1(mmm)(ii) of *EPEA* (the Substances);

WHEREAS the Substances, when released, may cause adverse effects as defined in section 1(b) of *EPEA*;

WHEREAS Erik Kuleba, Director, Field Operations South, has delegated authority to issue orders under section 113 of *EPEA* (the Director);

WHEREAS the Director is of the opinion that a release of the Substances has occurred, and that the Substances have caused, are causing, or may cause adverse effects;

WHEREAS Obsidian is a "person responsible" for the Substances as defined in section 1(tt) of *EPEA*;

THEREFORE, I, Erik Kuleba, Director, Field Operations South, under sections 113 and 241 of *EPEA*, do hereby order the following:

Immediate Action

1. Within seven (7) calendar days from the date of this Order, Obsidian must do the following:

a. Identify immediate actions that it can take to reduce the frequency and magnitude of induced seismic events caused by the Disposal Operation (Immediate Action Plan),

b. Meet with AER subject matter experts to determine the appropriateness of the proposed Immediate Action Plan,

c. Implement the Immediate Action Plan, and

d. Confirm in writing to the Director that Obsidian has implemented the Immediate Action Plan.

2. Within fifteen (15) calendar days from the date of this Order, Obsidian must establish real-time passive seismic monitoring in the area surrounding the Disposal Operation. The monitoring network must be capable of detecting all seismic events above 2.0 M_L within a 10 km radius of the Disposal Operation, unless otherwise directed by the AER.

3. Within fifteen (15) calendar days from the date of this Order, Obsidian must install accelerometers at strategic locations within a 10 km radius of the Disposal Operation, to the satisfaction of the Director.

Mitigation Plan

4. Within fifteen (15) calendar days from the date of this Order, Obsidian must submit, to the satisfaction of the Director, a plan to reduce the magnitude and frequency of induced seismic events caused by the Disposal Operation (Mitigation Plan). At a minimum, the Mitigation Plan must:

    a. Identify the mitigative measures that will be taken to reduce the magnitude and frequency of the induced seismic events related to the Disposal Operation;

    b. Provide milestones and/or deadlines for implementation of the mitigative measures; and

    c. Provide emergency and communication protocols that Obsidian will follow in the event of an induced seismic event that may have adverse impacts on infrastructure or public safety.

5. Obsidian must implement the Mitigation Plan as authorized in writing by the Director.

6. The Director must be notified of, and approve, any proposed deviations to the agreed upon Mitigation Plan.

Information for Submission

7. Within fifteen (15) calendar days from the date of this Order, Obsidian must submit the following data to the Director as a tabular database, unless otherwise authorized by the Director:

    a. all tubing injection pressure, water injection rate, and cumulative water injected data from the well listed in this Order since the startup of the Disposal Operation to present, and

    b. all bottomhole reservoir pressure measurements from the well listed in this Order since the startup of the Disposal Operation.

8. Obsidian must submit any real time monitoring data through the Incorporated Research Institutions for Seismology (IRIS) data repository using the protocol outlined in the Scientific Induced Seismicity Monitoring Network (SCISMN) Open File report on the AGS website.

9. Obsidian must submit any other information related to the Disposal Operation and seismic events or activity at the Disposal Operation that the Director requests in writing by the date specified in the Director's request.

General

10. All information and plans to be submitted to the Director under this Order shall be submitted electronically to fieldopscentral@aer.ca and erik.kuleba@aer.ca
11. Where a deadline has been specified in this Order, the Director may authorize in writing a different deadline.
12. This Order will remain in effect until such time as a permanent regulatory instrument is in place or the induced seismic hazard from the Disposal Operation has reduced to the satisfaction of the Director.

Dated at the City of Edmonton in the Province of Alberta, the 23rd day of March, 2023.

Erik Kuleba
Director, Field Operations South
Alberta Energy Regulator

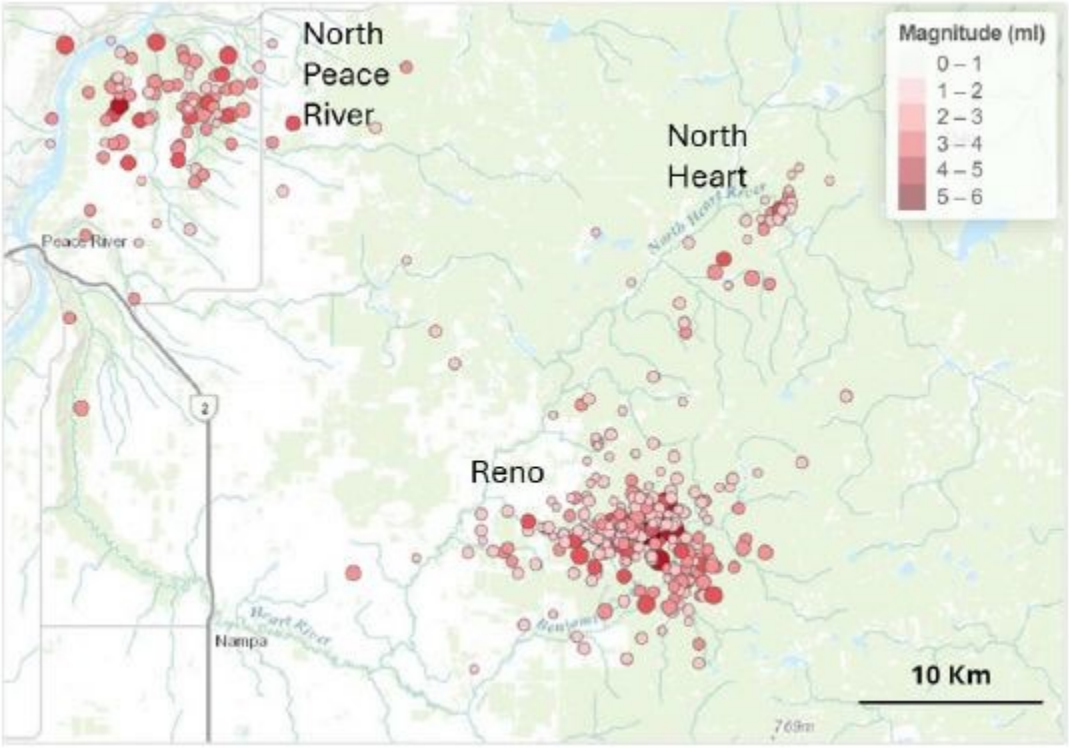
In complying with this order, the party or parties named must obtain all approvals necessary, notwithstanding the above requirements.

This order in no way precludes any enforcement actions being taken regarding this matter under the *EPEA* sections 113 and 241 or any other provincial or federal legislation, or by any other regulator with jurisdiction.

All enforcement actions issued by the AER may be subject to a follow-up review to confirm previous commitments have been completed and measures have been implemented, to ensure similar noncompliances are prevented in the future. The AER may request any information that demonstrates steps have been taken to prevent repeat noncompliances from occurring.

Under the *Responsible Energy Development Act*, an eligible person may appeal decisions that meet certain criteria. Eligible persons and appealable decisions are defined in section 36 of the *Responsible Energy Development Act* and section 3.1 of the *Responsible Energy Development Act General Regulation*. If you wish to file a request for regulatory appeal, you must submit your request according to the AER's requirements. You can find filing requirements and forms on the AER website, www.aer.ca, under Regulating Development: Project Application: Regulatory Appeal Process.

Appendix 3 Seismic Clusters in the Peace River Region



Appendix 4 Questions, Possible Responses, and Corresponding Scores for the Verdon Induced Seismicity Assessment Framework (source: Verdon et al. 2019)

Questions and possible responses	Score
Q1. Has there been previous (either historical or instrumental) seismicity at the same site, or within the same regional setting?	
a. Earthquakes have previously occurred in vicinity to the site, with similar rates/magnitudes.	-5
b. Earthquakes have occurred within the same regional setting with similar rates/magnitudes.	-2
c. Earthquakes have not occurred at similar rates/magnitudes within the regional setting.	+5
d. Past earthquakes occurred at similar depths within the regional setting.	-3
e. Earthquakes are significantly shallower than any past events observed within the regional setting.	+3
Q2. Is there temporal co-incidence between the onset of events and the industrial activities?	
a. The earthquake sequence began prior to the commencement of industrial activity.	-15
b. The earthquake sequence did not begin until a significant period of time after the cessation of industrial activity.	-5
c. The earthquake sequence began while the industrial activity was ongoing.	+5
Q3. Are the observed seismic events temporally correlated with the injection activities?	
a. The earthquakes are coincident with the industrial activity but there is minimal correlation.	-4
b. There is some temporal correlation between the seismicity and the industrial activity.	+4
c. There is strong temporal correlation between the seismicity and the industrial activity.	+15
Q4 Do the events occur at similar depths to the activities?	
a. Earthquakes do not occur at the same depth, and there is no plausible mechanism by which stress or pressure changes could be transferred to these depths.	-4
b. Earthquakes do not occur at the same depth, but plausible mechanisms exist by which stress or pressure changes could be transferred to these depths.	+2
c. Earthquakes occur at similar depths to the industrial activity.	+3
Q5 Is there spatial collocation between events and the injection?	
a. Earthquakes are distant to the activities, given the putative causative mechanism.	-10

Questions and possible responses	Score
b. Earthquakes are sufficiently close to the activities, given the putative causative mechanism.	+5
c. If earthquake loci change with time, this change is consistent with the industrial activity, for example, growing radially from a well or shifting in response to the start of a new well.	+10
Q6. Is there a plausible mechanism to have caused the events?	
a. No significant pore-pressure increase or decrease occurred that can be linked in a plausible manner to the event hypocentral positions.	-5
b. Some pore-pressure or poroelastic stress change occurred that can be linked in a plausible manner to the event hypocentral positions.	+2
c. A large pore-pressure or poroelastic stress change occurred that can be linked in a plausible manner to the event hypocentral positions.	+5
Q7. Do the source mechanisms indicate an induced event mechanism?	
a. The source mechanisms are consistent with the regional stress conditions.	0
b. Source mechanisms are not consistent with regional stress conditions but are consistent with a putative causative mechanism (e.g., thrust faults above a subsiding reservoir).	+4

Appendix 5 Locations of the Obsidian Well, Belloy Well, and the High-Volume Leduc Wells