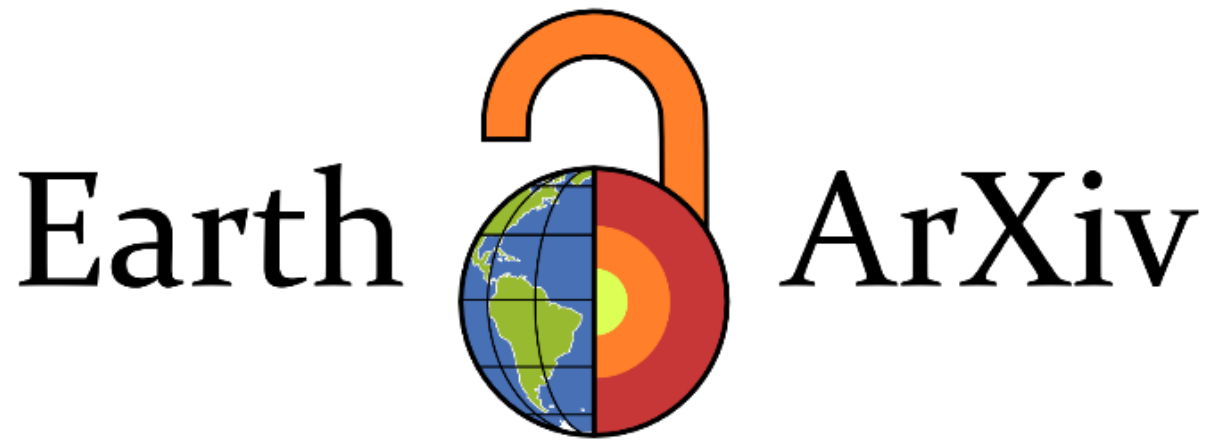




Peer review status:

This is a non-peer-reviewed preprint submitted to EarthArXiv.

Seismic Discrimination of Natural and Anthropogenic Events Near Atlanta, Georgia, USA

Xu Si¹, Michael Snook¹, Yunyi Qian², Zhigang Peng¹, Chang Ding¹, Karl Lang¹, Martha Cary Eppes³, and Sidao Ni⁴

¹ School of Earth and Atmospheric Sciences, Georgia Institute of Technology, USA

² State Key Laboratory of Coal Mine Disaster Dynamics and Control, School of Resources and Safety Engineering, Chongqing University, Chongqing, China

³ Department of Earth, Environmental and Geographical Sciences, University of North Carolina at Charlotte, USA

⁴ Innovation Academy for Precision Measurement Science and Technology, Chinese Academy of Sciences, China

Corresponding author Xu Si xsi33@gatech.edu

Key Points

- Machine-learning-assisted analysis of 14 years of N4.Y52A data identifies 2,181 high-confidence impulsive events around Atlanta.
- Temporal, pressure, and source-direction constraints indicate that the detected population is dominated by quarry-blast activity but also includes small local earthquakes.
- The 2023 Arabia Mountain rock exfoliation case shows that regional source discrimination requires independent seismic, pressure, spatial, and field constraints.

Abstract

Distinguishing small earthquakes from anthropogenic seismic sources is important for accurate fault characterization and seismic hazard assessment, yet remains challenging in regions with sparse seismic networks and frequent quarry activities. Around Atlanta, Georgia, only a small number of local natural earthquakes and one operator-confirmed quarry blast in July 2026 are reported in regional USGS catalogs in recent years. Here we use three cataloged earthquakes and the 2026 quarry blast as references to search 14 years of continuous seismic and pressure records at a nearby permanent station N4.Y52A. Based on a machine-learning-assisted workflow, we identify 2,181 impulsive events with clear seismic arrivals, associated pressure disturbances, and reliable particle-motion measurements. Most of them occur during weekday working hours and exhibit repeated source-distance and directional patterns that correspond to known quarry areas, indicating that the detected population is dominated by quarry-blast activity. The search also recovers smaller earthquake candidates and short event sequences with more ambiguous origins, demonstrating that waveform similarity or occurrence time alone cannot determine source type. As an independent case study, we reassess signals previously associated with a 17 July 2023 spontaneous rock exfoliation event at Arabia Mountain. The previously associated regional signal is more consistent with quarry activity, whereas subsequent exfoliation events in 2024 produced highly localized signals recorded only by a near-source dense array but not clearly at N4.Y52A. These results demonstrate that improved seismic detection must be accompanied by independent seismic, acoustic, spatial, and direct observational constraints for reliable source identification.

Plain Language Summary

Seismic stations record both natural earthquakes and signals produced by human activities such as quarry blasting, but distinguishing these sources can be challenging, particularly for small events in regions with limited seismic monitoring. We analyzed more than 14 years of seismic and air pressure data from a regional permanent monitoring station near Atlanta, Georgia, and identified 2,181 previously unreported seismic events. Most occurred during weekday working hours and showed source locations consistent with areas of known quarries,

indicating that quarry blasting was likely responsible for most of detected activity. We also revisited the documented 2023 rock-exfoliation event at Arabia Mountain during which a surface rock layer fractured and separated from the underlying rock. A seismic signal at the regional station previously associated with this event is more consistent with a quarry activity, whereas signals from subsequent rock-fracturing events in 2024 were detected by nearby instruments but not clearly recorded at the regional station. These results highlight the importance of combining seismic recordings with air pressure measurements, source-location information, and direct field observations to distinguish natural earthquakes from human-generated seismic activity.

1 Introduction

To accurately characterize natural fault processes, regional seismic monitoring must distinguish natural earthquakes from anthropogenic events such as quarry or construction blasts (Kim et al., 1993; Allmann et al., 2008; Marzen et al., 2021). Blasts misclassified as earthquakes can bias estimated seismicity rates and magnitude–frequency statistics, distorting the spatial patterns used to characterize active source regions (Gulia & Gasperini, 2021; Wiemer & Baer, 2000). Earthquake–explosion discrimination has traditionally relied on differences in source physics, propagation, and occurrence patterns. Quarry blasts commonly cluster near mine sites and during working hours (Wiemer & Baer, 2000), whereas waveform discriminants exploit differences in compressional, shear, and surface-wave excitation or in source spectral content (Allmann et al., 2008; Stump et al., 2002). Multi-station analysis and local-distance amplitude ratios involving crustal seismic phases such as P_g , S_g , and R_g provide additional constraints on source type and depth (Kintner et al., 2020; Pinsky & Shapira, 1998; Tibi et al., 2018a, 2018b). Combining phase-amplitude and magnitude-based measurements can improve separation relative to any single discriminant (Wang et al., 2020; Wang & Schmandt, 2021). However, source identification becomes more difficult for small events recorded by sparse regional networks, where source depth and focal mechanism are often poorly constrained and a shallow earthquake, quarry blast, or spontaneous rock-fracturing event may produce a similar impulsive signal at the same station. Moreover, seismic discriminants depend on regional structure, source population, frequency band, and station geometry, limiting the direct transfer of thresholds calibrated in one region to another. Reliable interpretation of locally reported shaking or explosive sounds therefore requires event detection and source identification to be treated as separate problems (Renouard et al., 2021).

The growing volume of continuous waveform data has motivated automatic event classification and similarity-based searches. Early classifiers used selected time- and frequency-domain attributes to separate earthquakes, blasts, and other signals (Hammer et al., 2013; Kortstrom et al., 2016; Reynen & Audet, 2017; Tang et al., 2020); more recent neural networks learn discriminative features directly from three-component waveforms or spectra (Eggertsson et al., 2024; Hourcade et al., 2023; Linville et al., 2019; Miao et al., 2020; Saad et al., 2024). Transfer-learning and interpretation studies show, however, that performance depends on the labeled training population and may degrade in a different source region (Kasburg et al., 2025; J. Zhu et al., 2024). Waveform correlation and feature-space searches address a related problem by retrieving signals similar to known examples and revealing repeated or similar event families (Beaucé et al., 2018; Gibbons & Ringdal, 2006; Mach et al., 2026; Peng & Zhao, 2009; Si et al., 2024; Yoon et al., 2015). Similarity alone does not determine source type: events can resemble one another because they share a source region, propagation path, or receiver response. Robust interpretation therefore requires waveform similarity to be evaluated together with phase behavior, air pressure observations, timing, and independent source information.

The growing availability of continuous waveform data, together with dense networks, template matching, and machine-learning methods, has enabled the construction of increasingly high-resolution seismic catalogs (Peng et al., 2026). However, improved detection sensitivity does not only recover additional tectonic earthquakes; it can also identify large numbers of quarry blasts and other repetitive anthropogenic sources (Skoumal &

[Trugman, 2021](#); [Ferreri et al., 2026](#); [Si, Z. et al., 2026](#)). If not removed, these events can create artificial spatial and temporal seismicity patterns, bias seismicity rates and magnitude-frequency statistics, and even produce spurious fault zone structures ([Wiemer & Baer, 2000](#); [Wiemer et al., 2005](#); [Gulia & Gasperini, 2021](#); [Ferreri et al., 2026](#); [Si, Z. et al., 2026](#)). High-resolution catalogs therefore require explicit source discrimination before they are used for seismicity, tectonic, or seismic-hazard analyses.

The greater Atlanta region of Georgia, USA provides a useful setting to examine these limitations. It lies within the relatively low-seismicity intraplate setting of the eastern United States ([Mueller et al., 2015](#); Calais et al., 2016), while numerous active quarries provide recurring shallow anthropogenic sources (Marzen et al., 2021). Occasional small natural earthquake swarms occurred in this region, but they were typically located near quarry sites or reservoirs/lakes (Long et al., 1994; Marzen et al., 2021; Peng et al., 2024b). A query of the Advanced National Seismic System (ANSS) Comprehensive Earthquake Catalog returns only eleven events with $M \geq 1$ in the Atlanta–Buford Reservoir study area (within 50 km of station N4.Y52A) during January 2000–September 2026 ([U.S. Geological Survey, Earthquake Hazards Program, 2017](#)). Three reported earthquakes near Lilburn and an operator-confirmed quarry blast on 29 July 2026 lie within approximately 2.2 km of one another (Figure 1). Their catalog locations demonstrate that proximity to a quarry, or to a previously reported earthquake, is insufficient by itself to classify a newly detected signal. The small number of independently identified local events also limits the construction of a conventional supervised classifier.

Other shallow natural processes, such as spontaneous rock exfoliation, can further complicate source discrimination. Rock exfoliation is a natural near-surface fracturing process distinct from quarry blasting, and the proposed association must be evaluated from independent timing and near-source observations in addition to waveform characteristics alone. Arabia Mountain, part of a National Heritage Area located about 25 km east of downtown Atlanta, provides an additional opportunity to evaluate the challenges of seismic source discrimination. The exposed Lithonia Gneiss contains surface-parallel fractures that can grow through thermally induced stresses and subcritical cracking ([Collins et al., 2018](#); [Collins & Stock, 2016](#); [Eppes & Keanini, 2017](#)). On 17 July 2023, local visitors reported ground motion and loud sounds, and field investigation documented fresh fractures, displaced rock sheets, and surface deformation associated with a spontaneous exfoliation event ([Dingler, 2023](#); [Reynolds et al., 2026](#)). Several impulsive signals recorded that day at a regional seismic station Y52A were initially associated with this event (Peng et al., 2024a).

Here we constructed a 14-year catalog of impulsive signals recorded at Y52A station and used it to investigate the discrimination of natural earthquakes and anthropogenic quarry blasts around greater Atlanta. Three reported earthquakes and the operator-confirmed 2026 quarry blast serve as references for a SeisCLIP (Si et al., 2024) similarity search of data from April 2012 through August 2026. We then measured waveform cross correlation and examined seismic phases, pressure transients, particle motion, and occurrence patterns to identify recurrent event families and evaluate their possible sources. Because most detections lack unique locations, this product is a single-station candidate-event catalog rather than a hypocentral earthquake catalog. Our primary objectives are to characterize the regional population of impulsive events, determine which observations support earthquake–blast discrimination, and document the limits of event-by-event classification with a sparse network. As a secondary application, we used the catalog, eyewitness timing, and local geophone observations to reassess the July 2023 signals previously associated with the rock exfoliation events at Arabia Mountain (Peng et al., 2024a; [Reynolds et al., 2026](#)).

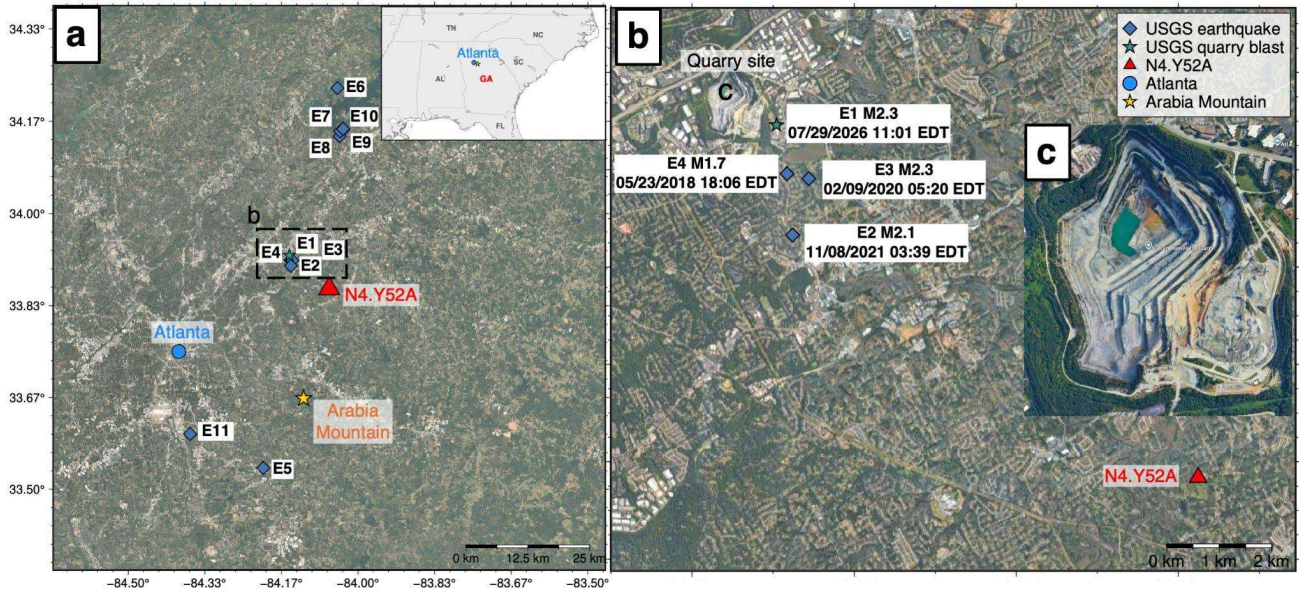


Figure 1 Study area and reference events around Atlanta, Georgia. (a) Regional map showing Atlanta (blue circle), station N4.Y52A (red triangle), Arabia Mountain (gold star), and USGS-cataloged events with $M \geq 1$ from January 2000 through September 2026. Blue diamonds denote cataloged earthquakes and the green star denotes the operator-confirmed quarry blast on 29 July 2026. The dashed box marks the Lilburn area enlarged in (b), and the inset shows the location of the study area in the southeastern United States. (b) Enlarged view of the four spatially clustered reference events near Lilburn: three cataloged earthquakes (E2–E4) and the 29 July 2026 quarry blast (E1). Labels give catalog magnitude and origin time in UTC. The location of N4.Y52A and nearby quarry sites are also shown. (c) Satellite image of the quarry adjacent to E1.

2 Data and Methods

2.1 Waveform Data and Reference Events

We analyzed continuous three-component ground-velocity and collocated barometric-pressure (BDF) records from station Y52A spanning April 2012 through August 2026. The station is located approximately 30 km northeast of downtown Atlanta, within several tens of kilometers of active quarries and areas of reported local seismicity (Figure 1a). This station was part of the larger USArray network (code: TA) established between 2012 and 2014 (network code TA), but was subsequently incorporated into the Central and Eastern United States Network (CEUSN), with network code N4. Seismic data recorded by this station has been used to document a cannonball explosion from the civil war more than 160 years ago (Peng, 2015). This long-term recording allows us to search for impulsive signals beyond those documented in regional catalogs and compare their seismic and pressure signatures with those of known local events.

To establish the cataloged source population, we queried the USGS Comprehensive Earthquake Catalog (ComCat) for events with $M \geq 1$ in the greater Atlanta region over the same period (U.S. Geological Survey, Earthquake Hazards Program, 2017). The query returned 11 events, comprising ten cataloged earthquakes and one quarry blast (Figure 1a; Table S1). These events are distributed across several source areas around Y52A. Four form a compact group near Lilburn: three cataloged earthquakes on 23 May 2018 (E4), 9 February 2020 (E3), and 8 November 2021 (E2), and a quarry blast on 29 July 2026 (E1). E1 lies adjacent to the quarry shown in Figure 1c, and its origin as a quarry blast was independently confirmed by the operator Vulcan Materials (WSB-TV news, 2026).

We selected E1–E4 as waveform references for the long-term similarity search. Their catalog locations lie within approximately 2.2 km of one another (Figure 1b), allowing comparison of contrasting cataloged source types with similar source–receiver geometry. This selection limits the geographic extent of the reference set while

including both reported earthquakes and a confirmed quarry blast. The remaining seven cataloged earthquakes represent other source regions and propagation paths; they are retained for comparison (Table S1) but are not used to initialize the search.

Figure 2 compares the P-aligned three-component seismic waveforms and corresponding air pressure (BDF channel) records of E1–E4. Their seismic waveforms differ despite the proximity of their catalog locations, and E1 exhibits a clear delayed pressure arrival at ~30 s following the seismic signal. We used the four seismic records for similarity-based retrieval and examined the pressure records separately for accompanying atmospheric disturbances. Similarity to either an earthquake or a quarry-blast reference identifies a candidate detection, not its source type. Likewise, a pressure transient alone does not establish a quarry-blast origin. Source attribution is evaluated subsequently by combining waveform and seismic phase characteristics, particle motion, estimated source distance and back azimuth, occurrence patterns, and pressure observations.

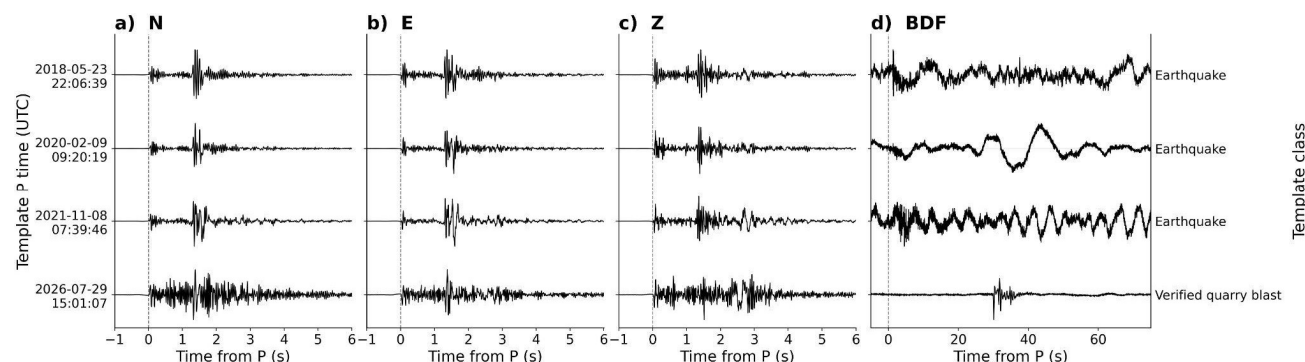


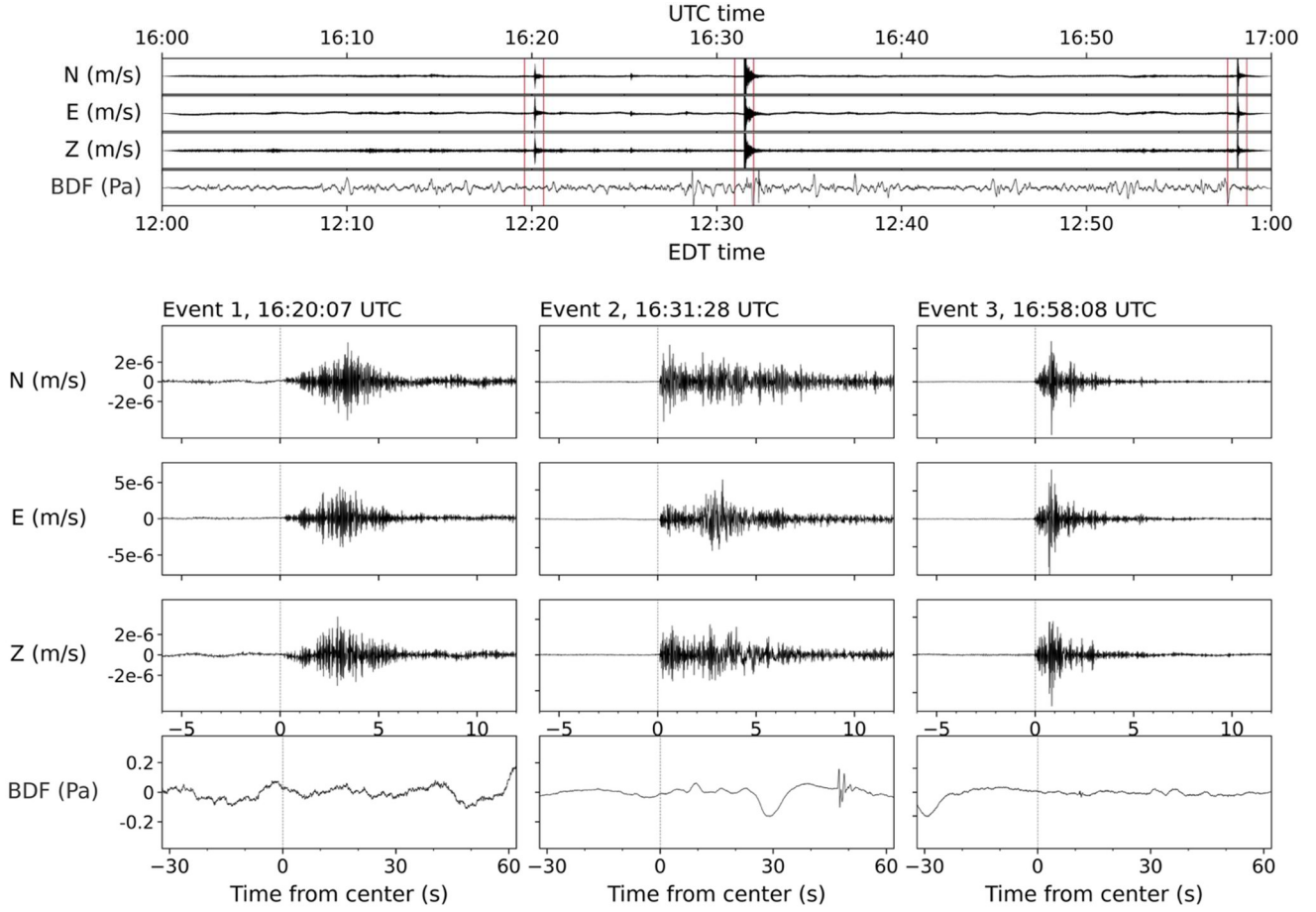
Figure 2 Reference seismic and pressure waveforms at station N4.Y52A. (a–c) P-aligned north, east, and vertical ground-velocity waveforms for three USGS-cataloged earthquakes on 23 May 2018, 9 February 2020, and 8 November 2021, and a confirmed quarry blast on 29 July 2026. Time is relative to the P arrival; labels at left give event origin times in UTC. (d) Corresponding barometric-pressure (BDF) records shown over a longer time window. Cataloged source types are indicated at right.

2.2 Rock-Exfoliation Observations at Arabia Mountain

On 17 July 2023, local visitors at Arabia Mountain reported evidence of a spontaneous rock exfoliation event (Dingler, 2023). Field reconnaissance identified fresh surface-parallel fractures, buckled rock sheets, and offset vertical fractures (Reynolds et al., 2026). These surface observations document a substantial rock-exfoliation event. They do not, by themselves, identify which seismic signals recorded at Y52A came from the observed movement. The event time remains uncertain. The first public account placed the disturbance around noon, local time (Dingler, 2023; William Witherspoon, personal communication, 09/2026), whereas a later eyewitness account placed the primary rock movement between 14:00 and 14:30 EDT (18:00–18:30 UTC) (Reynolds et al., 2026). Both times are approximate recollections rather than instrument-derived origin times. The difference between them prevents an individual seismic arrival from being assigned to the exfoliation event on eyewitness timing alone. We therefore consider the reported times alongside the waveforms rather than treating either as a known seismic origin time.

Y52A recorded three impulsive signals in the early afternoon of July 17, 2023, at 16:20:10, 16:31:31, and 16:58:10 UTC (Figure 3). Each has a recognizable onset on the three seismic components. The 16:31:31 signal was initially considered a possible seismic record of the exfoliation (Peng et al., 2024a). A pressure transient follows that seismic signal by approximately 45 s. This delay is compatible with an atmospheric arrival from a nearby surface source. However, the single-station record alone cannot uniquely distinguish exfoliation, quarry blasting, and other impulsive sources without additional timing, waveform, or location constraints. Our subsequent analysis therefore treats these signals recorded at N4.Y52A cautiously and evaluates them using

192 waveform modeling and similarity, phase information, source-distance estimates, and comparison with
 193 candidate quarry-blast events.



194
 195 **Figure 3** Seismic and pressure records of three impulsive signals on 17 July 2023. The top panel shows one hour of continuous three-
 196 component seismic velocity records and barometric pressure data from 16:00 to 17:00 UTC. Red boxes mark three visually identifiable
 197 events at 16:20:10, 16:31:31, and 16:58:10 UTC. The lower panels show zoomed waveform windows for each event, including the
 198 north, east, and vertical seismic components and the corresponding barometric-pressure record. The dashed vertical line marks the
 199 reference time of each event. The events are characterized by short-duration, high-amplitude seismic arrivals, while the pressure
 200 records provide complementary constraints on possible surface or near-surface source processes.

201 2.3 Long-Term Single-Station Event Detection

202 We searched the continuous recordings from April 2012 to August 2026 recorded at station Y52A using the four
 203 reference events described above and a multistage detection workflow (Figure 4). Continuous three-component
 204 records were divided into 60-s windows with a 30-s step and encoded using the pretrained spectrum encoder of
 205 SeisCLIP (Si et al., 2024). Windows with a cosine similarity greater than 0.55 to at least one reference were
 206 retained, and candidate windows separated by less than 60 s were merged. This feature-space search identifies
 207 intervals resembling known local events without assigning their source types.

208 We applied PhaseNet (W. Zhu & Beroza, 2019) to identify P–S arrival pairs within the candidate intervals,
 209 followed by screening based on phase probabilities, S–P time, signal-to-noise ratio, and waveform quality. The
 210 retained candidates were then compared using signed three-component waveform cross correlation in short P-
 211 referenced windows, allowing a common time shift across the components. Candidate-to-candidate comparisons
 212 allowed events to be retained through similarity to another detection rather than requiring a direct waveform
 213 match to an original reference. A best-pair correlation coefficient greater than 0.25, followed by a final 60-s
 214 merging step, yielded 4,011 distinct detections.

We further screened these detections to obtain a subset with measurable pressure disturbances and usable P-wave particle motion. BDF records were examined from 5 s before to 75 s after the P arrival. A peak-to-background ratio greater than 2.5 in the rolling root-mean-square pressure amplitude retained 2,345 pressure-positive candidates. P-wave particle motion was then evaluated in a 0.5-s window around the P arrival, with screening criteria based on signal-to-noise ratio, rectilinearity, horizontal fraction, directional stability, and S–P time. The resulting catalog contains 2,181 events satisfying the combined seismic, pressure, and particle-motion criteria. This catalog is a screened subset of the seismic detections, not a set of independently verified quarry blasts. Processing parameters, threshold selection, and intermediate screening counts are described in Supporting Text S1.

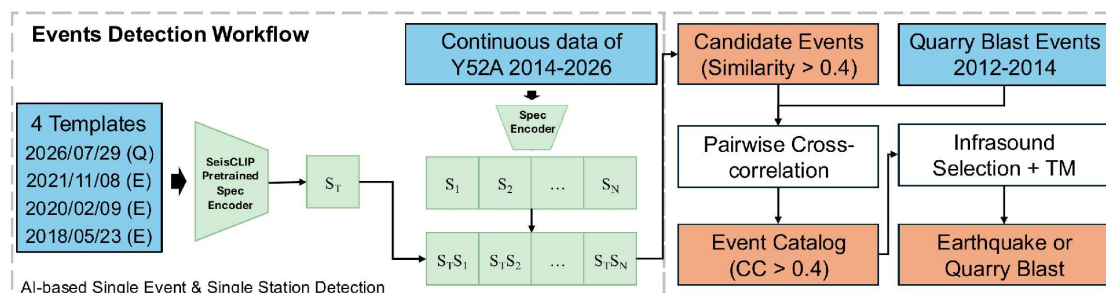


Figure 4 Long-term single-station detection and screening workflow. Four reference records seed a SeisCLIP search of continuous Y52A data. Phase picking, waveform-quality screening, and three-component cross correlation define the seismic detections. BDF pressure, particle motion, published quarry-blast records, and template matching provide additional constraints on candidate source type.

3 Results

3.1 Temporal and Spatial Characteristics of Potential Quarry-Blast Events

Of the 4,011 distinct seismic detections, 2,181 satisfy the combined pressure and particle-motion screening criteria. We examined this pressure-positive subset as a population of potential quarry-blast events. Associated acoustic arrivals provide additional evidence for quarry blasting when interpreted together with seismic observations (Czanik et al., 2021). However, a qualifying BDF disturbance is part of the selection procedure and does not independently confirm the source type of each detection.

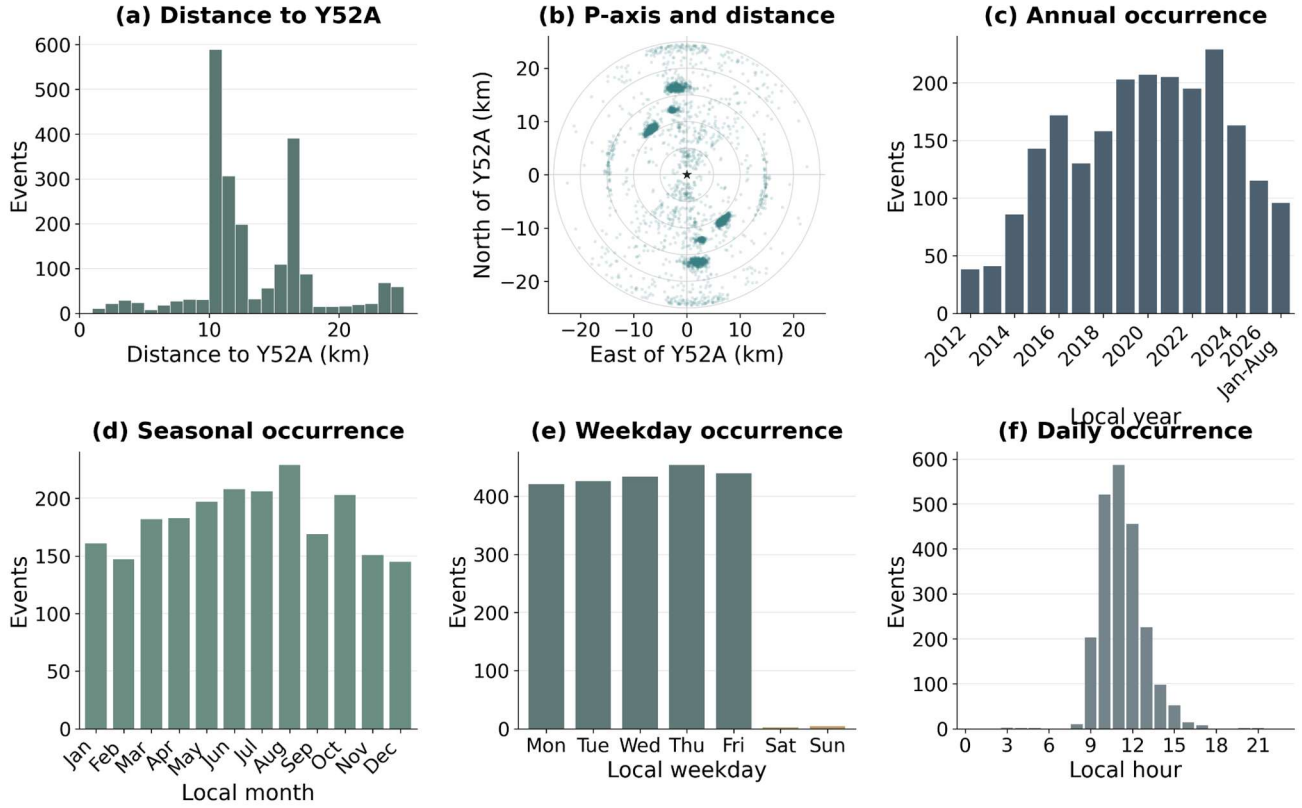


Figure 5 Temporal distributions and apparent source geometry of the 2,181 potential quarry-blast events. The events satisfy the pressure and P-wave particle-motion screening criteria described in Section 2. (a) Apparent source distances from N4.Y52A estimated from S-P times. (b) Horizontal P-wave polarization axes plotted at the corresponding apparent distances. Both azimuthal alternatives are shown where the direction remains unresolved; the black star marks N4.Y52A. These positions are directional-distance estimates rather than independently determined epicenters. (c–f) Event counts by local year, calendar month, weekday, and hour, respectively. The 2012 and 2026 records cover April–December and January–August, respectively. Counts are not normalized by recording availability.

The selected events exhibit pronounced weekday and daytime concentrations (Figure 5e,f). Nearly all occur from Monday to Friday, with few detections on weekends. Most occur between approximately 09:00 and 15:00 local time, with the highest counts in the late morning. This concentration within weekday working hours strongly supports an anthropogenic interpretation of the population, in addition to the pressure observations used in screening.

The apparent source-distance distribution shows several distinct concentrations, most prominently at approximately 10–12 km and 16–17 km from N4.Y52A, with a smaller population near 23–25 km (Figure 5a). When combined with the horizontal P-wave particle-motion orientations, these distances define several well-organized directional clusters rather than a diffuse distribution around the station (Figure 5b). Because single-station polarization provides an axis rather than a unique propagation direction, each event initially has a 180° azimuthal ambiguity. Independent location constraints examined in the following subsection favor the southern branches for two of the major clusters and the northeastern branch for another. These preferred directions and apparent distances correspond to areas containing known quarry sites around N4.Y52A, with the northeastern cluster showing particularly clear spatial agreement with a nearby quarry district visible (Figure 1a). The consistency between the distance–direction concentrations and the distribution of known quarry sites provide additional evidence that the pressure-positive catalog is dominated by repeated quarry-blast activity rather than randomly distributed regional sources.

3.2 Reference-Based Event Groups and Source Constraints

To compare the pressure-positive population with other impulsive signals, we assembled a detailed comparison set from the full population of 4,011 detections rather than restricting the analysis to the 2,181 pressure- and particle-motion-screened events. We calculated direct waveform cross correlations between each candidate and the four reference events, using thresholds greater than 0.40 for matches to any of the three earthquake references and greater than 0.30 for matches to the quarry-blast reference. These reference-based comparisons differ from the candidate-to-candidate correlations used in the automated detection workflow. The selected records were then examined manually using their three-component seismic waveforms and corresponding BDF records.

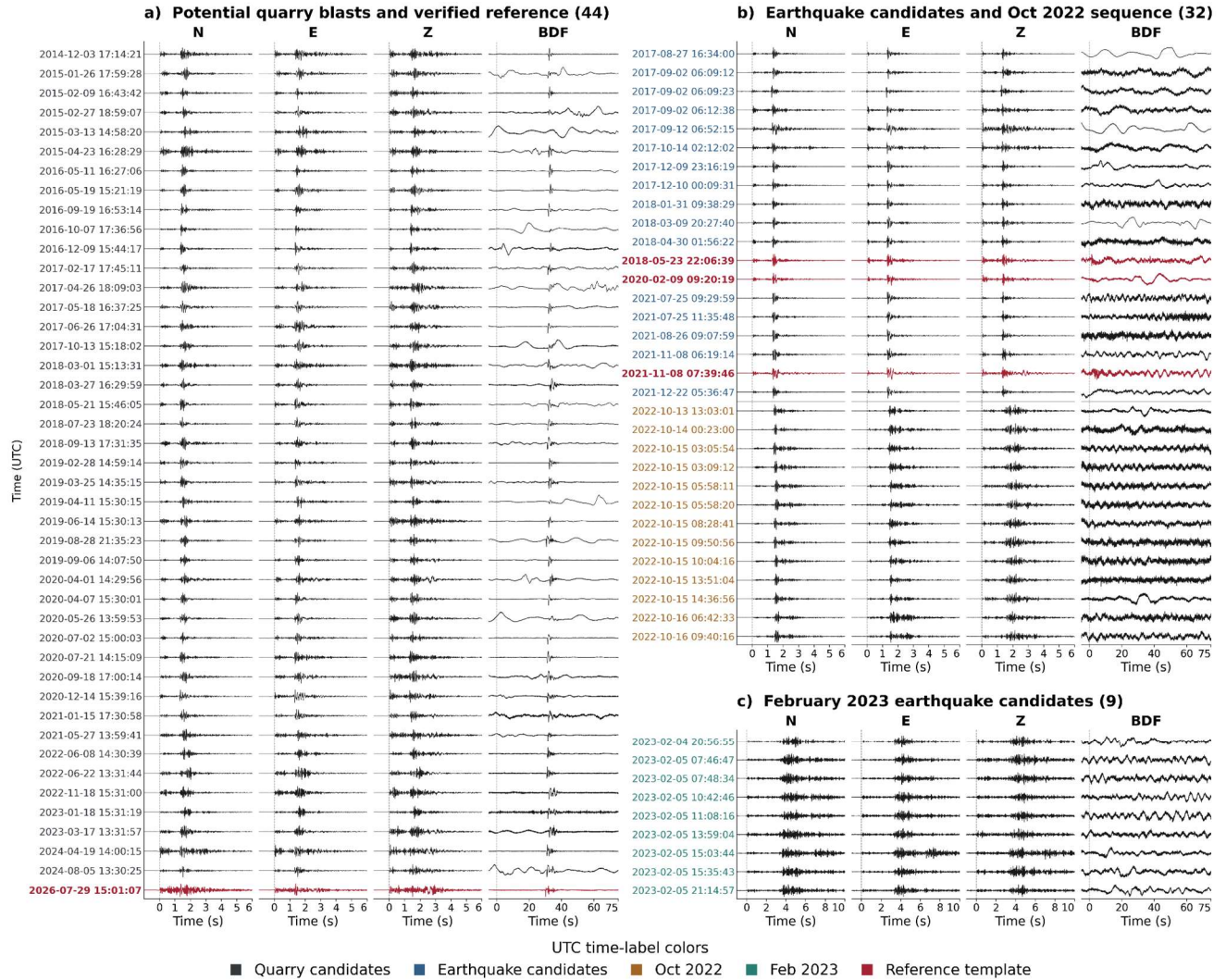


Figure 6 Seismic and pressure waveforms of the candidate source groups. *P*-aligned north, east, and vertical ground-velocity records and BDF pressure records are shown for (a) 44 potential quarry blasts, including the quarry-blast reference; (b) 19 earthquake candidates, including three cataloged earthquakes and the October 2022 sequence; and (c) nine events in the February 2023 sequence. Dashed lines mark the *P* reference time, red waveforms identify the four reference events, and date-time label colors distinguish the event groups. The October 2022 and February 2023 sequences are grouped by temporal occurrence; their source types are not independently verified.

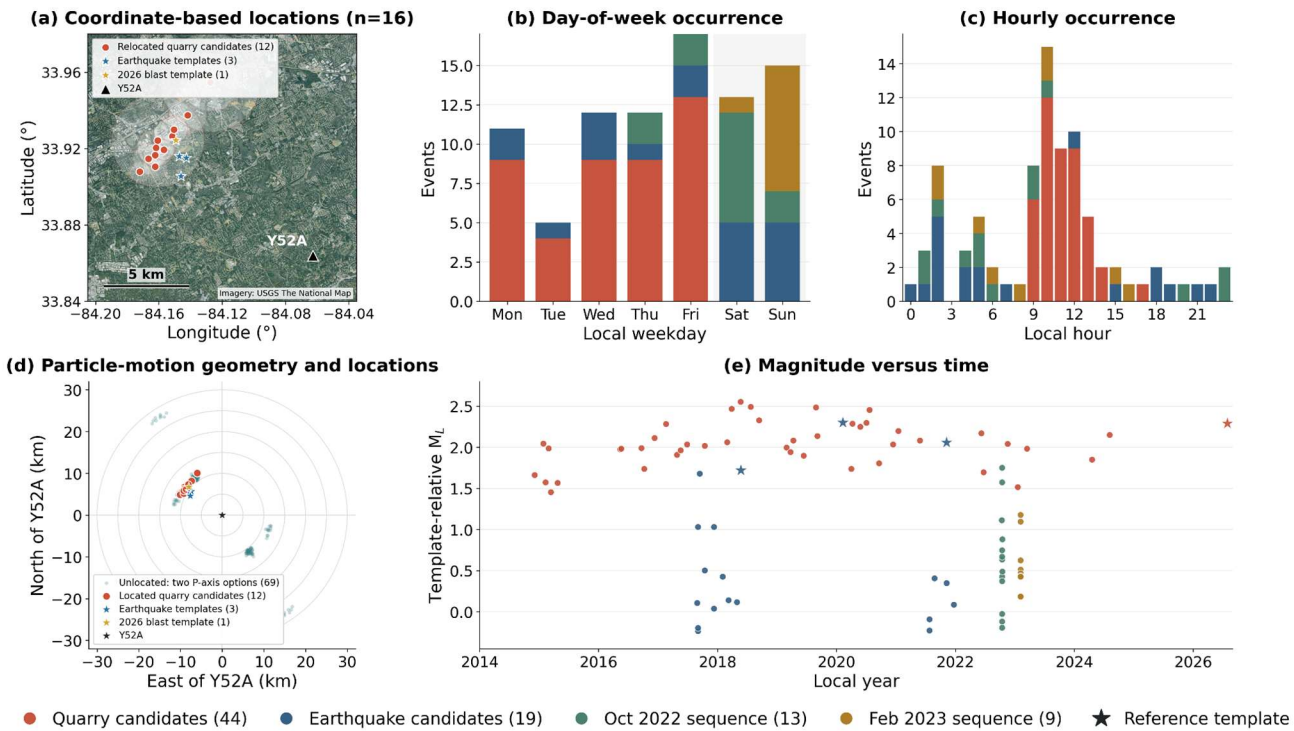
The comparison set contains 43 blast-like candidates, 16 earthquake candidates, 13 events in an October 2022 sequence, and nine events in a February 2023 sequence, together with the four reference events, giving 85 events in total (Table 1; Figure 6). Clear delayed pressure arrivals support the blast-like designation, whereas candidates resembling the earthquake references without comparably clear pressure arrivals are retained as earthquake

280 candidates. The two temporally concentrated sequences were identified during manual inspection and are
 281 retained as separate groups without assigning a common source type. Pairwise waveform cross-correlation
 282 coefficients within each group (without blast-like candidates) are shown in Figure S1. For the grouped
 283 distributions in Figure 7, the reference events are included in their corresponding categories, giving 44 blast-
 284 related events and 19 earthquake-related events, in addition to the two sequences.

285 **Table 1** Event counts for the candidate catalog and comparison groups.

	All candidates	Candidates with clear air waves	Blast-like candidates	Earthquake candidates	October 2022 sequence	February 2023 sequence
Events	4,011	2,181	43	16	13	9

286 We performed multi-station locations to assess whether the selected events originated near the reference-event
 287 source region. Only a limited number of permanent broadband stations provided identifiable arrivals, so we also
 288 examined available Raspberry Shake records around Atlanta (Figure S2). Timing uncertainties in some records
 289 limited their use for location. HYPOINVERSE (Klein, 2002) was applied to events with usable P-wave picks at
 290 more than four stations, yielding preferred locations for 12 blast-like candidates. Their epicenters cluster near
 291 the four reference events in the Lilburn area, northwest of N4.Y52A (Figure 7a). Because this area contains both
 292 cataloged earthquakes and the confirmed quarry-blast reference, spatial proximity alone does not establish a
 293 common source type.



294 **Figure 7** Spatial, temporal, and magnitude characteristics of the 85 detected events. (a) Preferred locations for 12 quarry-blast
 295 candidates, three cataloged earthquake references, and the 2026 quarry-blast reference; the black triangle marks N4.Y52A. (b, c)
 296 Event counts by local weekday and local hour, colored by event group. Weekend days are shaded in panel (b). (d) P-axis orientations
 297 and apparent source distances relative to N4.Y52A. Both azimuthal solutions are shown for 69 events without preferred locations. (e)
 298 Template-relative local magnitude, M_L , as a function of time; events without magnitude estimates are omitted.

300 For events without preferred locations, we combined the horizontal orientation of P-wave particle motion with
 301 apparent source distance estimated from the S–P time difference. This provides directional and distance
 302 constraints without treating the single-station estimates as unique epicenters. Figure 7d shows the preferred
 303 locations of the 12 located candidates and four references together with both azimuthal alternatives for the

remaining 69 events. The resulting distribution permits comparison with the Lilburn reference region while retaining the 180° ambiguity of unresolved arrival directions. The event groups have contrasting occurrence patterns (Figure 7b,c). The blast-related group is confined to weekdays and is concentrated in daytime working hours, consistent with the pattern of the larger pressure-positive population. In contrast, the earthquake candidates occur on both weekdays and weekends and across a wider range of local hours, without a comparable working-hour concentration in this selected sample. The October 2022 and February 2023 sequences are concentrated on weekends and contain multiple events within short intervals. These temporal concentrations distinguish them from the recurring weekday blast-like population but do not, by themselves, determine their source mechanisms.

The October 2022 and February 2023 sequences are particularly interesting because most of their events occurred during weekends, in contrast to the strong weekday pattern of the broader blast-like population. For the October 2022 sequence, the P-wave particle-motion orientations and S–P-derived apparent distances constrain the events to a source region near known quarry sites, although the single-station observations do not provide a unique location. The February 2023 sequence is more ambiguous from N4.Y52A alone because the particle-motion measurements and distance estimation permit two possible azimuthal directions. To further constrain the source region, we examined the same events at a regional permanent station US.GOGA (Figure S3). The P arrivals at US.GOGA occur approximately 3.5 s later than at N4.Y52A. Using this differential arrival together with the station geometry favors the southeastern source option relative to N4.Y52A. This inferred region is also close to known quarry sites. Thus, although both sequences occurred mainly during weekends, their available directional and travel-time constraints place their possible source regions near quarry areas. This spatial association raises the possibility that the sequences are related to anthropogenic activity, but the present observations are insufficient to determine the specific source process or to rule out a natural origin. We therefore retain the October 2022 and February 2023 sequences as separate groups and discuss their possible origins further in the Discussion.

Template-relative local magnitudes (Peng and Zhao, 2009) provide an additional comparison among the selected events (Figure 7e). Blast-like candidates recur over multiple years and have estimated M_L values of approximately 1.4–2.6, whereas most non-reference earthquake candidates have smaller estimates. Notably, all newly detected earthquake candidates have estimated magnitudes below those of the three cataloged earthquake templates used in the reference set. Their systematically smaller event sizes provide a plausible explanation for why these signals were not included in the regional USGS catalog. Because catalog detectability also depends on network geometry, signal-to-noise ratio, and phase availability, magnitude alone does not determine whether an event is cataloged; nevertheless, the magnitude distribution is consistent with the interpretation that the similarity search recovers smaller local earthquakes below the effective detection level of the regional catalog.

3.3 Noise Conditions and Environmental Variability

Because the long-term catalog is derived from a single station, temporal variations in event counts must be interpreted together with changes in background noise and station conditions. Figure 8 summarizes the monthly event counts and environmental observations from 2012 through August 2026. The event catalog shows substantial year-to-year and seasonal variability (Figure 8a), but its temporal pattern does not show a simple correspondence with air temperature. This is consistent with the interpretation that the screened catalog is dominated by recurrent anthropogenic activity rather than a temperature-controlled natural process.

To characterize changes in detectability, we calculated a daily normalized seismic-noise level from the continuous three-component records in the frequency bands of 2–16 Hz (Lecocq et al., 2020; Zhai et al., 2021). For each component, the median squared waveform amplitude was calculated over each day, and the three component values were then averaged and normalized over the full record. The resulting quantity provides a

relative measure of the daily seismic background rather than an absolute physical noise level. The BDF pressure-noise metric was calculated in the same manner using the single pressure channel, without component averaging.

The seismic-noise record exhibits pronounced long-term and seasonal variability (Figure 8b). Two instrumental changes are also evident: the network code transition from TA to N4 on 25 May 2014 and a station instrument change on 11 March 2019. These changes modify the baseline noise level and therefore need to be considered when comparing detection rates across the full record. Wind speed also varies seasonally and broadly covaries with the seismic-noise level during many intervals, consistent with previous observations that wind can contribute substantially to seismic background noise (Johnson et al., 2019; Lepore et al., 2016; McNamara & Buland, 2004).

The relationship with wind is even clearer in the collocated BDF pressure channel (Figure 8c). The BDF root-mean-square noise shows a pronounced seasonal cycle and numerous short-duration peaks that closely follow variations in wind speed. This correspondence indicates that a substantial fraction of the pressure-channel background is associated with wind-driven atmospheric fluctuations. Consequently, the detectability of delayed air-wave signals is not uniform through time: elevated wind noise can obscure weak pressure arrivals, whereas quieter periods provide more favorable conditions for identifying them.

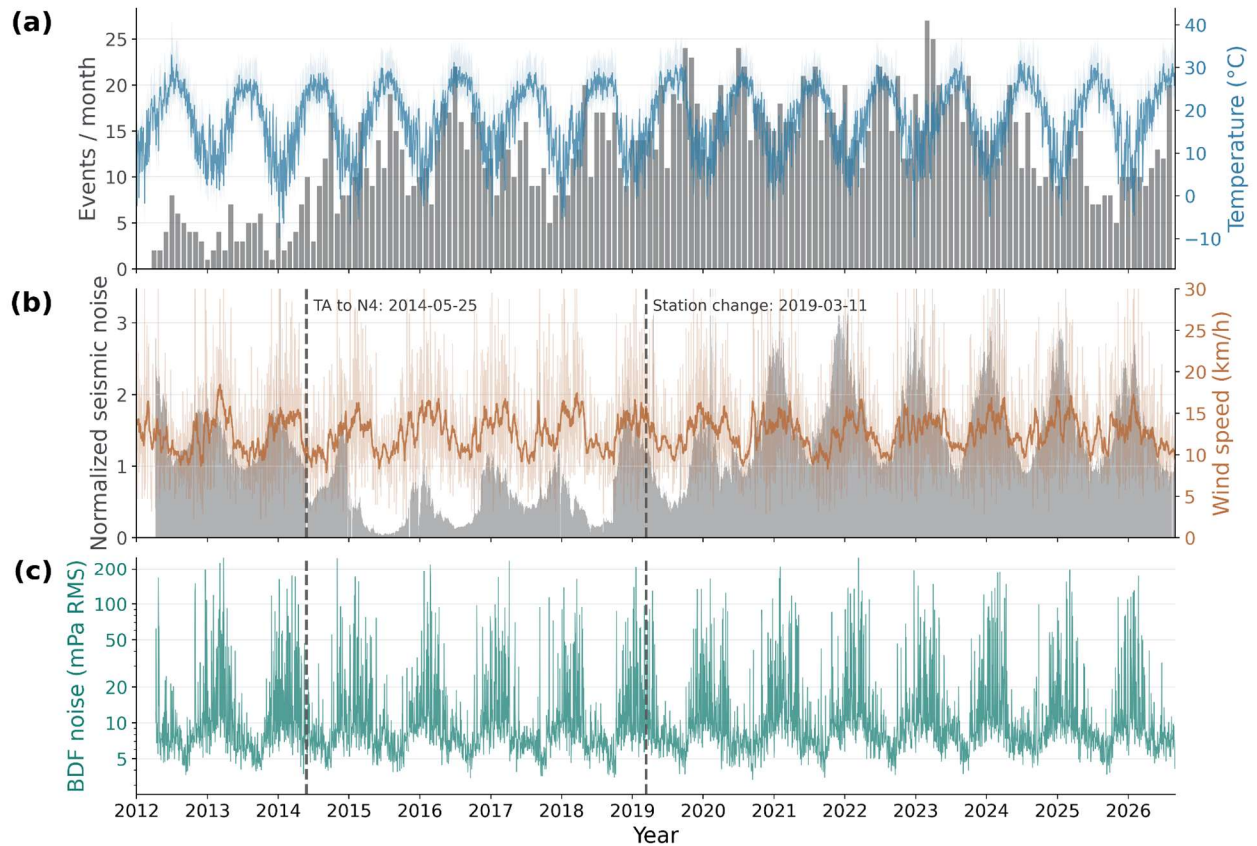


Figure 8 Temporal variation in event detections and noise conditions at station N4.Y52A. (a) Monthly candidate-event counts (gray bars) and air temperature (blue) from 2012 through August 2026. (b) Daily normalized three-component seismic noise (gray) and wind speed (orange). (c) Daily root-mean-square noise amplitude on the BDF pressure channel. Dashed vertical lines mark the transition from network TA to N4 on 25 May 2014 and a station change on 11 March 2019. The pronounced correspondence between wind speed and BDF pressure noise illustrates the strong influence of atmospheric conditions on the detectability of pressure arrivals.

These observations imply that temporal variations in the number of detected events should not be interpreted directly as changes in source activity. The catalog reflects both the occurrence of impulsive sources and time-

dependent detection conditions, including seismic background noise, atmospheric pressure noise, and instrumental changes. Nevertheless, the strong weekday and daytime concentration documented above persists over the long record and is therefore unlikely to result solely from seasonal environmental noise.

3.4 Seismic Events on July 17th 2023 and Near-Source Observations of Rock Exfoliation

The long-term detection results allow us to reevaluate the three impulsive signals recorded at N4.Y52A near noon on 17 July 2023 (Figure 3). These signals occurred at 16:20:10, 16:31:31, and 16:58:10 UTC (12:20-12:58 EDT), substantially earlier than the later eyewitness estimate of 14:00-14:30 EDT for the principal rock movement. Their characteristics are also consistent with the repeated quarry-blast-like population identified in the long-term Y52A record. The evidence is strongest for the 16:31:31 UTC signal, which is followed by a delayed pressure arrival and has similar events in the long-term catalog with comparable waveform and source constraints. The 16:31:31 UTC signal was also recorded by multiple permanent and Raspberry Shake stations at regional distances approaching 200 km (Figure S5). Regional waveform inversion gives a preferred source duration of 1.4 s and M_w 2.30, with an isotropic solution providing a variance reduction of 97.1% (Figure S6; Supporting Text S2). Together with the delayed pressure arrival and long-term waveform comparisons, these observations favor a nearby quarry-related source for the prominent noon-time signal rather than the documented exfoliation event.

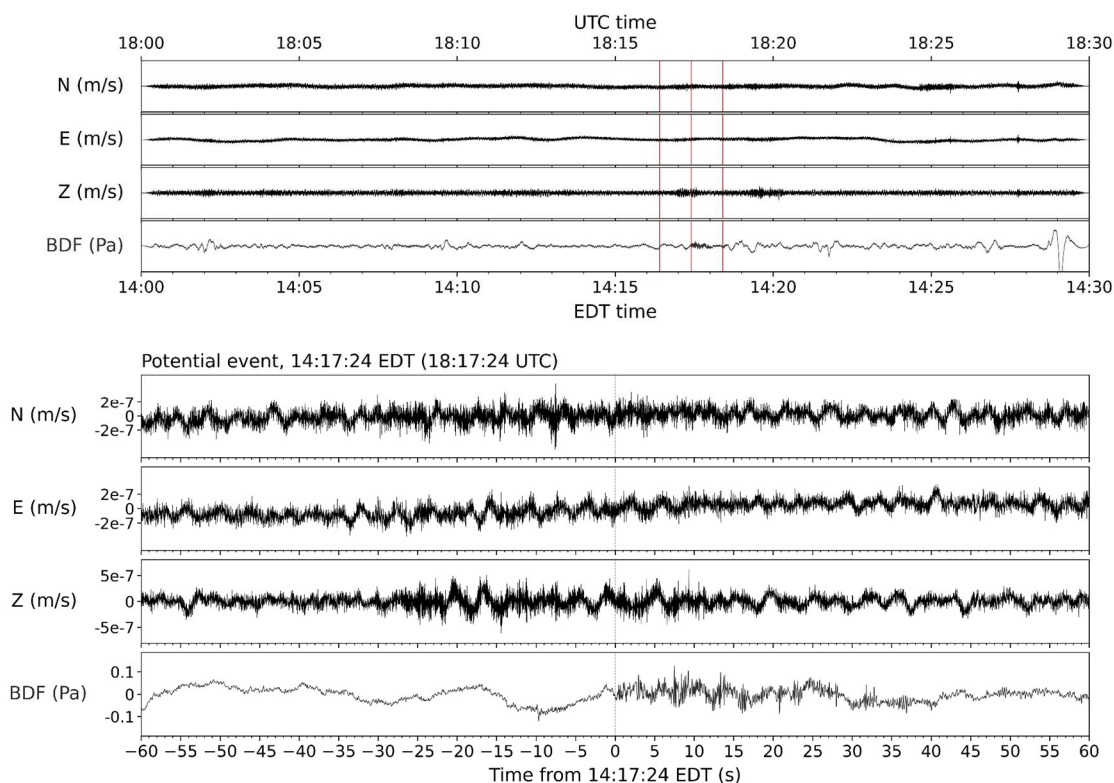


Figure 9 N4.Y52A records during the revised rock-exfoliation time window on 17 July 2023. The upper panel shows three-component seismic velocity and auxiliary barometric-pressure data from 14:00 to 14:30 EDT, corresponding to the constrained timing of the Arabia Mountain exfoliation event. No clear impulsive seismic arrival is visible on the seismic components during this interval. Red dashed lines mark a possible weak pressure disturbance near 14:17:24 EDT. The lower panel shows a 120 s window centered on this time. Although a small pressure perturbation is present, the associated seismic signal is weak or ambiguous. The relative lack of clear seismic energy at N4.Y52A suggests that the confirmed exfoliation event was not strongly recorded by this regional broadband station.

We therefore reexamined the later reported exfoliation interval. From 14:00 to 14:30 EDT, N4.Y52A shows no clear impulsive seismic signal comparable to the noon-time events (Figure 9); a weak disturbance near 14:17 EDT cannot be confidently associated with rock exfoliation. The later timing is also more consistent with the thermal conditions associated with other observed exfoliation events at Arabia Mountain (Reynolds et al., 2026). One possible explanation for the discrepant eyewitness accounts is that quarry activity near noon was heard or felt, while evidence of rock exfoliation was observed later, and the two may have subsequently been associated in recollection despite no direct confirmation that they occurred at the same time. We therefore separate the regional noon-time signals from the later rock-exfoliation process, while the precise timing and seismic expression of the 17 July 2023 exfoliation event remain uncertain.

The long-term analysis above primarily characterizes impulsive events that are detectable at the regional station N4.Y52A. We next examined a different class of shallow source discussed earlier in this study: spontaneous rock exfoliation at Arabia Mountain (Reynolds et al., 2026). An important question is whether such small, localized fracturing events produce signals that would also be recovered by the regional single-station detection workflow. Following the 17 July 2023 exfoliation event, a dense local geophone network was deployed across Arabia Mountain to monitor subsequent fracturing activity. The deployment geometry (Figure S7) has the highest station density concentrated around the active exfoliation area and additional sensors distributed across the surrounding rock outcrop. This near-source configuration provides substantially greater sensitivity to small surface-fracturing events than the regional station approximately 20 km away.

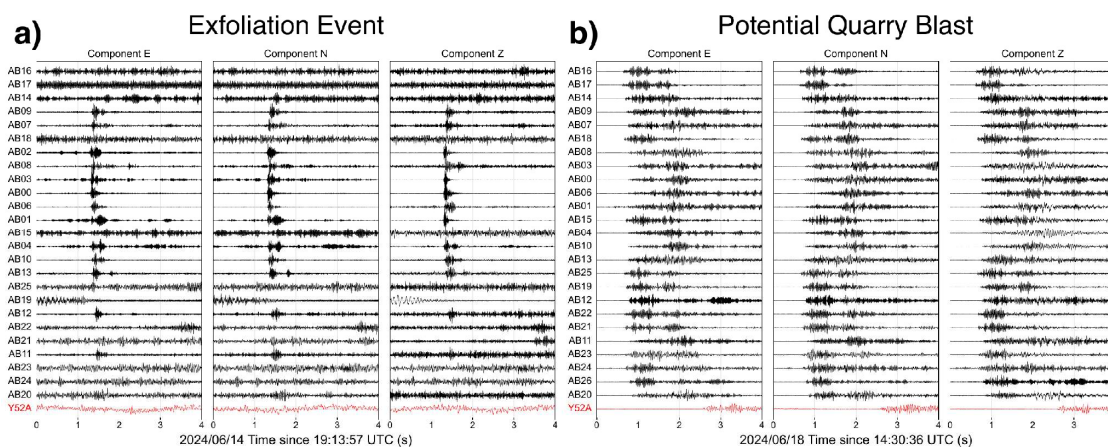


Figure 10 Comparison of local-array waveforms from rock exfoliation and a potential quarry blast. (a) Three-component waveforms for the camera-documented exfoliation event on 14 June 2024, plotted relative to 19:13:57 UTC. (b) Waveforms for a potential quarry blast on 18 June 2024, plotted relative to 14:30:36 UTC. East, north, and vertical components are shown from left to right, and traces are arranged by station; N4.Y52A is highlighted in red. The exfoliation signal is strongest near the fracture site, whereas the blast-like signal is coherent across a broader array aperture.

An exfoliation event captured on camera on 14 June 2024 provides a direct ground truth example (Figure 10a). The event produced clear impulsive signals at geophones close to the active rock sheet, but amplitudes decreased rapidly across the array and no clear corresponding signal is visible at N4.Y52A. Consistent with this limited recording footprint, the event was not recovered in the long-term Y52A detection catalog. Thus, the absence of exfoliation-like events from the regional catalog does not imply that such fracturing did not occur; at least some confirmed events are simply too localized to be clearly recorded at the regional station.

For comparison, Figure 10b shows a blast-like event recorded on 18 June 2024. In contrast to the exfoliation event, this signal is coherent across much of the local array and is also clearly recorded at N4.Y52A. The arrivals exhibit systematic moveout across the array, with northern stations recording the signal earlier than stations farther south, indicating an incoming regional wavefield rather than a source confined to the exfoliation site. The contrast between these two examples illustrates why the long-term Y52A catalog preferentially samples

larger regional impulsive sources, including quarry-blast-like events, whereas small exfoliation-related cracking is better resolved by dense near-source monitoring.

4 Discussion

The long-term N4.Y52A record reveals that most of the screened impulsive events share a set of characteristics consistent with recurrent anthropogenic activity. The 2,181-event catalog is strongly concentrated during weekday working hours, many events are accompanied by delayed pressure disturbances, and their apparent source distances and P-wave particle-motion orientations form several discrete spatial concentrations rather than a diffuse regional distribution. The preferred directions of these concentrations correspond to areas containing known quarry sites around N4.Y52A. While our single-station observation cannot uniquely confirm them as quarry blasts, the agreement among occurrence time, seismic waveform characteristics, pressure observations, and source geometry provides substantially stronger evidence than any individual discriminator. Similar combinations of spatial clustering, daytime occurrence, seismic characteristics, and seismoacoustic observations have long been used to identify quarry activity and remove anthropogenic contamination from earthquake catalogs ([Allmann et al., 2008](#); [Czanik et al., 2021](#); [Wiemer & Baer, 2000](#)). This distinction is important because quarry blasts included in earthquake catalogs can alter inferred seismicity rates and magnitude–frequency statistics ([Gulia & Gasperini, 2021](#)). We therefore interpreted the 2,181-event population as being dominated by potential quarry blasts, while recognizing that the source of every individual event is not independently confirmed.

The detailed comparison set nevertheless shows that the long-term record contains more than one source population. Events selected through similarity to the three earthquake references do not show the same pronounced working-hour concentration as the blast-like population, and all newly detected earthquake candidates have template-relative magnitude estimates below those of the three cataloged earthquake references. Their smaller amplitudes are consistent with why these signals may not have entered the regional catalog, although catalog inclusion also depends on network geometry, signal-to-noise ratio, and the availability of identifiable phase arrivals. The October 2022 and February 2023 sequences are more ambiguous. Most events in both sequences occurred during weekends, in contrast to the dominant weekday pattern of the blast-like catalog. For the October 2022 sequence, the P-wave particle-motion orientation and apparent source distance constrain a possible source region near known quarry activity. For the February 2023 sequence, the single-station solution initially permits two azimuthal alternatives, but the additional differential-arrival constraint from US.GOGA favors the southeastern source region relative to N4.Y52A (Figure S3); this region is also close to known quarry sites. These observations raise the possibility that both sequences have anthropogenic origins despite their weekend occurrence, but the available evidence does not establish the specific source process. More generally, their occurrence demonstrates why time of day or day of week is useful statistically but cannot be treated as a deterministic event-by-event classifier.

The recently cataloged 17 September 2026 event (E11) provides another example of this ambiguity. USGS's ComCat reports E11 as a 2.1 earthquake near Forest Park, Georgia, yet our waveform search identifies several earlier events with three-component cross-correlation coefficients exceeding 0.30 (Figure S8), indicating that E11 belongs to a repeated waveform family rather than representing an isolated signal. Its catalog location is also within a few kilometers of a quarry site. The vertical-component waveform recorded at another regional station US.GOGA and its envelope contain several distinct amplitude pulses following the initial onset. Such source multiplicity is compatible with sequential or delayed rapid-fire blasting, in which multiple charges are detonated with short time delays and can generate complex, multi-pulse seismic waveforms ([Kim et al., 1998](#); [Reamer et al., 1992](#)).

A delayed pressure disturbance is also visible in the BDF record of E11 at approximately 160 s after the seismic arrival, although it is weaker and less distinct than the air-wave signals observed for several closer quarry-blast candidates. The longer source–receiver distance of E11 may contribute to the reduced pressure amplitude. In addition, a closely matching event on 20 July 2022 exhibits a clearer delayed pressure arrival. The recurrence of similar seismic waveforms, the multi-pulse character observed at US.GOGA, the delayed pressure responses, and the proximity of the reported source region to a quarry collectively suggest that E11 may be better explained by an anthropogenic source than by an isolated tectonic earthquake. Independent quarry-operation records would nevertheless be required to confirm the source type.

These examples reinforce a central distinction in this study: sensitive event detection is not equivalent to reliable source attribution. Similarity searches are highly effective for recovering weak or repeated signals from continuous data (Peng & Zhao, 2009; Si et al., 2024; Yoon et al., 2015), and automated phase pickers such as PhaseNet allow those detections to be processed efficiently (W. Zhu & Beroza, 2019). However, waveform similarity can arise because different sources share a similar location and propagation path without sharing the same physical mechanism. Likewise, machine-learning classifiers can perform well within a labeled regional data set yet degrade when applied to a different source population; recent earthquake–quarry-blast discrimination studies explicitly demonstrate this dependence on the training data and study region (Ertuncay et al., 2024). Anthropogenic sources can also be remarkably repeatable: traffic, industrial infrastructure, and hydraulic systems can produce coherent or quasi-periodic seismic signals that resemble natural repeated events (Riahi & Gerstoft, 2015; Si & Peng, 2026). Our results therefore favor a workflow in which machine learning and waveform similarity are used for event retrieval, while source interpretation relies on independent physical constraints, including phase behavior, pressure observations, particle motion, multistation timing, spatial context, and, where available, external ground truth.

The 17 July 2023 Arabia Mountain event provides a particularly clear demonstration of this distinction. The exfoliation event itself is independently established by eyewitness observations, fresh fractures, surface deformation, and subsequent field measurements (Reynolds et al., 2026). Such spontaneous exfoliation is physically plausible in exposed crystalline rock, where thermal cycling and cumulative heating can promote fracture opening and subcritical crack growth (Collins et al., 2018; Collins & Stock, 2016). In this study, we did not focus on whether this exfoliation event occurred or not, but whether the prominent regional signal originally associated with it at N4.Y52A (Peng et al., 2024a) was generated by that fracturing event. The revised eyewitness timing places the major exfoliation event between approximately 14:10 and 14:20 EDT, during which no clear impulsive seismic signal is observed at N4.Y52A (Figure 9). In contrast, the earlier prominent signal at 12:31 EDT (16:31 UTC) has a delayed pressure arrival and source characteristics consistent with a shallow event. Its closest match in the long-term catalog, recorded on 10 May 2023, also shows similar seismic waveforms, a delayed pressure signal, and comparable particle-motion and apparent-distance constraints (Figure S4). Considered together with the broader population of repeated quarry-blast-like signals, these observations favor a nearby anthropogenic source for the prominent 16:31 UTC signal rather than the documented exfoliation event. The Arabia Mountain case therefore illustrates how a correct observation of a natural phenomenon can nevertheless be paired with an incorrect regional seismic association when event timing and source attribution are not independently constrained.

The near-source nodal observations since June 2024 (Reynolds et al., 2026) help explain why this association was difficult to evaluate from N4.Y52A alone. The camera-documented 14 June 2024 exfoliation event produced clear impulsive arrivals at geophones immediately surrounding the active rock sheet, but its amplitudes decayed rapidly across the local array and no clear corresponding signal is visible at N4.Y52A (Figure 10). The event was consequently not recovered by the regional single-station workflow. In contrast, the 18 June 2024 blast-like event was coherent across much of the local array, showed systematic moveout, and was also recorded at N4.Y52A. These observations demonstrate a substantial difference in recording footprint between small local

fracturing and regional blast-like sources. Direct observations of spontaneous exfoliation are intrinsically rare (Collins et al., 2018), and our results indicate that a regional catalog such as the one constructed here cannot be expected to provide a complete history of such small surface-fracturing events. Near-source geophones, time-lapse imagery, temperature and stress measurements, and repeated surface-deformation surveys therefore remain essential for identifying and interpreting exfoliation processes (Reynolds et al., 2026).

Detection conditions at N4.Y52A also vary substantially through time. Both seismic background noise and BDF pressure noise show seasonal changes, and the pressure-noise level closely follows variations in wind speed during much of the record (Figure 8). Instrumental changes further alter the long-term seismic-noise baseline. Such variability affects the probability of detecting both weak seismic arrivals and delayed atmospheric signals, so annual or monthly catalog counts cannot be interpreted directly as source-rate variations. More generally, anthropogenic and environmental changes are known to modify high-frequency seismic noise over timescales ranging from hours to months; traffic can dominate urban seismic records (Riahi & Gerstoft, 2015), and the COVID-19 lockdown produced a globally observed reduction in anthropogenic high-frequency seismic noise (Lecocq et al., 2020). In the present data, environmental variability likely modulates catalog completeness, but it cannot readily account for the persistent concentration of the pressure-positive population during weekday working hours. The temporal pattern therefore remains an important component of the quarry-blast interpretation, provided that it is considered together with the other source constraints.

Several limitations follow directly from the single-station design. Apparent source distances depend on phase identification and the assumed velocity relation, particle-motion measurements commonly retain a 180° directional ambiguity, and pressure detection depends on atmospheric propagation and background wind noise. The 2,181-event catalog is also conditioned on the successive detection and quality-control thresholds and should therefore not be interpreted as a complete inventory of either quarry blasts or natural earthquakes. Other anthropogenic sources—including construction, traffic, machinery, and infrastructure—can produce impulsive or repeated seismic signals (Riahi & Gerstoft, 2015; Si & Peng, 2026), while weak natural earthquakes may remain below regional catalog thresholds. These limitations argue for combining permanent regional stations with temporary dense arrays, pressure or infrasound sensors, multi-station relocation, and independent activity records. Seismoacoustic observations coupled with mine-operator confirmation have proved particularly effective for identifying quarry explosions and resolving closely spaced quarry sources (Czanik et al., 2021). Similar ground-truth constraints—including operator logs, field observations, video records, and other independent source information—are therefore critical when constructing increasingly complete catalogs with machine-learning or similarity-based methods. The broader implication is that improved detection sensitivity must be accompanied by equally careful source validation: a larger catalog is not necessarily a more accurate earthquake catalog unless natural and anthropogenic sources are independently distinguished.

5 Conclusions

We analyzed more than 14 years of continuous seismic and pressure observations at station N4.Y52A to characterize natural and anthropogenic impulsive events around Atlanta, Georgia. A machine-learning-assisted detection workflow identified 2,181 high-confidence events with seismic, pressure, and particle-motion constraints. Their strong concentration during weekday working hours, repeated source-distance and directional patterns, and spatial correspondence with known quarry areas indicate that the detected population is dominated by quarry-blast activity. The long-term record also contains smaller earthquake candidates and short event sequences with more uncertain origins, demonstrating that waveform similarity, occurrence time, or pressure observations alone cannot uniquely determine source type. The Arabia Mountain observations provide an independent example of this source-discrimination problem. The regional signal previously associated with the documented 17 July 2023 rock-exfoliation event is more consistent with quarry activity, whereas camera-documented exfoliation events in 2024 produced localized signals that were not clearly recorded at N4.Y52A.

Together, these results demonstrate that machine-learning and similarity-based methods can substantially improve event detection, but reliable discrimination between natural and anthropogenic sources requires multiple independent seismic, pressure, spatial, and field constraints.

Open Research Section

Continuous waveform data from station N4.Y52A were obtained through the NSF SAGE/IRIS Data Management Center. Station metadata and data availability for N4.Y52A are available from the IRIS Metadata Aggregator at <https://ds.iris.edu/mda/N4/Y52A/>. The video footages and the dense-array seismic data associated with the June 14th 2024 rock exfoliation events can be found in the supplementary material of (Reynolds et al., 2026). Weather and environmental data used for comparison, including air temperature and wind speed records, were obtained from the NOAA National Centers for Environmental Information (NCEI) Climate Data Online and Daily Summaries products. NOAA Climate Data Online provides access to historical weather and climate observations, including temperature and wind measurements, and the NCEI Daily Summaries product provides daily land-surface observations from the Global Historical Climatology Network. These data can be accessed at <https://www.ncei.noaa.gov/cdo-web/> and <https://www.ncei.noaa.gov/maps/daily-summaries/>. Satellite imagery used in Figure 1 was obtained from Google Earth at <https://earth.google.com/web/>. The analysis was performed using Python-based tools, including NumPy (Harris et al., 2020), SciPy (Virtanen et al., 2020), pandas (McKinney, 2010), ObsPy (Beyreuther et al., 2010), and Matplotlib (Hunter, 2007). Machine-learning feature extraction used the pretrained spectrum encoder of SeisCLIP (Si et al., 2024). Final code and processed catalogs will be archived in a public repository before publication.

Conflict of Interest declaration

The authors declare there are no conflicts of interest for this manuscript.

Acknowledgments

We thank Head ranger Robert Astrove and Davidson-Arabia Mountain National Heritage Area staff for access, field support, and observations related to the July 2023 and June 2024 events. We thank the field team members from Georgia Tech who installed and maintained the temporary geophone and environmental sensor deployment, including Phuc Mach, Aislin Reynolds, Oluwaseyifunmi Adeboboye, Clara Daniels, Sonia Hajaji, Nathalie Chavarria, Ashleigh Miller and Isabelle Osuna. We also thank members (e.g., William (Bill) Witherspoon and Scott Harris) of the Atlanta Geological Society (AGS) for their information and discussion on quarry blasts and rock exfoliation events.

References

- Allmann, B. P., Shearer, P. M., & Hauksson, E. (2008). Spectral discrimination between quarry blasts and earthquakes in southern California. *Bull. Seismol. Soc. Am.*, 98(4), 2073–2079. <https://doi.org/10.1785/0120070215>
- Beaucé, E., Frank, W. B., & Romanenko, A. (2018). Fast matched filter (FMF): An efficient seismic matched-filter search for both CPU and GPU architectures. *Seismological Research Letters*, 89(1), 165–172. <https://doi.org/10.1785/0220170181>
- Beyreuther, M., Barsch, R., Krischer, L., Megies, T., Behr, Y., & Wassermann, J. (2010). ObsPy: A python toolbox for seismology. *Seismol. Res. Lett.*, 81(3), 530–533. <https://doi.org/10.1785/gssrl.81.3.530>
- Calais, E., Camelbeeck, T., Stein, S., Liu, M., & Craig, T. J. (2016). A new paradigm for large earthquakes in stable continental plate interiors. *Geophysical Research Letters*, 43, 10,621–10,637. <https://doi.org/10.1002/2016GL070815>
- Collins, B. D., & Stock, G. M. (2016). Rockfall triggering by cyclic thermal stressing of exfoliation fractures. *Nat. Geosci.*, 9, 395–400. <https://doi.org/10.1038/ngeo2686>
- Collins, B. D., Stock, G. M., Eppes, M. C., Lewis, S. W., Corbett, S. C., & Smith, J. B. (2018). Thermal influences on spontaneous rock dome exfoliation. *Nat. Commun.*, 9, 762. <https://doi.org/10.1038/s41467-017-02728-1>

- Czanik, C., Kiszely, M., Mónus, P., Süle, B., & Bondár, I. (2021). Identification of quarry blasts aided by infrasound data. *Pure Appl. Geophys.*, 178, 2287–2300. <https://doi.org/10.1007/s00024-021-02748-5>
- Dingler, J. (2023). Did an earthquake strike Arabia mountain? Arabia Mountain Heritage Area Alliance, <https://arabiaalliance.org/field-notes/did-an-earthquake-strike-arabia-mountain/>. Retrieved from <https://arabiaalliance.org/field-notes/did-an-earthquake-strike-arabia-mountain/>
- Eggertsson, G., Lund, B., Roth, M., & Schmidt, P. (2024). Earthquake or blast? Classification of local-distance seismic events in Sweden using fully connected neural networks. *Geophysical Journal International*. <https://doi.org/10.1093/gji/ggae018>
- Eppes, M. C., & Keanini, R. (2017). Mechanical weathering and rock erosion by climate-dependent subcritical cracking. *Rev. Geophys.*, 55(2), 470–508. <https://doi.org/10.1002/2017RG000557>
- Ertuncay, D., De Lorenzo, A., & Costa, G. (2024). Seismic signal discrimination of earthquakes and quarry blasts in north-east Italy using deep neural networks. *Pure Appl. Geophys.*, 181, 1139–1151. <https://doi.org/10.1007/s00024-024-03440-0>
- Ferreri, A. P., Romeo, A., Giannuzzi, R., Ninivaggi, T., Filippucci, M., Cecere, G., Falco, L., Michele, M., Selvaggi, G., & Tallarico, A. (2026). The new seismic catalog of the Gargano area (Southern Italy) after a decade of seismic monitoring by OTRIONS network. *Earth System Science Data*, 18, 3177–3209. <https://doi.org/10.5194/essd-18-3177-2026>
- Gibbons, S. J., & Ringdal, F. (2006). The detection of low magnitude seismic events using array-based waveform correlation. *Geophysical Journal International*. <https://doi.org/10.1111/j.1365-246X.2006.02865.x>
- Gulia, L., & Gasperini, P. (2021). Contamination of frequency–magnitude slope (b -value) by quarry blasts: An example for Italy. *Seismol. Res. Lett.*, 92(6), 3538–3551. <https://doi.org/10.1785/0220210080>
- Hammer, C., Ohrnberger, M., & Fah, D. (2013). Classifying seismic waveforms from scratch: A case study in the alpine environment. *Geophysical Journal International*. <https://doi.org/10.1093/gji/ggs036>
- Harris, C. R., Millman, K. J., Walt, S. J. van der, Gommers, R., Virtanen, P., Cournapeau, D., et al. (2020). Array programming with NumPy. *Nature*, 585, 357–362. <https://doi.org/10.1038/s41586-020-2649-2>
- Hourcade, C., Bonnin, M., & Beucler, E. (2023). New CNN-based tool to discriminate anthropogenic from natural low magnitude seismic events. *Geophysical Journal International*. <https://doi.org/10.1093/gji/ggac441>
- Hunter, J. D. (2007). Matplotlib: A 2D graphics environment. *Comput. Sci. Eng.*, 9(3), 90–95. <https://doi.org/10.1109/MCSE.2007.55>
- Johnson, C. W., Meng, H., Vernon, F., & Ben-Zion, Y. (2019). Characteristics of ground motion generated by wind interaction with trees, structures, and other surface obstacles. *Journal of Geophysical Research: Solid Earth*, 124(8), 8519–8539. <https://doi.org/10.1029/2018JB017151>
- Kasburg, V., Zehner, M., Laaten, M. van, Muller, J., & Kukowski, N. (2025). Explainable seismic event discrimination: Improved explainability with vision transformers. *Journal of Geophysical Research: Machine Learning and Computation*. <https://doi.org/10.1029/2025JH000802>
- Kim, S. G., Park, Y., & Kim, W. (1998). Discrimination of small earthquakes and artificial explosions in the Korean peninsula using pg/lg ratios. *Geophys. J. Int.*, 134(1), 267–276. <https://doi.org/10.1046/j.1365-246X.1998.00575.x>
- Kim, W.-Y., Simpson, D. W., & Richards, P. G. (1993). Discrimination of earthquakes and explosions in the eastern United States using regional high-frequency data. *Geophysical Research Letters*, 20, 1507–1510. <https://doi.org/10.1029/93GL01267>
- Kintner, J. A., Cleveland, K. M., Ammon, C. J., & Nyblade, A. A. (2020). Testing a local-distance rg/sg discriminant using observations from the bighorn region, Wyoming. *Bulletin of the Seismological Society of America*. <https://doi.org/10.1785/0120190188>
- Klein, F. W. (2002). *User's guide to HYPOINVERSE-2000, a Fortran program to solve for earthquake locations and magnitudes* (Open-File Report No. 2002-171). U.S. Geological Survey. <https://doi.org/10.3133/ofr02171>
- Kortstrom, J., Uski, M., & Tiira, T. (2016). Automatic classification of seismic events within a regional seismograph network. *Computers & Geosciences*. <https://doi.org/10.1016/j.cageo.2015.11.006>
- Lecocq, T., Hicks, S. P., Van Noten, K., Van Wijk, K., Koelemeijer, P., De Plaen, R. S., et al. (2020). Global quieting of high-frequency seismic noise due to COVID-19 pandemic lockdown measures. *Science*, 369(6509), 1338–1343. <https://doi.org/10.1126/science.abd2438>
- Lepore, S., Grad, M., & Knapmeyer-Endrun, B. (2016). Impact of wind on ambient noise recorded by seismic array. *Geophys. J. Int.*, 205(3), 1406–1417. <https://doi.org/10.1093/gji/ggw093>
- Linville, L., Pankow, K., & Draelos, T. (2019). Deep learning models augment analyst decisions for event discrimination. *Geophysical Research Letters*. <https://doi.org/10.1029/2018GL081119>
- Long, L. T., Kocaoglu, A., Hawman, R. B., & Gore, P. J. W. (1994). The Norris Lake earthquake swarm of June through September, 1993: Preliminary findings. *Seismological Research Letters*, 65(2), 167–171. <https://doi.org/10.1785/gssrl.65.2.167>
- Mach, P., Si, X., Wang, D., Shcherbakov, R., He, P., Taymaz, T., et al. (2026). Foreshock behaviors and mainshock rupture properties associated with the 2025 mw 8.8 kamchatka earthquake sequence. *Earthquake Research Advances*, 100457. <https://doi.org/10.1016/j.eqrea.2026.100457>

- Marzen, R. E., Gaherty, J. B., Shillington, D. J., & Kim, W.-Y. (2021). Shaking in the Southeastern United States: Examining earthquakes and blasts in the Central Georgia–South Carolina seismic region. *Seismological Research Letters*, 92(5), 3145–3164. <https://doi.org/10.1785/0220210029>
- McKinney, W. (2010). Data structures for statistical computing in python. In *Proceedings of the 9th python in science conference* (pp. 56–61). <https://doi.org/10.25080/Majora-92bfl922-00a>
- McNamara, D. E., & Buland, R. P. (2004). Ambient noise levels in the continental United States. *Bull. Seismol. Soc. Am.*, 94(4), 1517–1527. <https://doi.org/10.1785/012003001>
- Miao, F., Carpenter, N. S., Wang, Z., Holcomb, A. S., & Woolery, E. W. (2020). High-accuracy discrimination of blasts and earthquakes using neural networks with multiwindow spectral data. *Seismological Research Letters*. <https://doi.org/10.1785/0220190084>
- Mueller, C., Boyd, O. S., Petersen, M. D., Moschetti, M. P., Rezaeian, S., & Shumway, A. M. (2015). Seismic hazard in the eastern United States. *Earthquake Spectra*, 31(S1), S85–S107. <https://doi.org/10.1193/110414EQS182M>
- Peng, Z. (2015). The Big Bang: Reverberations from the American Civil War recorded by an EarthScope station. *Seismological Research Letters*, 86(6), 1726–1727. <https://doi.org/10.1785/0220150220>
- Peng, Z., & Zhao, P. (2009). Migration of early aftershocks following the 2004 parkfield earthquake. *Nature Geoscience*, 2(12), 877–881. <https://doi.org/10.1038/ngeo697>
- Peng, Z., Reynolds, A., Qian, Y., Mach, P., Ding, C., Lang, K. A., et al. (2024a). Seismic detection of rock exfoliation events at Arabia Mountain, Georgia. In *AGU fall meeting abstracts* (Vol. 2024, pp. S11F–345). <https://agu.confex.com/agu/agu24/meetingapp.cgi/Paper/1636821>
- Peng, Z., Adeboboye, O., Neves, M., Figueiredo, P. M., & Ni, S. (2024b). What drives extremely shallow seismic events in the Southeastern U.S.? Abstract T43A-3292 presented at the 2024 AGU Fall Meeting, Washington D.C., Dec. 9-13, 2024.
- Peng, Z., Si, X., Ding, C., Zhu, S., Neves, M. and Adeboboye, O.E. (2026). Artificial intelligence in source seismology: Potential issues and possible future directions, *Big Data and Earth System*, revised.
- Pinsky, V., & Shapira, A. (1998). Kinematic multistation discriminator between local quarry blasts and earthquakes. *Geophysical Journal International*. <https://doi.org/10.1046/j.1365-246X.1998.00684.x>
- Reamer, S. K. et al. (1992). Near-source characterization of the seismic wavefield radiated from quarry blasts. *Geophys. J. Int.*, 110(3), 435–450. <https://doi.org/10.1111/j.1365-246X.1992.tb02084.x>
- Renouard, A., Maggi, A., Grunberg, M., Doubre, C., & Hibert, C. (2021). Toward false event detection and quarry blast versus earthquake discrimination in an operational setting using semiautomated machine learning. *Seismological Research Letters*. <https://doi.org/10.1785/0220200305>
- Reynen, A., & Audet, P. (2017). Supervised machine learning on a network scale: Application to seismic event classification and detection. *Geophysical Journal International*. <https://doi.org/10.1093/gji/ggx238>
- Reynolds, A. N., Eppes, M. C., Collins, B. D., Peng, Z., & Lang, K. A. (2026). *New constraints on the influence of thermal cycling on spontaneous rock exfoliation, arabia mountain, georgia, USA*. Retrieved from <https://doi.org/10.5194/egusphere-egu25-12839>
- Riahi, N., & Gerstoft, P. (2015). The seismic traffic footprint: Tracking trains, aircraft, and cars seismically. *Geophys. Res. Lett.*, 42(8), 2674–2681. <https://doi.org/10.1002/2015GL063558>
- Saad, O. M., Soliman, M. S., Chen, Y., Amin, A. A., & Abdel Hafez, H. E. (2024). Capsule neural network guided by compact convolutional transformer for discriminating earthquakes from quarry blasts. *Seismological Research Letters*. <https://doi.org/10.1785/0220230101>
- Si, X., & Peng, Z. (2026). Extremely shallow semi-repeating tremor caused by water hammers in a sewer pipe in social circle, georgia. *Seismol. Res. Lett.* <https://doi.org/10.1785/0220250421>
- Si, X., Wu, X., Sheng, H., Zhu, J., & Li, Z. (2024). SeisCLIP: A seismology foundation model pretrained by multimodal data for multipurpose seismic feature extraction. *IEEE Trans. Geosci. Remote Sens.*, 62, 1–13. <https://doi.org/10.1109/TGRS.2024.3354456>
- Si, Z., Wang, W., Li, L., Zhong, S., Liu, Z., Yu, Z., & Zhang, Y. (2026). Earthquake catalog in northeastern Tibetan plateau from the large aperture ChinArray-II through deep learning approach. *Geophysical Journal International*, 244(1), ggaf292. <https://doi.org/10.1093/gji/ggaf292>
- Skoumal, R. J., & Trugman, D. T. (2021). The proliferation of induced seismicity in the Permian Basin, Texas. *Journal of Geophysical Research: Solid Earth*, 126, e2021JB021921. <https://doi.org/10.1029/2021JB021921>
- Stump, B. W., Hedlin, M. A. H., Pearson, D. C., & Hsu, V. (2002). Characterization of mining explosions at regional distances: Implications with the international monitoring system. *Reviews of Geophysics*. <https://doi.org/10.1029/1998RG000048>
- Tang, L., Zhang, M., & Wen, L. (2020). Support vector machine classification of seismic events in the tianshan orogenic belt. *Journal of Geophysical Research: Solid Earth*. <https://doi.org/10.1029/2019JB018132>
- Tibi, R., Koper, K. D., Pankow, K. L., & Young, C. J. (2018a). Depth discrimination using rg-to-sg spectral amplitude ratios for seismic events in Utah recorded at local distances. *Bulletin of the Seismological Society of America*. <https://doi.org/10.1785/0120170257>

- Tibi, R., Koper, K. D., Pankow, K. L., & Young, C. J. (2018b). Discrimination of anthropogenic events and tectonic earthquakes in Utah using a quadratic discriminant function approach with local distance amplitude ratios. *Bulletin of the Seismological Society of America*. <https://doi.org/10.1785/0120180024>
- U.S. Geological Survey, Earthquake Hazards Program. (2017). Advanced national seismic system (ANSS) comprehensive catalog of earthquake events and products. U.S. Geological Survey. <https://doi.org/10.5066/F7MS3QZH>
- Virtanen, P., Gommers, R., Oliphant, T. E., Haberland, M., Reddy, T., Cournapeau, D., et al. (2020). SciPy 1.0: Fundamental algorithms for scientific computing in python. *Nat. Methods*, 17, 261–272. <https://doi.org/10.1038/s41592-019-0686-2>
- Wang, R., & Schmandt, B. (2021). Advancing local distance discrimination of explosions and earthquakes with joint p/s and ML–MC classification. *Geophysical Research Letters*. <https://doi.org/10.1029/2021GL095721>
- Wang, R., Schmandt, B., & Kiser, E. (2020). Seismic discrimination of controlled explosions and earthquakes near mount st. Helens using p/s ratios. *Journal of Geophysical Research: Solid Earth*. <https://doi.org/10.1029/2020JB020338>
- Wiemer, S., & Baer, M. (2000). Mapping and removing quarry blast events from seismicity catalogs. *Bull. Seismol. Soc. Am.*, 90(2), 525–530. <https://doi.org/10.1785/0119990104>
- Wiemer, S., Yoshida, A., Hosono, K., Noguchi, S., & Takayama, H. (2005). Correlating seismicity parameters and subsidence in the Tokai region, central Japan. *Journal of Geophysical Research: Solid Earth*, 110, B10303. <https://doi.org/10.1029/2003JB002732>
- WSB-TV news (2026). ‘Earthquake’ in metro Atlanta turned out to be something different. <https://www.wsbtv.com/news/local/earthquake-metro-atlanta-turned-out-be-something-different/6R43FHMAJBHZBL2D4BB6N33HSE/>
- Yoon, C. E., O’Reilly, O., Bergen, K. J., & Beroza, G. C. (2015). Earthquake detection through computationally efficient similarity search. *Sci. Adv.*, 1(11), e1501057. <https://doi.org/10.1126/sciadv.1501057>
- Zhai, Q., Peng, Z., Chuang, L. Y., Wu, Y.-M., Hsu, Y.-J., & Wdowinski, S. (2021). Investigating the impacts of a wet typhoon on microseismicity: A case study of the 2009 typhoon morakot in taiwan based on a template matching catalog. *Journal of Geophysical Research: Solid Earth*, 126(12), e2021JB023026. <https://doi.org/10.1029/2021JB023026>
- Zhu, J., Fang, L., Miao, F., Fan, L., Zhang, J., & Li, Z. (2024). Deep learning and transfer learning of earthquake and quarry-blast discrimination: Applications to southern california and eastern kentucky. *Geophysical Journal International*, 236(2), 979–993. <https://doi.org/10.1093/gji/ggad463>
- Zhu, W., & Beroza, G. C. (2019). PhaseNet: A deep-neural-network-based seismic arrival-time picking method. *Geophys. J. Int.*, 216(1), 261–273. <https://doi.org/10.1093/gji/ggy423>