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Expanding Lower Monitoring Limits for Seismic Precursor of Destructive Earthquakes to Microseismics

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Abstract

Even for the seismic networks with higher density, the lower limit of the monitorable seismic magnitude (M) with a relatively reliable number of events as the seismic precursor to destructive earthquakes is about 1. Thus, people counted only about 10% with seismic precursor, of the total number of destructive earthquakes. This statistic is incomplete and likely due to insufficient data observation and processing capabilities. Based on the relationship between M and corresponding frequency, or number of happened events, as well as rock mechanics experiments and fatigue damage inspection in engineering, the M of the events as the precursor to the destructive earthquakes should reach the microseismic range, i.e., $M \leq 0$, dozens or even thousands of times smaller than $M \approx 1$ in seismically released energy. Vector stacking (VS), based on the essence or first principle of microseismic monitoring, has been basically perfected in the energy field. On the other hand, after more than a century of research and development, the natural seismology has established a solid foundation for the performance of seismic instruments and the construction of seismic networks. At least in the areas prone to destructive earthquakes, many networks have higher density and huge continuous records suitable for microseismic monitoring. These have laid the foundation for real-time monitoring of small-micro earthquakes as seismic precursor, analyzing small-micro seismicity, and thus achieving breakthrough progress in destructive earthquake forecasting.

Keywords: Earthquake, Seismic-precursor, Forecast, Microseismic.

Introduction - Current status of monitoring seismic precursor of destructive earthquakes

Statistics on the California earthquakes observed by USGS (2026) (Figure 1 and Table 1) show that the current lower limit for seismic precursor monitoring to destructive earthquakes (e.g., magnitude $M \geq 5$) can reach $M \approx 1$.

$$\log N = a + b(8-M) \quad (1)$$

Equation (1) (Gutenberg & Richter, 1944 & 1954) is the relationship between the frequency (N) of and different M ranges, through extensive observation and statistics, where a and b are coefficients which vary slightly over time and space. Generally, an earthquake occurrence within a certain M range is associated with ~ 8 -time more events within the sub-magnitude range, as shown at the rightmost column of Table 1 through annual global earthquake events (Kasahara, 1981). The statistics in Table 1 for California earthquakes in half a year up to $M=1.0$ show that the general M - N relationship is roughly valid; Below, however, the number of recorded events sharply decreases. Similar statistical examples can be seen in China's earthquake networks, and the number of destructive earthquakes with seismic precursors is accounted for only about 10% of the total (Xue, 2025). This proportion is clearly unreliable

Based on general relationships of M - N up to $M=1.0$, rock mechanics experiments (Figure 2), and fatigue damage inspection in engineering, it is suspected that the missing records in Figures 1 and Table 1 are due to insufficient observation capabilities and flaws in data processing, such as insufficient seismic network density and failure to properly extract seismic information from background noise. For example, a large number of $M \geq 5$ earthquakes occur in widespread uninhabited areas without dense seismic network, and their seismic precursors may not be detectable or accurate even if $M=[2,3]$, let alone $M \approx 1$. Large earthquakes, including some slow earthquakes (e.g. Gualandi et al., 2020; Chen, 2026), the M range of their seismic precursors is very likely to reach microseismic M .

Table 1 Magnitudes (M) and corresponding frequency (N) of USGS recorded earthquakes in Feb. 17, 2026-Aug. 17, 2026 at California in the range of 31.391-42.267N and 126.716-113.137W (Figure 1). Data from USGS (2026). For comparison, the corresponding data in whole world in a half year based on Equation (1) are listed (Kasahara, 1981), but ignoring its absolute frequency column.

M	California		World
	N	Latter M/Last M	Latter M/Last M
5.9-5.0	5		7.4
4.9-4.0	26	5.2	7.8
3.9-3.0	204	7.8	7.9
2.9-2.0	1772	8.7	8.0
1.9-1.0	9683	5.5	8.0
0.9-0.0	9713	1.0	8.0
-0.1- -1.0	134	0.01	8.0
-1.1- -2.0	0	0.0	8.0

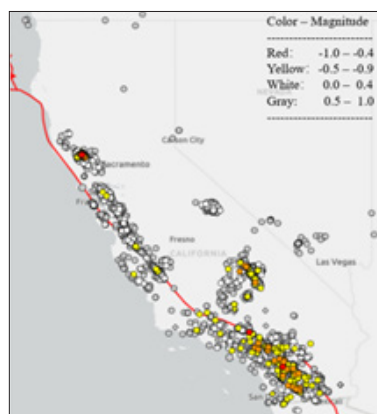


Figure 1 Distribution of USGS recorded earthquakes in the half year from Feb. 17, 2026 to Aug. 17, 2026, California, in the range of 31.391-42.267N and 126.716-113.137W. Data from USGS (2026). The red line is the San Andreas Fault. See also Table 1.

Here, in terms of absolute energy level (Gutenberg & Richter, 1944 & 1954), we define the epitaxial M to $M \approx (-3, 0)$ roughly at the energy level from firecrackers to kg of explosives, called the microseismic equivalent M (Feng & Liang, 2023). In a relative sense, after effective noise evasion and denoising, any recorded event with a signal-to-noise ratio (S/N) of ≤ 1 that cannot be traditionally localized may be defined as a microseismic, even if its $M > 0$. For the latter definition, the corresponding observation distance in this case can be called the far-field of microseismic monitoring.

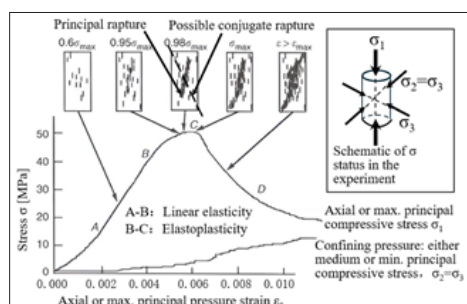


Figure 2 Schematic diagram of rock mechanics experiments under typical crustal stress conditions. It was made by Hallbauer et al. (1973). Cited by Jaeger et al. (2007), and used here by adding proper explanation by this paper author. This shows that before the final fracture (point C), there should be a number of tiny cracks.

Therefore, the lower monitoring threshold for seismic precursors of destructive earthquakes should be extended to microseismic. To this end, in addition to spatially expanding the density of seismic networks, effective data processing must be adopted to use existing general networks. Only by observing relatively complete seismicity expressed by released energy above a certain lower limit of microseismics, e.g. $M \approx 0$, or even $M \approx -1$, the patterns of precursors to destructive earthquakes can be studied and determined, so that people may make breakthrough progress in earthquake forecasting.

Possibility to extend seismic precursor monitoring to microseismic

Essence and current status of microseismic monitoring

There are two important characteristics of microseismic: tiny, and fractures with mainly shear and dislocated mechanisms (Liang & Zhu, 2004; Maxwell, 2014; Liang & Wang, 2017; Liang et al., 2023). Thus the characteristics of microseismic monitoring are: often $S/N < 1$ at several hundred meters away, traditional location fails; The hypocenter radiates longitudinal wave (P) and transverse or rotating wave (S) into space, with wave amplitude and polarity varying with direction. This is the essence or the first principle of microseismic monitoring (Liang, 2025a; Liang & Wang, 2026).

The current status, problems, and known solutions for microseismic monitoring (Liang, 2025a; Liang & Wang, 2026) are the fact that many people:

1. Adhere to the traditional relocation based on $S/N > 1$, such as costly borehole proximity monitoring (BPM) without improvement, persistently but effect-limited denoising, or being at a loss; and fail to coexist with residual noise after effectively denoising, and implement data migrating and stacking (DMS) to extract microseismic information;
2. Use DMS but not (correctly) extract seismic wave vectors from the 3-component records based on the far-field displacement solution generated by the shear focal mechanism, especially the two independent propagation components SV and SH (Aki & Richards, 1980) of transverse S wave with the large amplitude, slow attenuation, and far-propagation;
3. Do not consider that the arrival amplitude and polarity of the seismic wave at different seismic stations are function of the coming direction of an earthquake; That is, the shear focal mechanism for tectonic earthquakes is not used in DMS and the explanation of microseismicity.

These issues are clearly present in many detections of surface, BPM, mine safety warnings, inversion for velocity models, and monitoring precursors before destructive earthquakes. In the following sections of this chapter, we use VS as an example to illustrate how to solve the dilemma of microseismic monitoring.

VS Principle

Based on the microseismic characteristics and the first principles of the monitoring, VS has undergone nearly 30 years of research and development. Its real-time application in the energy field has been basically perfected (Liang et al., 2023; Liang, 2025a; Liang, 2025b), including the establishment of the equivalent magnitude of microseismic (Feng & Liang; 2023). To ensure the reliability of VS application with high probability, many necessary conditions (Liang, 2025a; Liang & Wang, 2026) should be followed (see section below). VS uses a unified spatiotemporal distribution of seismic released energy to express seismicity, which is beneficial for analyzing the geological and mechanical laws involved. It is also suitable for unified monitoring of small events ($S/N > 1$) and microseismic ($S/N \leq 1$).

To meet general microseismic monitoring, based on the microseismic and monitoring characteristics, VS uses the following formula to express the microseismic released energy at any point P in space and time,

$$E_p = r(P) - r_{\min} = \left(\frac{\frac{1}{M} \sum_{j=1}^L \left(\sum_{i=1}^M x_{ij} \right)^2}{\sum_{j=1}^L \sum_{i=1}^M x_{ij}^2} \right) - r_{\min} < S/N = \frac{\sum_{j=1}^L \sum_{i=1}^M s_{ij}^2}{\sum_{j=1}^L \sum_{i=1}^M n_{ij}^2} \quad (2)$$

The right part of equation (2) defines S/N (Robinson & Treitel, 2000), which first squares the useful signal sample point s_{ij} and noise sample point n_{ij} for a wave vector, then sums the M stations and L sample points in a time window. The middle part of equation (2) defines the correlation coefficient among

the station station records (Cheng, 2003); It uses a certain wave vector from all M observation station records, aligns it with a point P in space, and extracts the correlation coefficients r , $0 \leq r \leq 1$ by DMS. $r_{\min}$ is the minimum value in a spacetime with very little useful signal; $r(P) - r_{\min}$ means E_p starts at 0.

In the early days, DMS was mostly used for seismic exploration in energy field. VS modified the original Samblance scalar superposition (Sheriff R. 1991) into a wave vector stacking, which consists of direct P waves from the source radiation, and two independently propagated components of S wave: SH and SV (Aki & Richards, 1980; Fu et al., 1980; Bullen & Bolt, 1985; Zhou & Xu, 2018) (Figure 3). For most far-field cases, VS often uses the S waves with large amplitude, slow attenuation, and long-propagation.

In equation (2), $x_{ij} = s_{ij} + n_{ij}$, the useful microseismic signal s_{ij} is usually submerged within the background noise n_{ij} . It is impossible to strictly separate s_{ij} from n_{ij} . However, if the arrival initial polarity ($\pm$) of s_{ij} at each station is unchanged and distributed according to the focal mechanism of tectonic earthquakes (Liang & Wang, 2026), then based on a known velocity model, we first calculate the time difference for each station receiving a certain initial motion and aligns the staggered shift (i.e. migration) for a point P in space, which is equivalent to moving the receiving points of each station to a reference point. We can then stack the x_{ij} containing a certain wave vector s_{ij} within a time period. This superposition will reduce noise and enhance the microseismic signal.

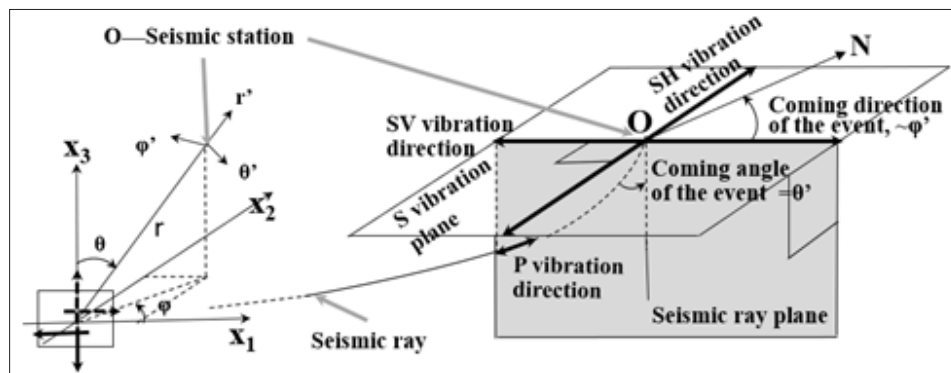


Figure 3 Schematic diagram of the shear dislocation focal mechanism. The small square at the origin of the X coordinate system in the lower left part means the fault dislocation surface, and the force couple in the horizontal direction (in the X1-X3 plane) acts on both sides of it. The other force couple is orthogonal to the horizontal one. The equivalent spherical coordinate system, $r\theta\phi$, is usually used to describe far-field displacement solutions. Compared with the $r\theta\phi$ system, the $r'\theta'\phi'$ system can be set up to express the specific P, SV, and SH vibration directions according to the different receiving points and propagation processes.

See text and Liang & Wang (2026) also.

E_p is also the lower limit of S/N . If it can be determined, and the actual S/N is greater than it, the reliability of microseismic monitoring at this point or even in an area during a certain period can be determined. According to statistics from thousands of fracturing stages in VS applications, the minimum S/N for high microseismic energy released near fracturing perforation is $\sim 1\%$, meaning that in VS applications, $E_p \geq 1\%$ can be considered the threshold for possible microseism in a given time and space. Except for extremely rare cases such as strong microseism induced by mining goafs ($M \geq -1.5$, possibly

$S/N \geq 1$), the S/N found in VS applications is generally less than 10%.

VS uses a shear focal mechanism (Figure 3) to guide data stacking. That is, for a certain period, any specified station record contains microseismic initial arrival as a reference, and all possible large-scale combinations with varied possible initial arrivals are performed on all other station records, observing different E_p combinations and selecting the one that most likely contains the highest microseismic released energy

(i.e., the best correlation coefficient among the stations, also the best S/N). SH and SV waves, which have much larger amplitudes than P wave, are mainly used. For spatial points without microseismics, the correlation of random background record combinations from stations and networks is generally low.

Even if $E_p \geq 1\%$, the residual noise interference, by chance, cannot be completely ruled out, such as distant earthquakes or heavy machinery near the network contaminating most seismic stations, and even random noise may stack out some high value. These residual interferences need to be removed by using statistical concepts (see Section below). Regarding the essence of microseismic monitoring, probability and mathematical statistical concepts should be used in all processing and interpretation steps of VS (Chen et al., 2025).

Equation (2) also holds in $S/N > 1$, as well as when the hypocenter is an explosion or the natural collapse of a mine's goaf. That is, equation (2) can be used as the most general formula expressing the distribution of released energy. In fact, even the traditional location with circled point-and-dot is often interpolated as the distribution of released energy similar to E_p to better analyze seismicity. Additionally, equation (2) should only be applied after effective denoising (Liang et al., 2017), meaning the background noise records for DMS should be random or nearly random.

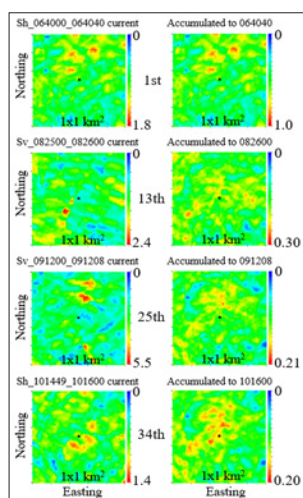


Figure 4 2D planar microseismic energy distribution during the period of real-time fracturing microseismic monitoring of coalbed methane well 7-41M, with a vertical depth of 2026m. This is the selection and integration after removing the suspicion of strong interference in the interpretation process (see conditions 7 & 8 in section below), which are called the important periods, and a total of 34 groups, each group is ~minute, were found. Only groups 1, 13, 25 and 34 are shown here. The left column is for the output of current time interval, and the right column is the accumulated result from all important intervals until this time; the final one is the SRV (Stimulated rock volume) of fracturing stage in space (see Figure 5a). 064000 means 06:40:00 (hour:minute:second), and black point is fracturing point.

Figure 4 shows typical output of VS fracturing monitoring for a stage of coalbed methane well that had undergone the overall data acquisition, processing, and interpretation steps. Denoising run throughout. Figure 5 shows microseismicity obtained after obtaining reliable E_p distributions and further interpretation and analysis. Liang (2025b) demonstrated that in stratified structural fracturing, almost all SRVs are confined to the reservoir. These all conform to the geological and mechanical observation patterns of passive earthquakes in the crust, and are consistent with the characteristics of microseismic and its monitoring.

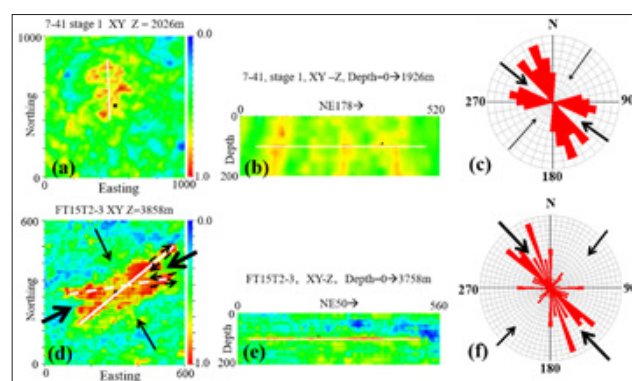


Figure 5. (a) and (b): SRV distribution of fracturing stage with high probability of high rupture energy expression in 2D for well 7-41. (a): Plane 2D, geese flight. The solid white line is the main direction of SRV. The black dot is projection of the perforation segment of the inclined well. (b): The profile of the solid white line in a 2D plane, the white line is the tendency. The vertical error of the upper and lower parts of the reservoir is large. (d) and (e): same as (a) and (b); However, the scale is 600mx600m in (d), and the conjugated fracture zone is represented by a virtual white line, and the vertical error above and below the reservoir is concentrated near the reservoir after a large number of accumulation of different time periods (Liang, 2025b). The dotted black arrow pairs indicate the dislocation direction of the crack zones. (c) and (f): the statistical rose plot of the main strike of the fault zone with high rupture energy distribution in each fracturing stage of the large shale gas horizontal well and the coal mine roof before mining, respectively; The latter is still able to identify X-shaped crack bands due to the presence of numerous laneways. In (c), (d), and (f), the thick and thin black arrow pairs represent the possible orientations of maximum and minimum principal stresses, respectively.

Necessary conditions to ensure reliable monitoring with high probability

It is difficult to give sufficient conditions to ensure the reliability of microseismic monitoring. However, based on the characteristics of microseismic monitoring, forward and inverted simulations, and a large number of experiments, many necessary conditions can be proposed to ensure reliable monitoring with high probability (Liang et al., 2023; Liang, 2025a; Liang & Wang, 2026).

The indispensable conditions for the reliability of far-field microseismic monitoring in identification and inspection in VS applications include:

1. We should use geophones with a lower natural frequency suitable for monitoring microseismics, such as $\sim 5\text{Hz}$. It has a spiral shell that screws into the ground to maintain a high coupling to the earth.
2. Each monitoring station of the seismic network should be at a quantitatively determined quiet location, and the discrete horizontal distribution covers the monitoring area in at least 2D.
3. DMS must take into account shear rupture characteristics. Generally, P wave with much smaller amplitudes is rarely used (e.g. only at shallower areas), and S waves, namely SV and SH, that can carry much more energy to reach farther places, are generally used.
4. We should use a statistically significant minimum number of stations, $N_{\min} (\geq 10 \pm 2)$. The seismic network should contain $\geq 2 \times N_{\min}$ of microseismic stations.
5. Effective denoising, especially for teleseisms and ground machines, must be performed to make background noise recordings random or near-random.
6. The lower limit of S/N (or the energy released, or the correlation between stations) output by DMS is $\geq 1\%$, which is the threshold for the possible existence of microseismic (statistical results).
7. Characteristic parameters with a quantitative range are studied and used to remove some E_p with remnant noise-coherent interference, and obtain those $E_p(t)$ or SRV(t) in time released by microseismicity.
8. By accumulating all SRV(t), the final spatial distribution of SRV in the target domain is defined and judged in terms of probability and statistical significance.

The research and development of VS process show that microseismic and its monitoring characteristics determine that the conditions required for such monitoring are fine and harsh. For example, conditions 7 and 8 are based on repeated comparisons of DMS output and possible noise interference, and finally in recent years confirm that denoising must continue until the final interpretation stage. In other words, due to the extremely small feature of microseismic and the fact that even random noise may occasionally accumulate high values, we must eliminate any period suspected of noise interference (Chen et al., 2025) to ensure a high probability of successful application.

The above conditions are confirmed on the basis of seismology, including seismometry, and a large number of experiments and applications, some are statistical, some are strict but can be satisfied, and some are in accordance with the monitoring principle to try to satisfy the requirements of better S/N. These conditions can be further quantitatively refined to specific values. Accordingly, a quality inspection system for data collection, observation network, data processing and interpretation has been established. These, coupled with the improvement of BPM, mine safety warning, and small

microseismic monitoring before large earthquakes, etc. constitute microseismology, including microseismometry.

Discussion on technical route for monitoring seismic precursor of destructive earthquakes

Monitoring small and micro earthquakes as the precursor of destructive earthquakes requires two foundations:

1. Understanding the nature, principles, all the steps of data acquisition, processing, and interpretation in the microseismic monitoring, as described in the last Chapter;
2. The current status of existing observation capabilities for natural earthquake monitoring, the development and determination of seismicity observation capabilities for small and micro earthquakes before destructive earthquakes, such as network geometry, network density, geophone and recorder parameters, velocity model geometry and distribution, discrimination and removal of various noises, comparison with other precursor types, and so on.

The technical route for monitoring seismic precursor to large earthquakes must ultimately be implemented to achieve acceptable observation accuracy and a complete distribution of released energy by small and micro earthquakes above a certain magnitude within the target area, paving the way for obtaining the patterns of small and micro seismicity before destructive earthquakes. This requires natural seismologists and/or microseismologists, including seismometry specialist, to develop the technical route for seismic precursor monitoring based on familiarity with the above two points. Here, recommendations are provided only on several issues related to the principles and necessary conditions of microseismic monitoring (the last Chapter).

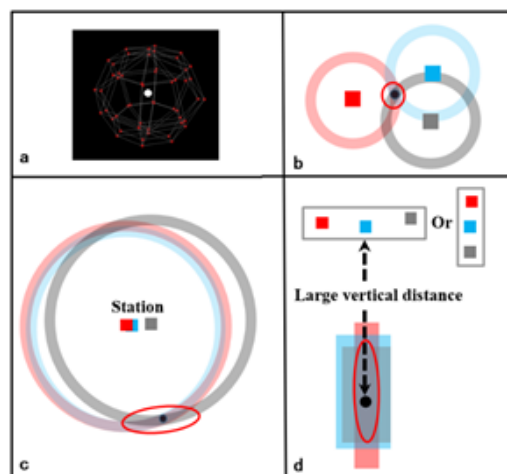


Figure 6 Schematic of seismic network geometry and spatial relocation errors. a: An ideal network where observation points (red dots) stagger around the target (white sphere), approaching the target, recording a higher S/N with low location error. However, this is difficult to achieve in practice. b: Observation stations within the network have low error and uniform bidirectional errors. Red, blue, and gray solid squares represent seismic stations; From the known seismic wave

arrival records and the known velocity model, the spherical radius can be obtained; The intersection of several spheres is the epicenter (black circle); The spherical surface (here, the plane circle) has a certain width indicating a certain error; the superimposed shadow of the three circles at the intersection point indicates the localization location error, enclosed by a red ellipse. c: Same as figure b, but the target is in a certain horizontal direction outside the network; the overlay display error is uneven and large. d: Same as b, but the target is very vertically far from the stations, and the actual vertical error of the overlay is large.

Improvement of the observation network

The network observation capability is the primary issue. Figure 6 illustrates the relationship between geometric distribution of network geometry and hypocenter location errors. We note that the hypocenter location accuracy in USGS (2026) is one decimal place after decimal point, meaning the maximum error is within 100 meters. We hope that our microseismic monitoring accuracy should be at least within 100 meters. Only then can future monitoring analyze the small and micro seismicity, and the pregnant volume of large earthquakes. Even considering only shallower earthquakes that pose a significant threat to humans (such as within tens of or even 20 km of the crust), except for the horizontal density and distribution of networks that can be continuously improved through research and observation, current various seismic networks lack 3D geophone distribution at least several kilometers deep.

For the development of seismic sensors in ultra-deep wells, reaching depths of several kilometers or even more than ten kilometers (SEG, 2025), the energy field has mature experience and could be applied or combined with natural earthquake monitoring to approach the ideal seismic network (Figure 6a). This may greatly reduces the vertical depth location error for monitoring small and micro earthquakes.

Seismic wave velocity model

Compared to the traditional location above small earthquakes, say $M \geq 1$, one of the necessary conditions for monitoring microseismics is a finer velocity structure of seismic wave.

Besides the better elimination of vertical errors and increased network density described in the previous section, high location precision can be achieved by using much finer velocity models than before. In the energy field, because the monitoring area is small, people can obtain finer velocity data through drilling and/or artificial seismic exploration. This experience can be used for seismic precursor monitoring, such as well-developed logging technology exceeding 10,000 meters, including built-in sensors (SEG, 2025). On the other hand, waiting for enough natural seismic events to invert for large depths and wide-area velocity structures is unrealistic. High-speed trains are known inexpensive sources with wide and dense distribution, as seen in Higuere et al. (2026). Exploring and confirming the impact of velocity distribution, velocity model grid size, and surface curvature on accuracy is one of the tasks for monitoring seismic precursors.

Known research and development of VS in energy field and exploration of precursor monitoring

The microseismic monitoring purpose of VS is to obtain:

1. The spatiotemporal patterns of microseismicity within the target area;
2. The correlation between these patterns and production and living events; and
3. The known or possible local rock physical, chemical, and geological structural characteristics corresponding to these patterns and associations.

In the oil and gas energy field, fracturing, water/gas injection production, mine safety warnings, and other methods are often evaluated through effective microseismic monitoring. Through forward and reverse simulations and extensive practical experiments, the principles of VS and the guaranteed conditions for the successful application of VS have been established, as described in the last Chapter.

Table 2 lists the qualitative and/or quantitative results VS has encountered and resolved to date to achieve clear results. As a reference for the technical route of the precursor monitoring, the third column, "Precursor monitoring expectations", includes some possible expectations for the seismic precursor monitoring.

Table 2: Known current results of VS. SRV is the stimulated rock volume, or the monitoring target domain.

Content		VS Known results	Precursor monitoring expectations
Seismograph and geophone	Max. distance from hypocenter (km).	For $M \sim 3$, $\sim 4-5$ can be monitored;	Determined by experiment
	Distance between seismic stations (m).	≥ 40 (2 times of max. GPS error, and usually ~ 100)	$> \sim \text{km}$
	Vertical density	Determined by experiment	Determined by experiment
	Natural Frequency Lower Limit (Hz)	≈ 5	Determined by the min. frequency of lower M limit of microseismics
	Min. number of stations for DMS	$> \sim 10$, and the total number of stations in a network commonly $> 2 \times 10$	Determined by experiment
	Degree of consistency with the ground	The spiral shape allows it to screw into the soil, or Pit-digging cement pouring	If established long-term, Pit-digging cement pouring
	sample interval (ms)	≤ 2	Determined by the min. M, for example, 4-10
Denoising	Random or near random record	Known noise sources, such as ground machinery and remote earthquakes	Determined by experiment
	Removing noise suspicion in SRV(t)	Residual hidden noise, pollutes a lot of stations	Determined by experiment
General monitoring capabilities	Horizontal scale of target domains	$\approx 1 \times 1 \text{ km}^2$	$\sim 100 \times 100 \text{ km}^2$
	S/N threshold of microseismic existing	$> \sim 1\%$	Determined by experiment
	Location error (m)	Horizontal $\sim 10-20$, vertical similar in shallower layer, or else ≥ 2 -time larger than horizontal	$< \sim 100$
	Velocity model grid scale(m)	10-20	Determined by location error
	Real-time or near real-time lag time	About 4-8 minutes, depending on the number of stations in data stacking	Hour or day
Microseismicity	Equivalent magnitude of microseismics (M)	$\approx [-3, 0]$, general microseismic period: $\approx 0.1 \text{ s}$	Determined by experiment
	Intermittent with time and jumping in space	Intervals between seconds and tens of minutes of cumulatively repeat release; Before large fracture formed, the rapture points are highly flexibly happened	Inspection. The overall similarity should be observed
	Connection with the main event	It is closely related to fracturing, pumped water/gas injection, and nearby active faults	Inspection. The overall similarity should be observed
	Relationship with tectonic focal mechanisms	Clearly related	Inspection. The overall similarity should be observed

The overall purpose and specific engineering parameters of precursor monitoring are similar to VS but may differ significantly. For example, studying the spatiotemporal distribution of energy released from small and micro earthquakes, including the final real-time display; striving to achieve the lower limit of microseismic magnitude reaching $M \approx 0$, -1, or even lower (with a wide range of energy values); The distance from the epicenter to the seismic station can reach tens or even hundreds of kilometers; It is necessary to develop long-term, networked, ultra-deep, anti-high-temperature, and anti-high-pressure sensor strings at depths of several thousand to ten thousand meters to greatly improve vertical location accuracy; Noise interference discrimination may differ greatly from what is possible in the energy field, requiring careful investigation and verification. It can be mutually validated with other precursor monitoring methods, such as thermal release energy (Zhong, 2025), and each real-time process also has its own particularities; and so on.

Observing microseismics is more difficult than observing small earthquakes, stealth spacecraft and navigation vehicles, which is determined by the essence of microseismic monitoring. Except for their tiny, because the target and detector are separated by solid, misdiagnosis is highly likely, so reliability must be ensured with a high probability.

Finally, please focus our research and development on basic mathematics, geology, probability and statistics, signal processing principles, logic analysis, and the development of ultra-deep sensors, rather than fantasizing that AI and the internet, which often follow “mainstream” or “authority”, can solve the problems embodied in microseismic monitoring. For example, 3-component recordings already include various complex spatial deformations, including shear or rotational movements, which need to be correctly extracted as mentioned earlier, rather than adding additional rotational components to geophones (Li, 2026).

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