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Miloš Briestenský [ID][a], Stanka Šebela [ID][b], Petar Stefanov [ID][c] and Uroš Novak [ID][b,d]

[a]Department of Engineering Geology, Institute of Rock Structure and Mechanics, Czech Academy of Sciences, Prague, Czech Republic; [b]Karst Research Institute, ZRC SAZU, Postojna, Slovenia; [c]National Institute of Geophysics, Geodesy, and Geography, Bulgarian Academy of Sciences, Sofia, Bulgaria; [d]Graduate School, University of Nova Gorica, Nova Gorica, Slovenia

ABSTRACT

Long-term extensometric monitoring across Central Europe reveals a pronounced tectonic hiatus between 2015 and 2019. Using high-resolution data from the EU TecNet network of optical – mechanical TM-71 and TM-72 extensometers installed along major fault zones, we document a widespread attenuation or cessation of fault-related micro-displacements that coincided with a marked decrease in regional seismicity. The hiatus was most prominent in the Western Carpathians, where fault movements were arrested at nearly half of the monitored sites, preferentially affecting major NNE – SSW-striking fault systems that represent the principal structural grain of the region. Despite the overall quiescence, extensional fault opening developed at several sites since 2015, followed by significant vertical subsidence recorded across much of the Western Carpathians in 2018. Similar patterns of tectonic quiescence were observed in the Bohemian Massif, Slovenia, and Bulgaria, indicating that the phenomenon extended over large parts of Central and Southeastern Europe. The temporal evolution of deformation and its correspondence with seismicity suggest that the 2015–2019 hiatus reflects a transient regional-scale reorganisation of the stress field, likely linked to variations in plate-boundary forcing, rather than a response to climatic effects or local processes.

1. Introduction

Long-term monitoring aimed at detecting active tectonic processes requires sustained observational efforts and a sophisticated network of geodetic instruments. Over the past two decades, an extensive system has been developed across Central Europe, culminating in the deployment of nearly two hundred extensometric gauges along major fault zones. This network, known as EU TecNet, formed part of the EPOS (European Plate Observing System) infrastructure. Its primary objective is to investigate contemporary upper crustal deformation, enable cross-regional comparisons, and identify synchronous tectonic activity across the European plate (Briestenský, 2018; Briestenský et al., 2015). For this purpose, TM-71 and TM-72-type extensometers have been employed due to their high sensitivity and long-term stability. Using the TM-71 in geodynamics is analogous to employing a watchmaker's magnifying loupe: while large tectonic plates (continents) can be observed with coarse-scale tools such as GPS, the investigation of minute yet critical displacements within fractures (faults) requires a highly sensitive instrument capable of amplifying imperceptible micrometric motions into observable and quantifiable patterns, thereby revealing even the slowest tectonic processes.

In this study, the phenomenon referred to as a tectonic hiatus corresponds to what is more commonly termed seismic quiescence (Joswig, 2001) or a seismic gap in seismology (Mogi, 1979) – a seismic anomaly that frequently precedes large events (Wyss & Habermann, 1988). Documented examples include precursory quiescence before the Palermo earthquake (M 5.8; DiGiovambattista & Tyupkin, 2004); in Central Apennines in 1997 (M 5.6; Console et al., 2000); major earthquakes in Kamchatka and the Caucasus region (M ≥ 7 and M 6.9; Sobolev & Tyupkin, 1997, 1999); the 1999 Umbria – Marche earthquake in Italy (M 5.8; DiGiovambattista & Tyupkin, 2000); the Kobe (M 7.2) and Nemuro Peninsula (M 6.8) earthquakes in Japan (Huang & Sobolev, 2001; Huang, Sobolev, & Nagao, 2001); the Urakawa-Oki (M 7.1; Taylor et al., 1991); in Wenchuan in China (M 8.0; Huang, 2008) and the Izmit earthquake (Mw 7.4) in Turkey (Huang et al., 2002). For

example, Gentili (2010) demonstrated that seismic quiescence was detected prior to at least 66% of earthquakes with magnitude ≥ 4, and before all earthquakes with magnitude greater than 5. Similarly, Rudolf-Navaro et al. (2010) confirmed that earthquakes with magnitudes greater than 7.6 in Mexico during the period 1975–2009 were preceded by seismic quiescence. In contrast to classical seismic quiescence, the tectonic hiatus documented here is defined by the cessation or strong attenuation of fault-related microdisplacements measured directly on faults. Our recent study presents data associated with a tectonic hiatus – a break in fault-related deformation – that commenced in early 2015 and ended in 2019. This period was marked by a notable reduction in seismic activity and fault activity, particularly in the Western Carpathians, with similar trends observed across broader parts of Central and Eastern Europe. The aim of this study is to document, quantify and interpret a multi-year tectonic hiatus observed between 2015 and 2019 across Central Europe, based on high-resolution extensometric monitoring, and to evaluate its relation to regional seismicity and plate-scale geodynamic processes.

2. Methodology

The EU TecNet network comprises specially designed optical-mechanical extensometers capable of recording three-dimensional microdeformations and block rotations in two orthogonal planes. Several monitoring sites within the network have been operational for decades without interruption or instrumentation failure. In 2023, the 50th anniversary of continuous monitoring was celebrated at the Parohy site in the High Fatra Mountains, Western Carpathians (Briestenský et al., 2011), demonstrating the long-term durability and robustness of the TM-71 extensometer, even under harsh climatic conditions.

The TM-71 and the newly developed TM-72 optical – mechanical extensometers are designed to measure relative three-dimensional displacements and angular rotations between two rock blocks separated by a fault or fracture (Klimeš et al., 2012; Košťák, 1969; Marti et al., 2013). The gauge is mounted in the rock walls using thick-walled steel brackets (Figure 1(a)) with anti-corrosion treatment. The bracket diameter is 40 mm with a wall thickness of 5 mm. It is then cemented into a 400 mm-deep borehole in the rock. The device itself is made of stainless steel or an aluminium alloy, both of which resist corrosion, especially in underground environments. The device operates on the moiré phenomenon of optical interference (Nishijima & Oster, 1964; Oster & Nishijima, 1963). Moiré patterns (Figure 1(c)) arise when two identical overlapping periodic structures (Figure 1(c)) undergo slight relative displacement, producing a system of characteristic macroscopic interference fringes (Košťák & Popp, 1966; Marti et al., 2013). These moiré patterns are converted to metric values by counting fringes, determining the axis of symmetry, and solving the
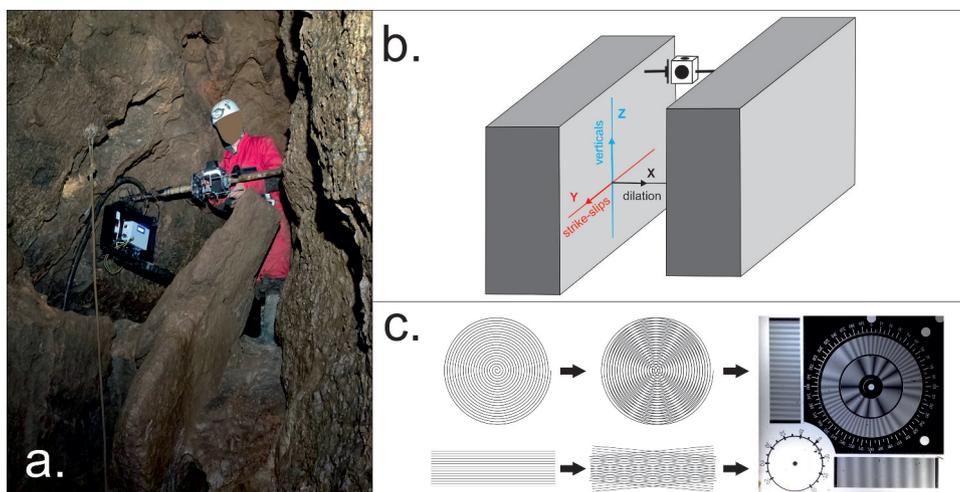

Figure 1. Extensometer of the TM-71 type: (a) example installation of a TM-71 extensometer in the Krásnohorská Cave (photo by: T. Fussgänger), with two brackets anchored into the rock walls and the instrument mounted between them. The gauge is equipped with a data logger for automatic data collection; (b) schematic representation of the displacement system measured by the TM-71 instrument; (c) two overlapping concentric spirals and sets of parallel lines create the moiré effect used in the TM-71 gauge.

corresponding equations (Košťák & Popp, 1966). The distance between the glass plates is then derived from the fringe count and displacement direction along the principal symmetry axis.

The TM-71's unique design allows it to record lateral and shear displacements as well as block rotations, providing a key methodological advantage: all relative movements between blocks can be measured with high precision (~0.0125 mm). Relative angular deviations across a discontinuity can be resolved to better than 3.2×10^{-4} rad (≈0.018°) (Košťák et al., 2011).

The advantages and limitations of the extensometer have been well established through long-term installations in the Czech Republic, Germany, Slovenia, Slovakia, Bulgaria, Italy, U.S.A., Greece, Canaries, Switzerland, Peru, Austria, Poland, and the Arctic (e.g. Blahůt et al., 2020; Briestenský et al., 2015; Gosar et al., 2009; Hoppe et al., 2015; Kontny et al., 2005; Šebela et al., 2009; Stemberk et al., 2010); methodology and its practical applications have been extensively documented in recent studies (Briestenský, 2018, 2021; Klimeš et al., 2012; Marti et al., 2013; Rowberry et al., 2016; Stemberk et al., 2019; Vavra et al., 2024).

Seasonal and climatic variations can be detected and separated from the recorded movements (Blahůt et al., 2020; Briestenský et al., 2010), and thermal expansion of the TM-71 is analytically corrected, allowing precise monitoring of gravitational or tectonic processes. Its suitability for geodynamic studies is supported by comparisons with horizontal tiltmeters, geodetic measurements, and groundwater-level observations (Košťák et al., 2011; Vavra et al., 2024), or with significant earthquakes (e.g. Briestenský et al., 2007; Košťák et al., 2007; Stemberk et al., 2019). Fault displacements can be visualised in Cartesian (x, y, z) coordinates (Figure 1(b)) or in the s, h, p system, adapted to fault geometry. These components are then used to calculate the total slip vector, which consists of the components A_s (trend) and φ_s (plunge), and is complemented by the sense of slip. Afterwards, paleostress methods can be applied to datasets of kinematic characteristics on the studied faults to determine the orientation of the stress field (Briestenský, 2018, 2021; Stecz et al., 2025; Stemberk et al., 2019).

Moreover, subsurface installation of the instruments, often in caves, tunnels, or mines, significantly reduces the impact of seasonal temperature fluctuations, which commonly affect surface measurements (Briestenský et al., 2010). Although the TM-71 was originally designed for manual data acquisition, early attempts at automation were initiated at the Parohy site. Fully digital and more reliable versions of the instrument emerged in the 21st century and continue to be developed and improved.

3. Tectonic hiatus in the western Carpathians – results

According to seismic data provided by the European-Mediterranean Seismological Centre (https://emsc-csem.org/), a significant decrease in earthquake occurrence was observed across Central Europe between 2014 and 2019 (Figure 2). For this analysis, we focused on a region encompassing Czechia, Slovakia, Hungary, Slovenia, and Austria. The decline in seismic activity began in the second half of 2014 and was particularly notable in the Western Carpathians at extensometric stations.

Extensometric measurements from the Western Carpathians region revealed trends highly consistent with the seismological data (Figure 2). Fault activity either ceased or markedly slowed at many monitoring stations between late 2014 and early 2015 (Figures 3–5). In Slovakia alone, this tectonic pause was documented across 15 fault structures out of 29 observatory sites (Table 1). The fact that this interval was protracted and did not involve an abrupt cessation of fault activity across all sites indicates that the hiatus does not represent, in the sense of 'earthquake quiescence' (as discussed in the Introduction), a seismic anomaly that commonly precedes major events. On the contrary, we infer that the primary driver of tectonic activity in the Western Carpathians was attenuated, such as a cessation of the northeastward motion of the Adriatic microplate or a brief interruption of the collision between the African and Eurasian plates. Interestingly, a spatial pattern was evident. The hiatus was predominantly associated with faults exhibiting a general NNE – SSE striking (Figure 3(a)), which corresponds to the principal structural grain of major fault systems traversing the Western Carpathians. Among these, the Mur – Mürz – Leitha fault system is particularly significant, representing one of the most seismically active zones in the Eastern Alps and the Western Carpathians. This fault system extends through the Little Carpathians (in the western part of the Western Carpathians reaches the city of Žilina, where it is sometimes referred to as the Mur – Mürz–Žilina Fault (Jarosiński, 1998). This zone also follows the course of the deep contact between
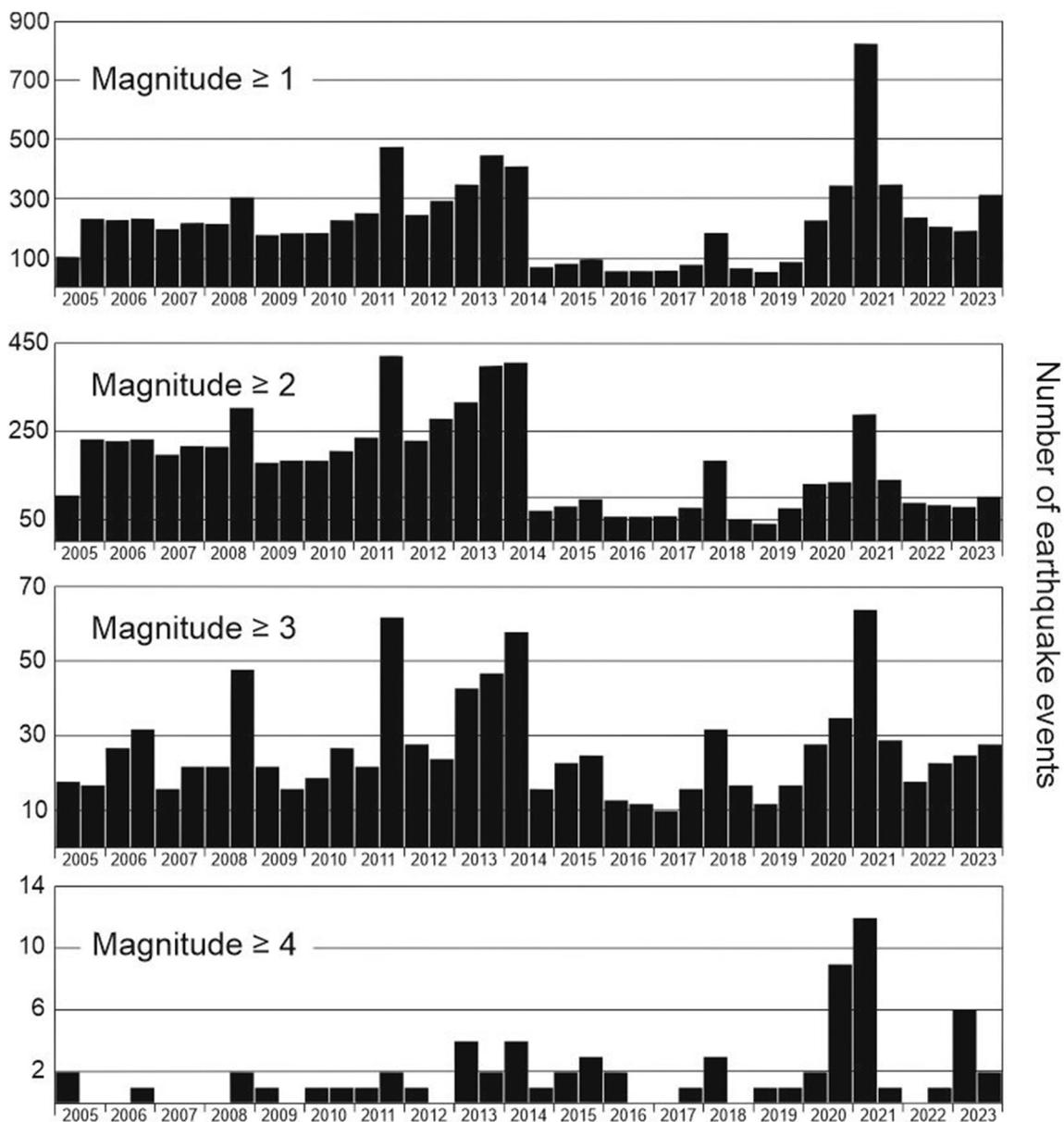
Figure 2. Seismic activity in Central Europe (2005–2023). The graph displays half-yearly totals of earthquake events recorded between 2005 and 2023 within a defined region bounded by 45.27°–51.34°N and 11.47°–22.89°E, which includes Slovakia, Czechia, Hungary, and Slovenia. Seismic data were sourced from the European-Mediterranean Seismological Centre (https://www.emsc-csem.org). A noticeable decline in seismic activity is observed starting in the second half of 2014.

the Bohemian Massif and the Western Carpathians (Šamajová et al., 2019) and allows the movement of the Carpatho-Pannonian plate advancing towards the north-northeast relative to the European plate (Bada et al., 2007; Jarosiński, 1998). In western Slovakia (the western part of the Western Carpathians), a network of 17 extensometric observatories equipped with TM-71 instruments has been established within this zone, only two of which are located at the surface. A second major tectonic line of this orientation that extends into Slovakia – and thus into the Western Carpathians – is the Balaton Line, which represents the eastward continuation of the Periadriatic Lineament (Haas et al., 2000) and, within the Western Carpathians, continues towards Rožňava as the Darnó Fault Zone (Petrik et al., 2016). The recent kinematic mechanism of the Darnó Fault Zone is considered to be sinistral strike-slip (Fodor et al., 2005). The same mechanism is recognised for the Mur – Mürz–Žilina Fault Zone mentioned above. The Darnó faults are monitored at our observatories in the Krásnohorská Cave, the Skalistý Potok Cave, and the Drienovecká Cave (Briestenský, 2018). Our
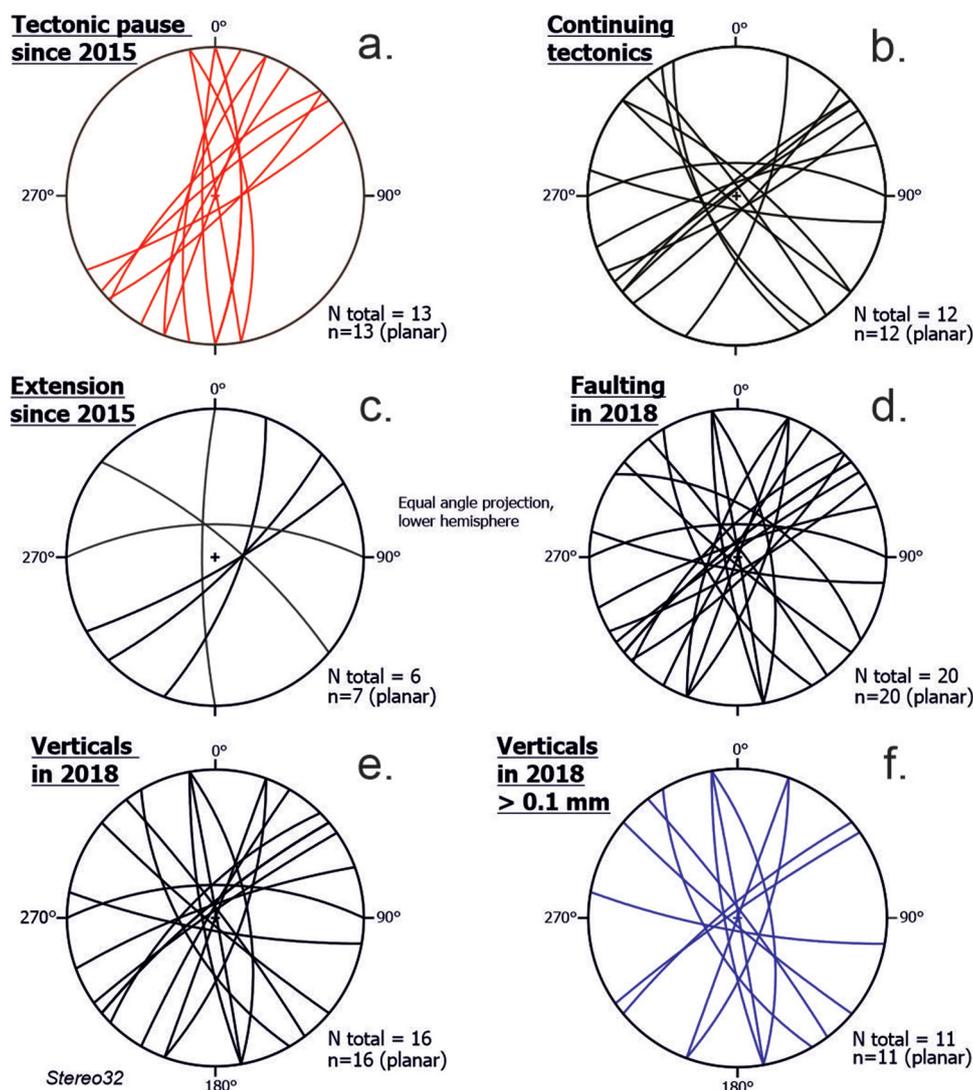
Figure 3. Classification of fault activity in Slovakia during the 2015–2019 period: (a) faults exhibiting tectonic hiatus; (b) faults with continued activity during 2015–2018; (c) faults showing extensional deformation with a significant opening component observed in 2015–2017; (d) faults active specifically during 2018; (e) vertical displacements recorded in 2018; (f) significant vertical block movements (exceeding 0.1 mm) documented across monitored faults in 2018.

results therefore demonstrate that fault movements along these major NNE – SSE-striking structures (Figure 3(a)) were effectively arrested for several years during the 2015–2019 interval.

However, faulting activity did not cease uniformly across the region. At several sites, deformation processes persisted (Figure 3(b)). On the other hand, six observatories recorded notable extensional movements (fault opening) beginning in 2015 (Figures 3(c), 6, Table 1). Furthermore, a phase of significant subsidence along faults was observed at 16 sites across the Western Carpathians in 2018 (Figures 3(e), 7, Table 1). Of these, 11 sites exhibited subsidence exceeding 0.1 mm (Figures 3(f), Figure 4, Figure 7), which again leads us to infer that the compressional stress from the southeast/ south was terminated after 2014, subsequently allowing relaxation (fault opening) and, consequently, the block subsidence in 2018. Figure 8 presents a simplified block model summarising the kinematic evolution of fault blocks in the Western Carpathians during the 2015–2019 tectonic hiatus inferred from the extensometric observations.
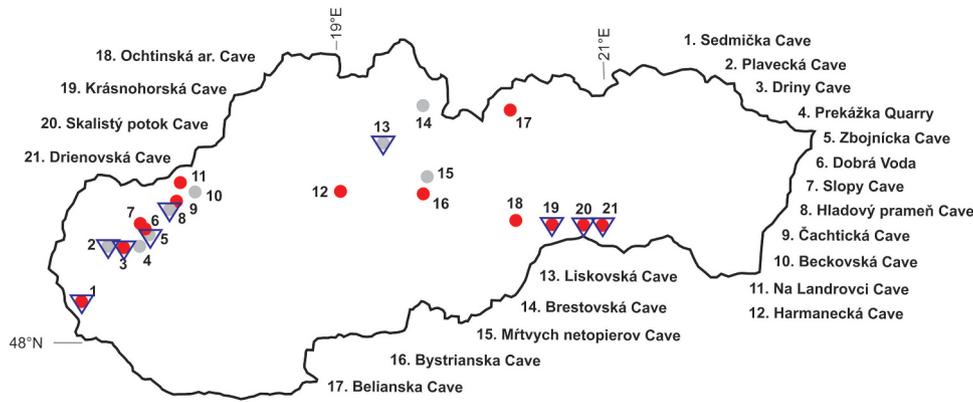
Figure 4. Extensometric observatories within the Slovak EU TecNet network. Red dots indicate sites where a tectonic hiatus was observed during 2015–2019, while blue triangles represent sites with vertical displacements exceeding 0.1 mm recorded in 2018. The map excludes observatories dedicated to monitoring slope deformations.

3.1. Summary of results for the period 2015–2019

Phase 1: Cessation of displacements along NNE – SSW-striking faults in 2014–2015 (observed at 45% of analysed sites);

Phase 2: Onset of notable extensional movements (fault opening) in 2015–2017 (observed at 21% of analysed sites);

Phase 3: Subsidence in 2018 (affecting 55% of analysed sites).

4. Discussion

Changes in climatic conditions may potentially influence near-surface measurements of fault displacements, particularly through variations in water content that affect frictional properties along fault planes. Indeed, the role of fluids in modulating fault strength is well established. In Central Europe, however, the past decade has not been characterised by a cessation of precipitation, but rather by changes in its temporal distribution, reflecting a period of climatic fluctuation rather than a unidirectional climatic trend.

Our results clearly demonstrate that fault movements were suppressed for nearly five years, and that this tectonic hiatus was highly selective in the Western Carpathians, predominantly affecting faults with a NNE – SSW strike (Figure 3). These structures represent some of the most seismically active fault systems in Central Europe, and their origin is closely linked to the northward displacement of Alpine units and regional uplift during the Late Cretaceous (Ratschbacher et al., 1991). The pronounced selectivity of the hiatus with respect to fault orientation, together with its multi-year duration, argues against a primary climatic control and instead supports a tectonic origin of the observed signal. This interpretation is consistent with earlier studies demonstrating that major changes in geodynamic activity are driven by tectonic processes rather than by slope instabilities or climatic fluctuations (Košťák et al., 2006).

Periods of tectonic quiescence preceding enhanced deformation phases, often referred to as tectonic or pressure pulses, have been reported previously. Stemberk et al. (2010) documented a phase of tectonic quiescence that preceded a tectonic pressure pulse, which subsequently initiated increased geodynamic activity across Central and Southern Europe. This episode was associated with compression along the Sudeten Marginal Fault Zone and culminated in two strong local earthquakes. We have similarly reported a tectonic pulse affecting large parts of Europe at the turn of 2012/2013 (Briestenský et al., 2015). Another pulse was observed at the turn of 2014/2015 and documented across Central Europe, extending from Svalbard to Greece (Briestenský, 2018). Importantly, this latter pulse directly preceded the tectonic hiatus of 2015–2019 discussed in the present study.
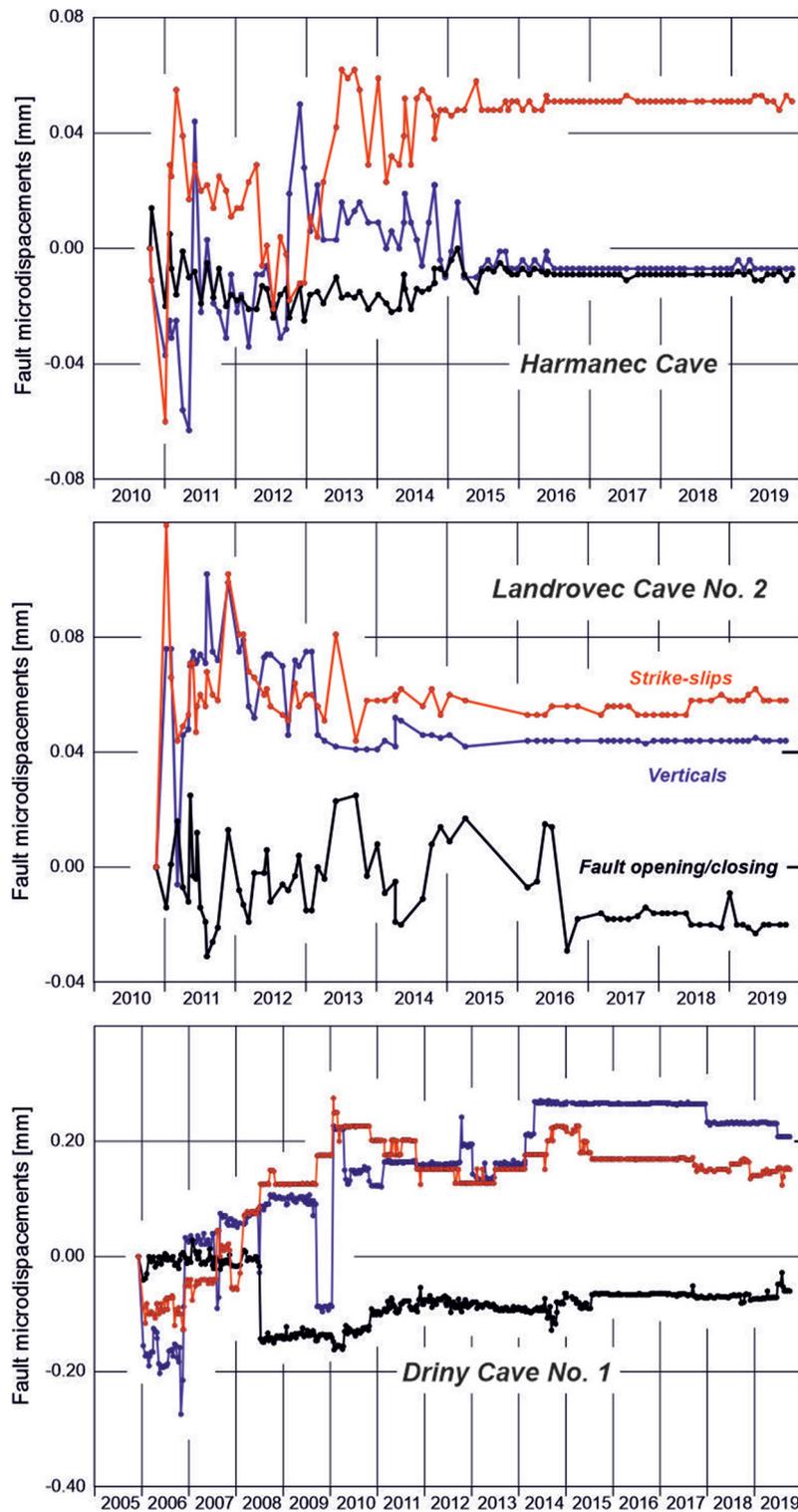
Figure 5. Tectonic hiatus observed during the short period of 2015–2019. The cumulative graphs depict fault activity recorded in three selected caves within the western Carpathians.

Analysis of the European earthquake catalogue (EMSC) suggests that the tectonic pulse at the turn of 2014/2015 May have been related to elevated seismic activity in Italy and the Balkan region during the second half of 2014, when 342 earthquakes with M ≥ 4, 22 events with M ≥ 5, and 3 events with M ≥ 6 were recorded. In contrast, seismic activity during the first half of 2015 decreased to 145 events with M ≥ 4, representing a reduction of approximately 57% relative to the preceding half-year. The geodynamic
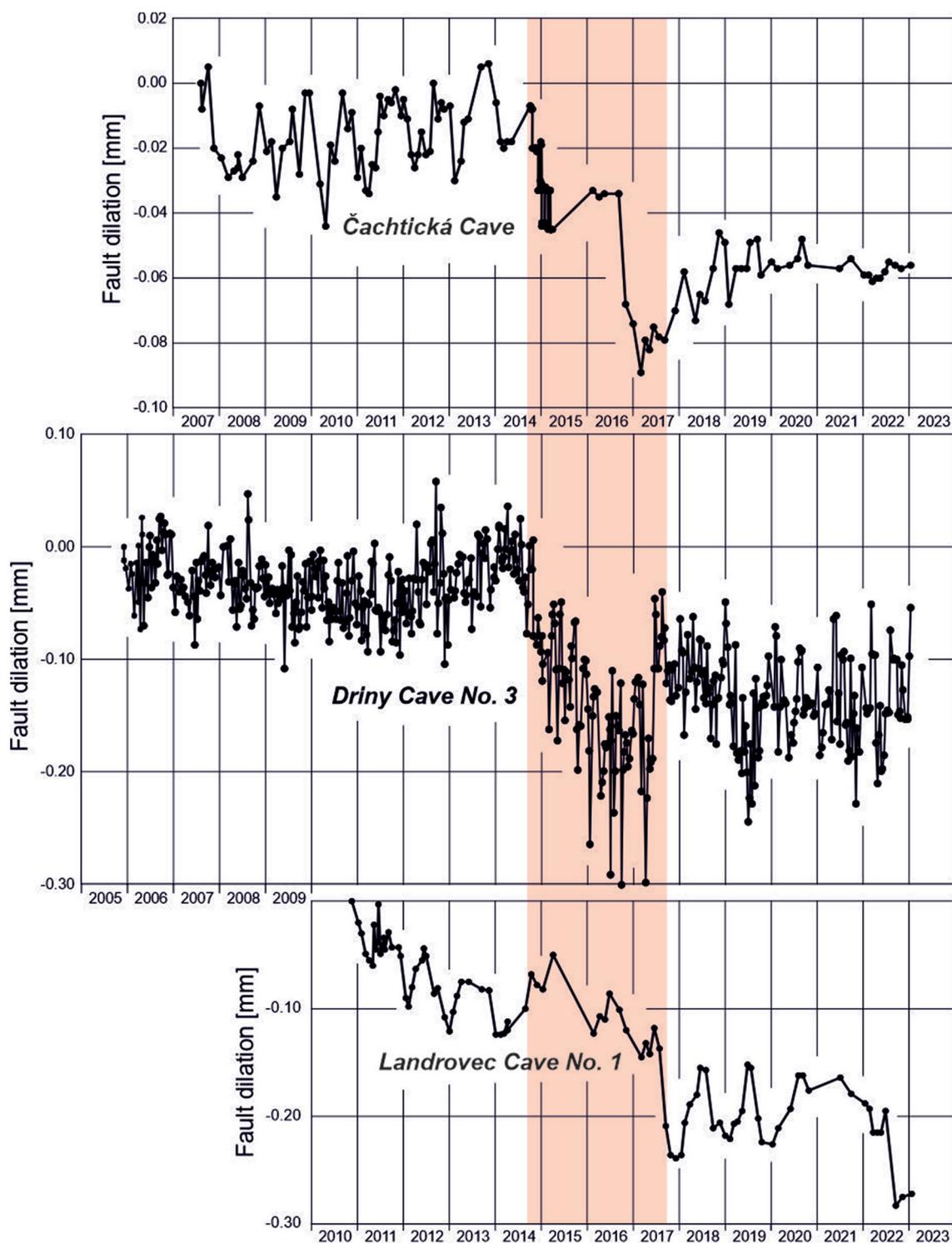
Figure 6. The tectonic hiatus was accompanied by extensional deformation, characterised by fault opening. This extension generally persisted from 2015 to 2017.

importance of the Balkan region is linked to the subduction of the African plate beneath the Aegean microplate. This system, known as the Hellenic Subduction System, accommodates oblique convergence at a rate of approximately 35 mm/yr between the Eurasian and African plates in the eastern Mediterranean (McClusky et al., 2000; Reilinger et al., 2006) and is considered the oldest actively subducting lithosphere on Earth (Granot, 2016).
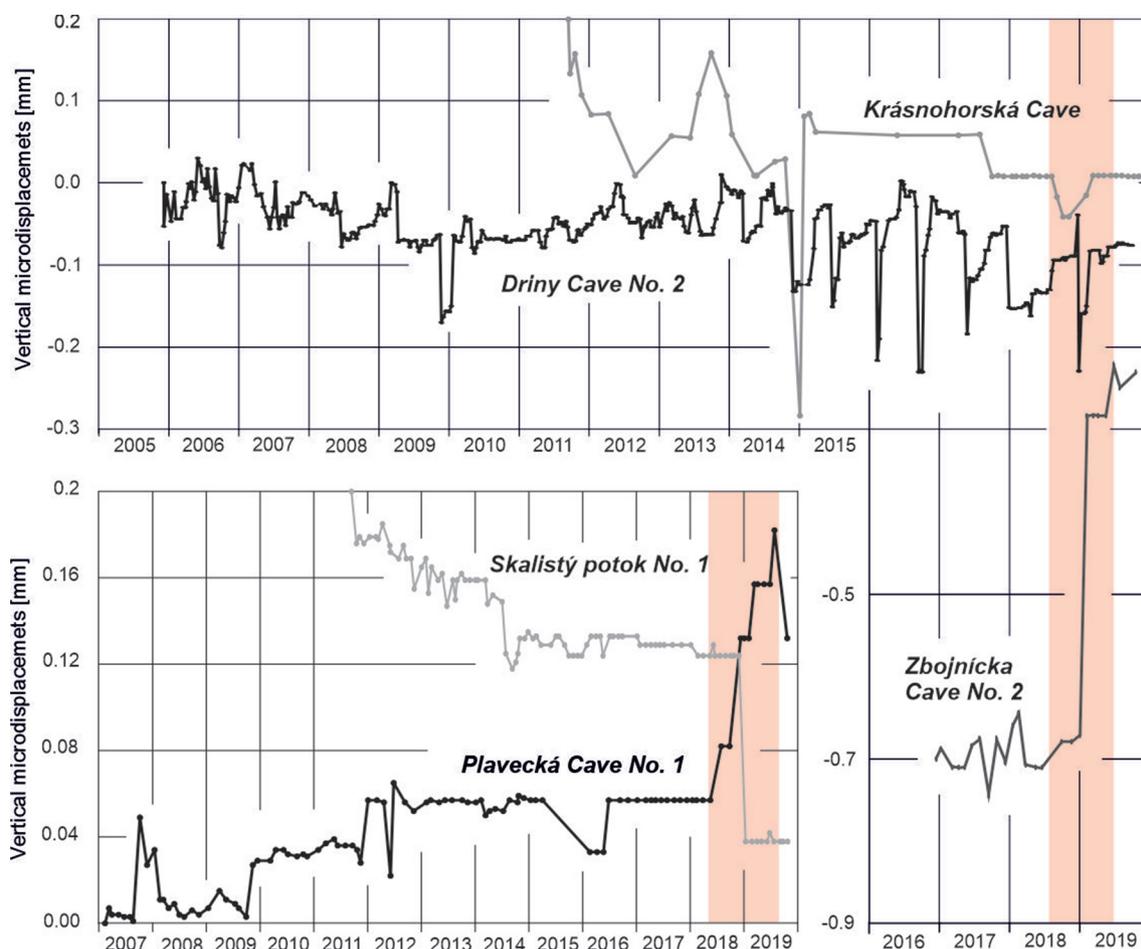
Figure 7. Vertical displacements observed in 2018 in five caves of the western Carpathians.

A comparison of earthquake frequencies with M ≥ 1 in Central Europe and Greece reveals a clear temporal correspondence (Figure 9). From 2005 to mid-2014, seismicity in both regions increased nearly linearly, followed by an abrupt decrease in the second half of 2014. It was during the culmination of this period that the largest fault displacements were recorded across the European plate (Briestenský, 2018). Concurrently, pronounced strike-slip movements were observed along the eastern margin of the Bohemian Massif, enabling the derivation of a NNW – SSE-oriented compressional stress component from extensometric data (Briestenský et al., 2021). The period characterised by pronounced strike-slip movements in this area lasted from late 2013 to mid-2015.Together, these observations support the interpretation that the tectonic hiatus of 2015–2019 represents a regional-scale reorganisation of the stress field rather than a response to short-term climatic variability.
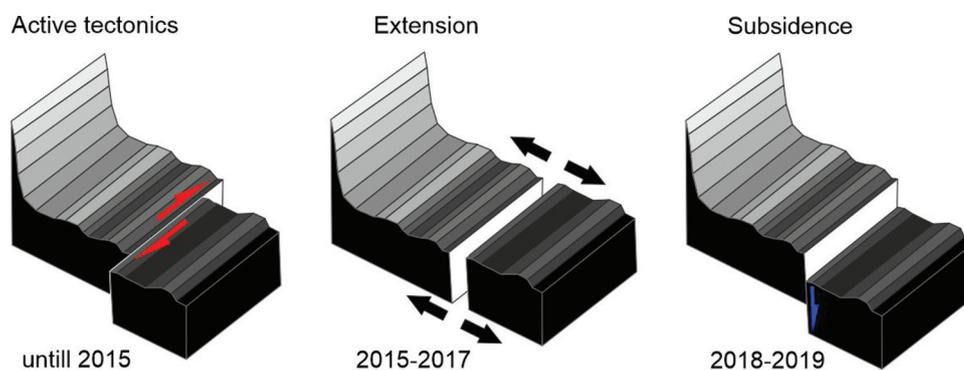
Apart from the Western Carpathians, the tectonic hiatus of 2015–2019 was also observed in other parts of Europe:

4.1. Bohemian Massif

In the Bohemian Massif, a significant cessation of fault movements was also documented, notably at the Bozkov and Zbrašov aragonite caves, which are located approximately 213 km apart. As illustrated in the graphs in Figure 10, this period of tectonic quiescence was subsequently followed by pronounced fault movements characterised by the activation of the strike-slip component, i.e. directional horizontal displacements that most directly reflect the regional horizontal stress regime. Earlier studies (Briestenský et al., 2021) reported an acceleration of fault movements preceding the onset of this quiescent interval, particularly in

Table 1. Classification of fault activity in Slovakia during the 2015–2019 period. Red cells indicate intervals of tectonic hiatus, whereas green cells denote periods of significant fault activity.

Site No.	Site Name	Fault dip direction° →dip°	Tectonic hiatus 2015-2019			Extension 2015-2017	Tectonic activity in 2018		
			dialation	strike-slip	veticals		dialation	strike-slip	veticals
1.	Beckovská Cave	320→80						green	green
2.	Belianska Cave	90→70	red	red	red			green	
3.	Brestovská Cave	320→86							green
4.	Bystrianská Cave	90→70	red	red	red			green	
5.	Čachtická Cave	270→80		red	red				green
6.	Drienovecká Cave	190→80				green	green		green
7.	Dobrá Voda (surface station)	136→76		red		green			
8.	Driny Cave 1	290→70	red	red	red	green			green
9.	Driny Cave 2	110→70				green			green
10.	Driny Cave 3	40→75				green			
11.	Harmanecká Cave	280→70	red	red	red				green
12.	Hladový prameň Cave 1	260→80					green		green
13.	Hladový prameň Cave 2	34→55					green		green
14.	Krásnohorská Cave	320→80	red	red	red				
15.	Na Landrovci Cave 1	150→80				green	green		
16.	Na Landrovci Cave 2	150→80	red	red		green	green		
17.	Laudriky (surface station)	134→80					green		green
18.	Liskovská Cave 1	340→80	red	red	red		green	green	
19.	Liskovská Cave 2	220→85							green
20.	Mŕtvych netopierov Cave	360→65				green			green
21.	Ochtinská aragonitová Cave	300→85	red	red		green	green		green
22.	Plavecká Cave 1	290→90	red	red	red		green		green
23.	Plavecká Cave 2	240→65	red	red	red		green		green
24.	Sedmička Cave	80→89	red	red	red				green
25.	Skalistý potok Cave 1	80→65	red	red	red				green
26.	Skalistý potok Cave 2	53→85							green
27.	Slopy Cave	315→70			red		green		green
28.	Zbojnícka Cave 1	245→65							green
29.	Zbojnícka Cave 2	325→85							green

Figure 8. Generalised block model of fault movements in the western Carpathians during the tectonic hiatus in the years 2015–2019.

the eastern margin of the Bohemian Massif. This phase of increased activity was accompanied by significant directional displacements, and stress tensor analyses indicated a stress field with the principal compressive axis oriented NNW – SSE.

4.2. Bulgaria and Slovenia

A reduction in fault activity has also been observed at several sites, notably in the well-known Postojna Cave (Figure 11) in Slovenia (Šebela et al., 2021) and Bacho Kiro Cave in Bulgaria. The distance between Bacho Kiro Cave and, for instance, the Bozkov Dolomite Caves in the Czech
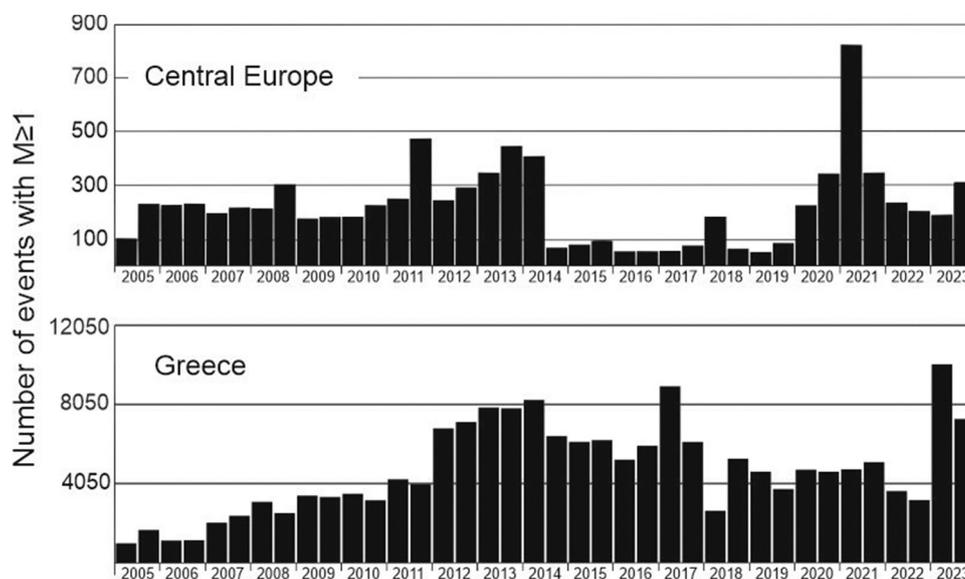
Figure 9. The graphs show half-yearly totals of earthquake M ≥ 1 events recorded in Central Europe (bounded by 45.27°–51.34°N and 11.47°–22.89°E) and Greece (bounded by 32.881°–43.102°N and 16.826°–37.15°E) between 2005 and 2023. Seismic data were obtained from the European-Mediterranean Seismological Centre (https://www.emsc-csem.org). A noticeable decline in seismic activity is evident in both regions starting in the second half of 2014.

Republic (previously mentioned) is approximately 1150 km to the southeast. This wide geographic extent supports the interpretation that the tectonic hiatus described was a widespread phenomenon affecting large parts of Europe.

Another important implication arises from the presented data. If recent stress and ongoing deformation in the Carpatho-Pannonian region are primarily governed by the counterclockwise rotation and north – north-eastward drift of the Adriatic microplate (Bada et al., 2007), and if this stress regime is not stationary but may alternate between compressional and extensional states over multi-year timescales, as suggested by our observations, then palaeostress interpretations based on outcrop data alone may not fully capture the transient nature of the regional stress field. In this context, the extensional tectonic regimes inferred by Vojtko et al. (2008) for the western part of the Central Western Carpathians could reflect such temporally limited stress states rather than a long-term regional regime.

5. Conclusion

This study documents a distinct tectonic hiatus affecting large parts of Central Europe between 2015 and 2019, as revealed by long-term extensometric monitoring within the EU TecNet network. In the Western Carpathians, fault movements were strongly attenuated or completely arrested for nearly five years, particularly along major NNE – SSW-striking fault systems that rank among the most seismically active structures in the region.

The hiatus was not spatially uniform and was followed by a complex deformation sequence, including fault opening beginning in 2015 and widespread block subsidence in 2018. These deformation phases indicate relaxation processes following the termination of compressional stress acting from the southeast/south after 2014. The temporal coincidence of the tectonic hiatus with a significant reduction in earthquake frequency across Central Europe further supports the interpretation of a regional-scale tectonic signal.

Comparable quiescent intervals recorded in the Bohemian Massif, Slovenia, and Bulgaria demonstrate that the 2015–2019 hiatus was not confined to the Western Carpathians but represented a widespread European phenomenon, preceded by a tectonic pulse detected across the continent at the turn of 2014/2015. The observed selectivity of the hiatus with respect to fault orientation and its multi-year duration argue against a primary climatic control and instead point to a transient reorganisation of the regional stress field,
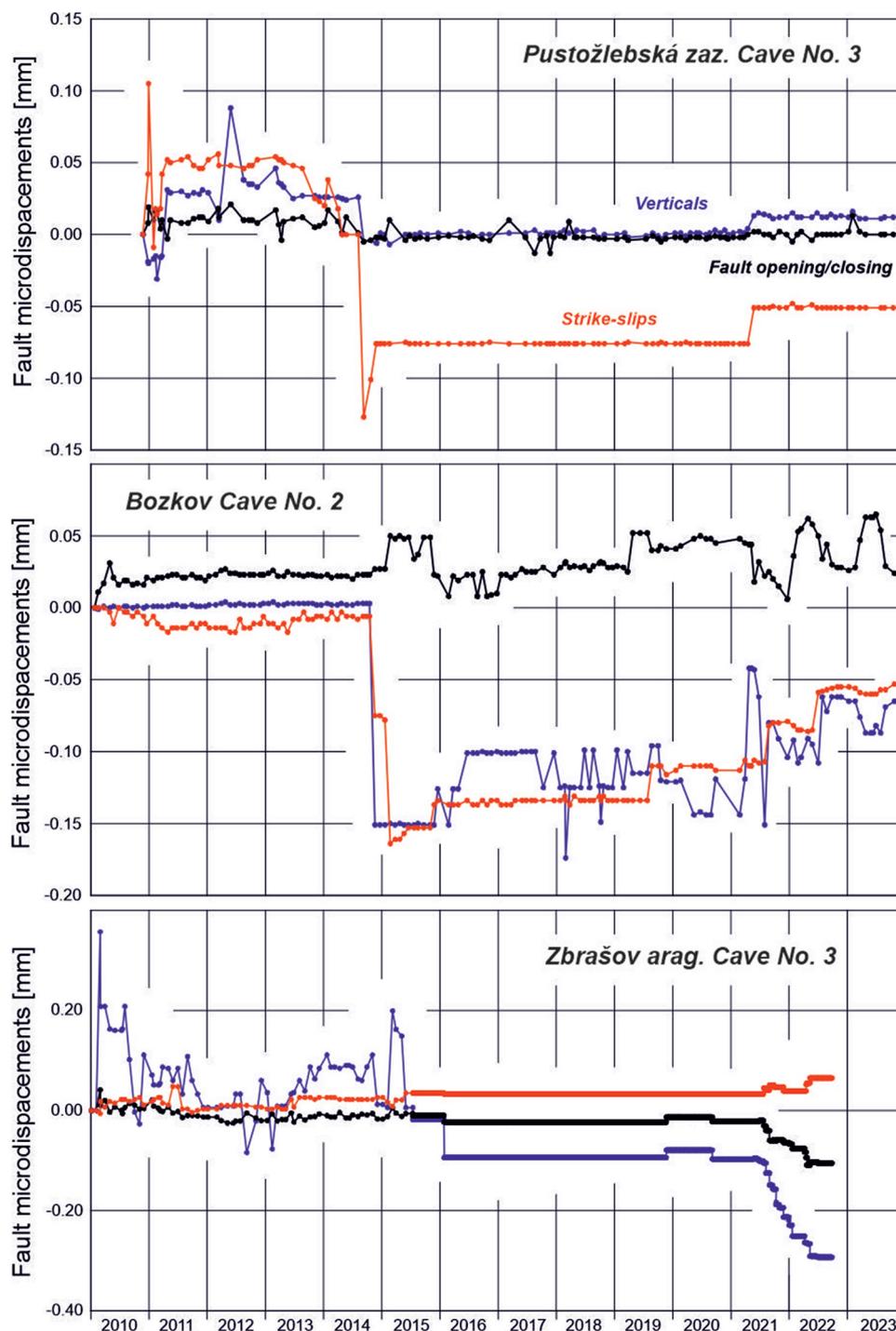
Figure 10. The tectonic hiatus resulted in cessation of faulting activity at numerous sites within the Bohemian Massif. It began after significant activity in 2014/2015.

likely related to variations in the dynamics of the Adriatic microplate and the African – Eurasian plate interaction.

Finally, this study highlights the critical importance of long-term, high-resolution extensometric observations for detecting subtle and transient tectonic processes. Such measurements provide an essential complement to seismic and geodetic data, offering unique insight into the short- to medium-term evolution of stress and deformation within actively deforming continental interiors.
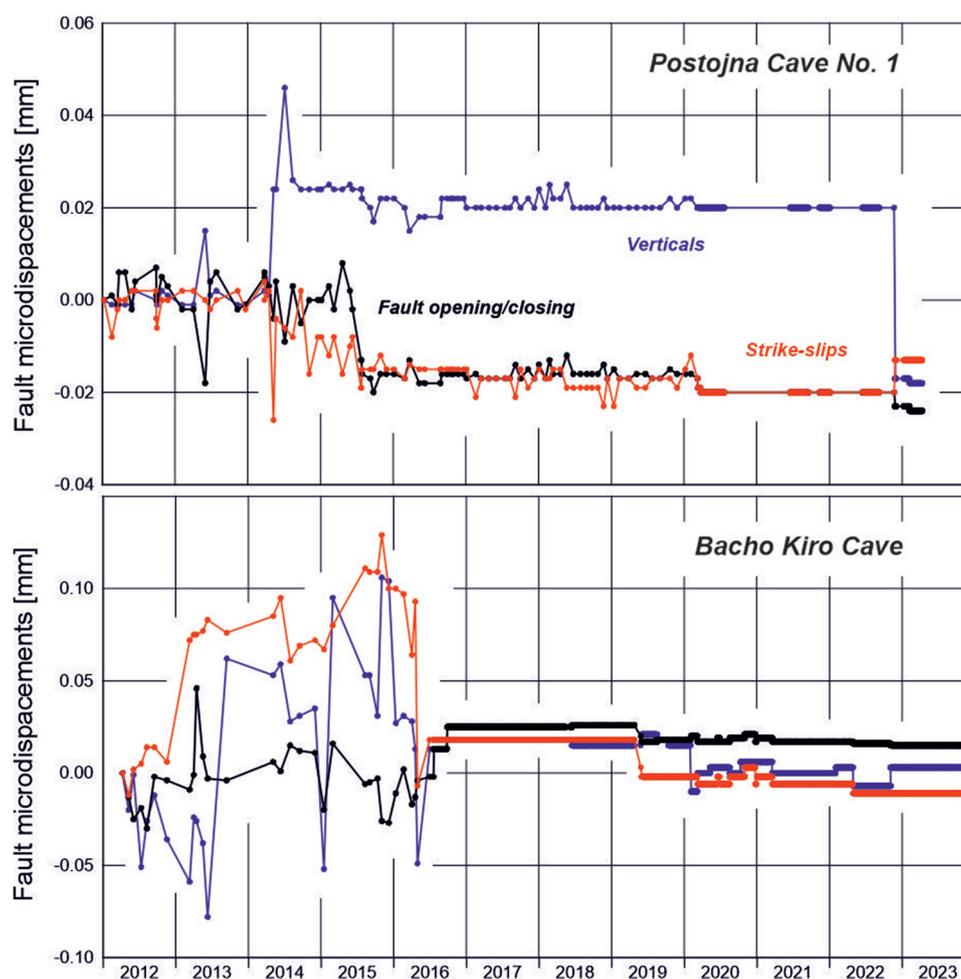
Figure 11. Tectonic quiescence observed in the Dinaric Alps south of the western Carpathians, as well as in the Stara Planina region at the Bacho Kiro Cave.

Author contributions

CRediT: **Miloš Briestenský:** Conceptualization, Data curation, Formal analysis, Funding acquisition, Investigation, Methodology, Project administration; **Stanka Šebela:** Conceptualization, Data curation, Funding acquisition, Investigation, Project administration; **Petar Stefanov:** Conceptualization, Data curation, Funding acquisition, Investigation, Project administration; **Uroš Novak:** Conceptualization, Data curation, Formal analysis, Investigation, Methodology.

Disclosure statement

No potential conflict of interest was reported by the author(s).

Notes on contributors

Miloš Briestenský is a researcher at the Department of Engineering Geology, Institute of Rock Structure and Mechanics (IRSM), Czech Academy of Sciences. His research focuses on geodynamic hazards such as earthquakes, landslides, active tectonics, and radon emanation. He has carried out extensive fieldwork at tectonically active sites across Europe and leads regional extensometric and radon monitoring networks (EU TecNet).

Stanka Šebela is researcher and lecturer at Karst Research Institute ZRC SAZU (Postojna, Slovenia), at University of Nova Gorica (Slovenia), at University of Primorska Faculty of Humanities (Koper, Slovenia). Her research focuses on karst geology, structural-geological implications on karst areas, cave micro-climate, sustainable use of show caves for tourism.

Uroš Novak is a researcher at the Karst Research Institute, ZRC SAZU, Slovenia. His work focuses on advancing the understanding of geological processes in karst. His research interests include karst geology, structural geology, tectonics, and active tectonics. He is engaged in both field-based investigations and theoretical studies aimed at unraveling the complex interactions between geological structures and karstification processes.

Petar Stefanov is a geographer researcher at the National Institute of Geophysics, Geodesy and Geography, Bulgarian Academy of Sciences. He specializes in karstology, geomorphology, and regional geographic research, with a focus on karst geosystems, cave climate, radon activity, and tectonic-seismic processes in caves. He has organized numerous interdisciplinary field expeditions and leads integrated monitoring projects in karst environments.

ORCID

Miloš Briestenský http://orcid.org/0000-0002-0302-0176
Stanka Šebela http://orcid.org/0000-0002-0023-6019
Petar Stefanov http://orcid.org/0000-0003-4646-9667
Uroš Novak http://orcid.org/0000-0002-1250-0315

Data availability statement

The datasets generated during the current study are available from the corresponding author upon reasonable request.

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