ГЕОЛОГІЧНА ІНФОРМАТИКА

UDC 550.8.6221
DOI: http://doi.org/10.17721/1728-2713.100.15

S. Vyzhva[1], Dr. Sci. (Geol.), Prof.,
E-mail: vyzhvas@gmail.com;
V. Zatserkovnyi[1], Dr. Sci. (Tech.), Prof.,
E-mail: vitalii.zatserkovnyi@gmail.com;
I. Zobniv[1], Student,
E-mail: ivannazobniv333@gmail.com;
M. De Donatis[2], Associate Prof.,
E-mail: mauro.dedonatis@uniurb.it;
I. Tsiupa[1], PhD (Geol.),
E-mail: tsyupa@ukr.net;
[1]Taras Shevchenko National University of Kyiv, Institute of Geology,
90 Vasylkivska Str., Kyiv, 03022, Ukraine;
[2]Department of Theoretical and Applied Sciences,
University of Urbino "Carlo Bo", Urbino, 61029, Italy

APPLICATION OF GEO-INFORMATION TECHNOLOGIES IN DETERMINING THE DEPTH OF EARTHQUAKE IN THE MONTE NERONE DISTRICT (MARCHE DISTRICT, NOTHERN APENNINES IN 1781)

(Представлено членом редакційної колегії д-ром геол. наук, ст. дослідником О.І. Меньшовим)

In the work, the main fault of the Monte Nerone anticline (Marche – Northern Apennines) was investigated, as well as the study, identification and fixation of faults: the normal fault system in the Monte Nerone area and the search for correlations on the ground of the Monte Nerone fault with the earthquake in the Marche Apennines in 1781. A small-angle eastern normal fault dipping at a small angle in the structure of extensive deformations was interpreted, it was based on the seismic profiles of the crust. Therefore, seismic events registered in this tectonically active zone can be related to this fault, as, for example, recent events in the area of the southern Umbrian-Marchean Apennines. The main local tectonic structure is an anticlinorium, oriented in NW-SW, corresponding to the regional Apennine depression, with a longitudinal extension of about 30 km and a wavelength of 5–6 km.

The work on sounding the Monte Nerone main fault was developed in several stages: project preparation, terrain surveying, data processing and synthesis. The project included a CTR of the Marche region, a geodetic reference map based on the international ellipsoid centered on Monte Mario (Rome 1940), a geological map at a scale of 1:10 000 and satellite orthophoto plans of the reference areas. Reference layers were created in the work in the form of a shape file to be able to catalog and share the information obtained in the field. These layers included: metadata, data containing measurements, annotation. During the fieldwork, a route and stops were planned where more detailed measurements were made and played the role of landmarks for checking with previously obtained data to confirm or refute the hypothesis. In the route, nine main stops were selected, where reconnaissance of the territory was carried out, geological characteristics of the formation were determined, measurements and recording of the main fault, its direction, angles of dip and extension, slope were carried out. All measurements were recorded in the software environment and previously created database. Using a Bluetooth GPS connected to a tablet PC, accurate tracking of the position where the measurements were made was obtained.

With the help of the measurements carried out, it was possible to put forward the hypothesis that the Monte Nero fault extends from the west, starting from La Valle, crossing the western, southern and eastern slopes of Monte Nerone and extending to Monte La Montagnola, continuing to Pietralunga on its entire along the length of about 9.9 km. In addition, having the CTR with the geological map, we were able to confirm certain geological deposits. A 3D terrain model was created in ArcScene software to fully account for the terrain situation. The topography of the area was modeled in relation to the geological situation, the fault was marked, and the collected data were interpreted. Given the 54° dip, 90° inclination of the rocks we measured along the route, it can be assumed that the earthquake was shallow, with a maximum depth of about 10 km.

Keywords: GIS, GPS, CTR, structure-from-motion, 3D modelling, historical earthquake, instrumental seismicity, extensional tectonics.

Introduction. An important factor for determining the characteristics of seismic tectonically active areas is the mapping of faults and soil deformation. For this, geologists and geophysicists use digital tools to minimize the time of field research, reduce measurement errors to a minimum, and increase the accuracy of data acquisition and observations.

In the research carried out by the authors, the territory that experienced a strong earthquake on June 3, 1781 (6.5 MW) was selected. The earthquake significantly affected the northern sector of the Umbria-Marche Apennines. The catastrophe caused by this event was reported in many archival documents of the time. However, very little is known about the tectonic and structural features associated with this event (*Colacicchi et al., 1970; Castellarin et al., 1982).*

Since a large number of people live in the mentioned territory, and the event that occurred may be repeated in the future, it is extremely important to find clear evidence of the unequivocal connection of the faults coming to the surface with the earthquake.

The purpose of the work was to map the main fault of the Monte Nerone anticline (Marche – Northern Apennines), conduct research, identify and fix the characteristics of possible faults: the normal fault system in the Monte Nerone area and search for correlations on the ground of the Monte Nerone fault with the earthquake that occurred on Apennines in the Marche area in 1781. The fault crosses the Monte Nerone (PU) ridge, continues westward north of Serravalle di Cardo, and extends in a southeast direction to Mount La Montagnola (*Centamore et al., 1971, 1975*).

The territory of the study. The Marche region is located in the center of the country, on the coast of the Adriatic Sea, divided into the provinces of Ancona, Ascoli Piceno, Macerata and Pesaro-e-Urbino (Fig. 1).

Monte Nerone is a mountain in the Marche region, belonging to the Umbria-Marche Apennine range, located in the municipalities of Apecchio, Cagliari and Piobbico, in the provinces of Pesaro and Urbino, reaching a height of 1.525 m above sea level with a height difference of 1.200 m from the valley floor. It is located to the north of the Monte Catria group, which gives its name to the Catria and Nerone mountain range (Fig. 2).

Fig. 1. The image of the researched area, on the Google map server. Region of Marche, the capital of Pesaro and Urbino province

Fig. 2. Image of three mountains belonging to Umbria-Marche Apennine range in the researched area

This is a limestone massif, with a significant variety of landscapes; sinkholes, gorges, vertical walls and magnificent karst formations, both underground and surface. On its slopes there are limestone layered rocks of marine origin, belonging to the Jurassic period.

Tectonic structure. The extreme part of the northern Apennines, the Umbrian-Marchean Apennines, is a fold-thrust orogenic chain formed by the rotation of the Sardinian-Corsican block towards the Adriatic coast *(Tozer et al., 2002*). Deformations migrated from the western to the eastern direction, from the inner side of the Tyrrhenian Sea to the outer side of the Adriatic from the Oligocene to the Pliocene-Quaternary age, involving carbonate successions and syntectonic terrigenous deposits in the orogen (*Lavecchia et al., 1988; Pauselli et al., 2006*). The formation of the orogenic chain was then accompanied by progressive tectonic stretching, always in the same direction from northeast to southwest *(Malinverno and Ryan, 1986*).

The shortening structures are cut by successive normal faults in the Tyrrhenian-Tosco-Umbrian region (Fig. 3), while a compressional regime persists beyond the Apennine watershed, towards the Adriatic (*De Donatis et al., 2021*).

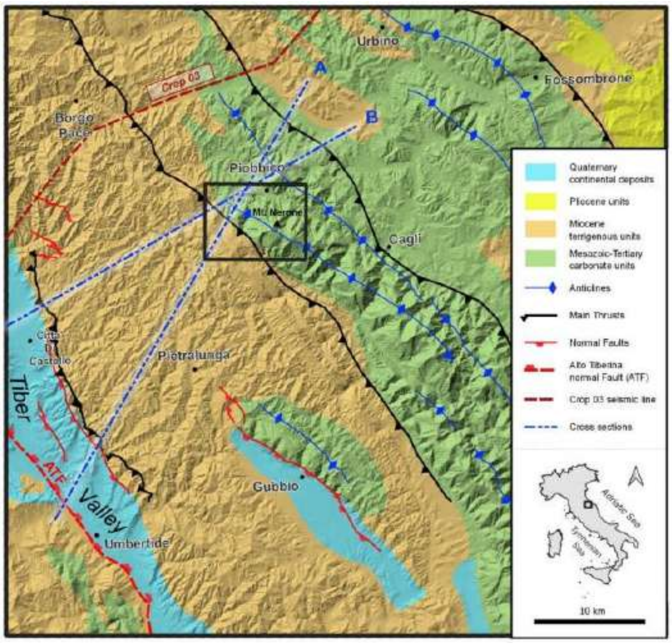

Fig. 3. Map-scheme of the northern sector of the Umbrian-Marchan Apennines (northern Apennines) on which the researched area and faults traces are shown by black rectangle

However, this hypothesis is questioned by various authors who believe that the extensional regime is no longer limited to the Tyrrhenian sector, but that even to the east, beyond the Apennine watershed, there are signs of a recent extensive expansion of tectonics (*Chiaraluce et al., 2017*). A low-angle east normal fault (LANF) dipping at a low angle was interpreted in the structure of extensional deformations based on crustal seismic profiles *(Mirabella et al., 2011*).

Therefore, seismic events recorded in this tectonically active zone (*Mantovani et al., 2014*) may be related to this fault, as, for example, recent events in region of the southern Umbrian-Marchean Apennines (*Carannante et al., 2013*).

Geological features of the studied area. The study area is the interior sector of the Umbrian Marchese Apennines (province of Pesaro-Urbino, northern Marche), which includes the northwestern edge of the Monte Nerone anticline and the adjacent areas of the valley of the Biscubio River and its tributaries. The stratigraphy can be summarized as a carbonate sequence of Lower Jurassic to Oligocene age. This succession was deposited in a basin on the margin of the

African Platform during the transition from Liassic rifting to drift and developed on the margin. In the upper section, the content of terrigenous finely dispersed sediments increases in the sequence. The rock formation indicate the transition to the turbidite complex of the Miocene substage, represented in this region by the Marnoso-Arena Formation (*Butler et al., 2000).* The main local tectonic structure is an anticlinorium, oriented in NW-SW, corresponding to the regional Apennine depression, with a longitudinal extension of about 30 km and a wavelength of 5–6 km. In the studied area, this structure has a periclinal termination overlain by the latest terrigenous formations due to out-of-sequence thrusts (*Menichetti et al., 1991).* In addition, the anticlinorium is dissected by numerous NW-SW trending faults, these faults dissect the entire structure. Recent and insignificant normal faults, with a length of several kilometers and extending NW-W, dissect the structure without obvious signs of connection with larger faults (Fig. 4).

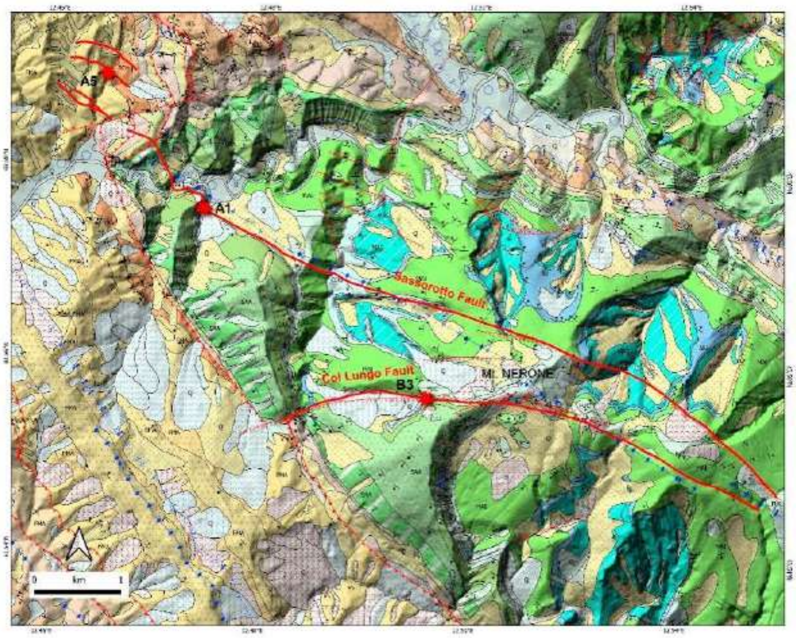

Fig. 4. Simplified geological map of the researched area of region Marche, scale 1 : 10 000. Fault traces mapped in this research are indicated by thick red lines

Research methods. The research of the Monte Nerone main fault was developed in several stages:

I – project preparation;

II – shooting of the area;

III – Data processing and synthesic.

Chamber (laboratory) and field work alternated from beginning to end. At the beginning, preparatory work was carried out in the laboratory. During a survey, field data can be used to interpret and test new hypotheses. The project structure may also be modified to improve data collection and observations, both for ground and aerial surveys. During the period of work, it was necessary to alternate laboratory and field work. The final laboratory stage involved the final interpretation and synthesis of two- and three-dimensional maps, sections, and models.

The algorithm of the workflow with the phases of the survey and mapping processes is presented in Fig. 5.

Project preparation. The first procedure was to develop a project using QGIS software, which allowed the work file to be customized as needed. The project included a CTR of the Marche region, a geodetic reference map based on the international ellipsoid centered on Monte Mario (Roma 1940), a geological map at a scale of 1:10 000 and satellite orthophoto plans of the reference areas.

In the next step, reference layers were created in the form of a shape file to be able to catalog and separate the information, layer by layer:

1. deposits (dedicated to measurement and registration of exposure layers);

2. exposure (faults, layering).

Different fields were created for each layer, where you can define the type of information, data, measurement by setting three main fields:

1. metadata (identifiers, detectors, who performed the measurement, location and date of measurement);

2. measurement data;

3. annotations (places to insert notes for comments or attachments such as photos or log files).

Finally, for each layer, a type and the corresponding symbology of the type of information to be recorded are defined.

An illustration of the created map of Mount Mote Nerone: at the top of the CTR, in the center of the overlap of the CTR and the orthophoto, at the bottom of the overlap of the CTR with the geological map is presented in fig. 6.

In Fig. 7. the main layers, their types and symbols are presented on the left; on the right is an example of data collection for deposits.

Data processing. Data and measurements were collected using traditional instrumentation followed by analysis and cataloging digitally, noting directly in the QGIS project the position, orientation and type of added information.

By having a digital format of the completed work, you can comment and share with other researchers the information and assessments carried out on site.

In Fig. 8 illustrated the stops made during the route, where measurements were taken and data were collected.

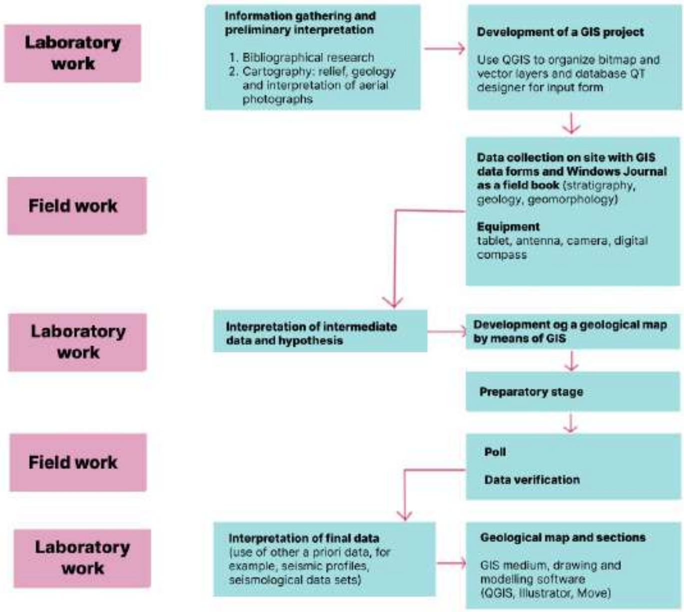

Fig. 5. Workflow algorithm with phases with phases of survey and mapping process

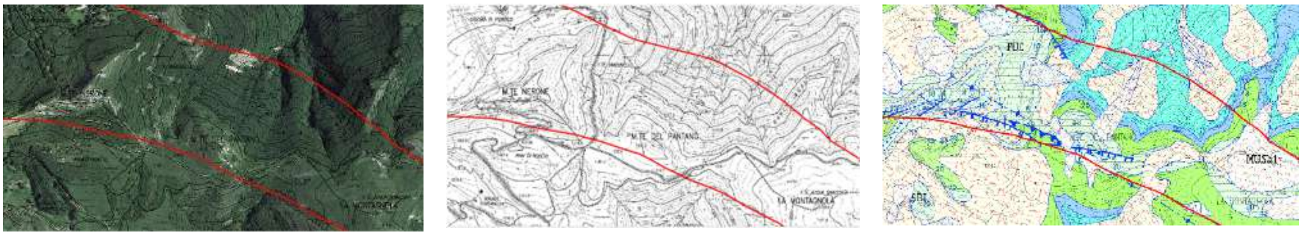

Fig. 6. Illustration of map which relates to Mote Nerone: at top – CTR, in the center of CRR and geological map overlap

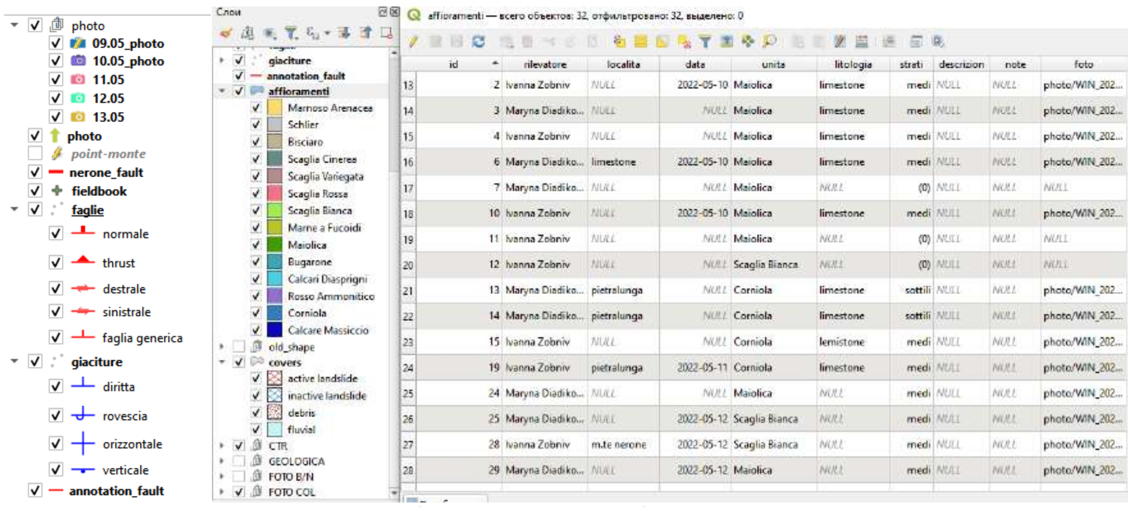

Fig. 7. Illustration of main layers on the left, their types and symbols; on the right there is an example of data collection for deposits

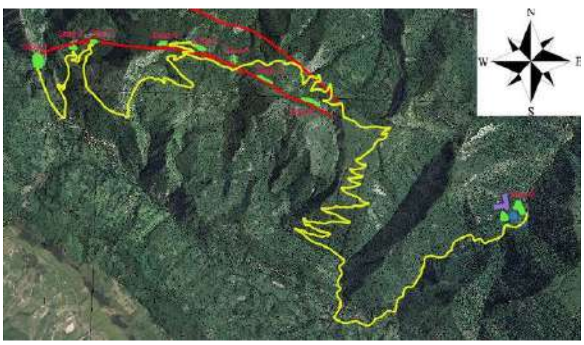

Fig. 8. Illustration of stops made along the route where measurements were taken and data collected

Stop No. 1: Several formations such as Scaglia Cinerea, usually marly gray or gray-green marly limestones, are exposed in this area on the southern slope. Unfortunately, it was not possible to carry out the measurement. Scaglia Variegata, represented by marly limestones and calcareous marls with a steepness of 223° and a slope of 76°, was found on the northeastern slope (Fig. 9).

Stop No. 2: The site is represented by well-stratified deposits of Maiolica – white micritic limestones with gray-black flint of medium thickness of 90°. Since it bordered an old, unused quarry, where vegetation prevented the view of the exposed area, it was not possible to carry out detailed measurements.

Stop No. 3: The site is also represented by Maiolica deposits. North direction 5°. Two measurements of the occurrence of rocks were made. Type – direct lying, dip 184°, slope 45°. The second type is straight, 180° fall, 87° slope. The southern side of the main fault was recorded, dip 190°, slope 59° (Fig. 10).

Stop No. 4: The observation site is located in the Monte Nerone chain, the outcrop represents the geological characteristic of the Maiolica formation; direction 180°, measurements of the main fault were made at two points with different positions: the first has a strike of 352°, a slope of 83°, the second has a strike of 175°, a slope of 75° (Fig. 11).

Fig. 9. Deposits of the rock world at the foot of the mountain on the south-western slop (left), on the right – a map of the observation area

Fig. 10. Illustration on the left of the fault plane with cracks, on the rights – an image of the study area

Fig. 11. Fault lines on the Monte Nerone ridge

Stop No. 5: On the southern slope of Monte Nerone, the outcrop represents the geological feature of the Scaglia Bianca Formation with white microclimatic limestones interspersed with black flint. The upper part contains a black layer composed of argillites and siltstones. This is an isochronous layer corresponding to the second anoxic oceanic event (Upper Cenomanian), which may contain fish remains.

The measurements of the southwest showed that the main fault has a dip angle of 340°, a slope of 71°. The angles were measured directly on the geological deposits in three places: the first measurement – dip 145°, steepness 20°, the second measurement – dip 84°, slope 42°, the third measurement – dip 280°, slope 4° (Fig. 12).

Slightly east of the previous place on the slope of Monte Nerono, the angle of incidence was 65°, the slope was 26° (Fig. 13).

To the left of the southeastern slope of Mount Nero (Fig. 14), the angle of incidence was 150°, the slope was 72°. A map of the observation area is presented on the right.

Fig. 12. South-western slope of Monte Nerone

Fig. 13. The dimension to the east further from the previous place, angle of incidence 65°, slope 26°

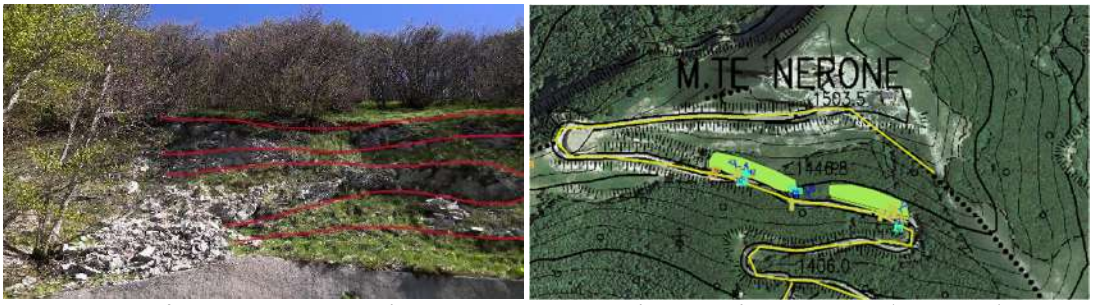

Fig. 14. South-eastern slope of Monte Nerone on the left, angle of incidence 150°, slope 72°, on the right a map of the observation area

Stop No. 6: Eastern slope of Monte Nerone (Fig. 15). The outcrop represents the geological characteristic of the Maiolica Formation. Signs of a general fault with a dip of 170° and an inclination of 46° were revealed. Direct drop 50°, slope 14°, second drop 50°, slope 40°.

Stop No. 7: On the southeastern slope of Mount Montagnola, an outcrop represents the geological feature of the Maiolica Formation. No obvious traces of the fault are found, but various places indicate the continuation of the fault from Monte Nerone to La Montagnola. Two positions were measured with different depth and inclination (Fig. 16).

Fig. 15. The eastern slope of Monte Nerone

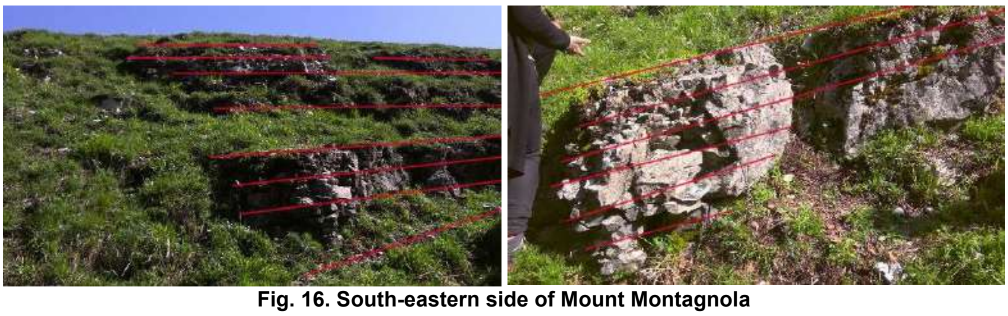

Fig. 16. South-eastern side of Mount Montagnola

Southwest direction 90°. Direct dip 265°, slope 14°, dip 165°, slope 40° (Fig. 17). To the left of the slope, two measurements were made: the first point of dip 325°, slope 30°, the second point of dip 280°, slope 27°, nearby the same dip 350°, slope 27°, down the slope of the dip 25°, slope 55°, to the right of the dip slope 315°, slope 30°.

Stop No. 8: On the southeastern slope of Mount La Montagnola. The outcrop represents the geological characteristic of the Maiolica Formation. The presence of faults with a total dip of 160° and an inclination of 49° was revealed. Direct steepness 165°, slope 27°, second standing place steepness 185°, slope 25° along the slope steepness 50°, slope 18° (Fig. 18).

Fig. 17. South-eastern side of Montagnola

Fig. 18. South-east side of La Montagnola mountain, mixed beds of Maiolica

Stop No. 9: Measurements were made on the southern slope of Pietralunga mountain, where different types of formations were found, such as ammonite-red alternating marls and limestones with a characteristic red color. Fossil formation rich in ammonites was found.

Further south is a gray, uniform and regularly layered microclimatic salt marsh formation that may contain sponge spicules, radiolarians, foraminifera, gastropods and ammonites. Here, the presence of general violations was revealed, with a dip of 210°, an inclination of 69°. The fault separates the carnelian formation, which highlights vertical beds with a dip of 54° with a dip angle of 90°, nearby beds with a dip of 302° with a dip angle of 13°, and a control point with a dip of 225° with a dip angle of 19°. The northwestern side of the carnelian formation is shown in Fig. 19.

North-eastern side of the carnelian formation is presented on Fig. 20.

Fig. 19. North-western side of carnelian formation

Fig. 20. Illustration of north-eastern side of carnelian formation

Results. According to the results of the conducted research and measurements of the fault and nearby outcrops along the route, it was possible to record the continuation of the Monte Nerone fault in the north-eastern direction with a length of about 9.9 km (Fig. 21). Having a CTR (Carta tecnica Regionale – regional technical documentation, 1:10 000, drawn up in the conformal representation of "Gauss-Boag" (Eastern Zone), with a geodetic reference based on the international ellipsoid centered on Monte Mario (Roma 1940), and a geological map of the region, it became possible to confirm the existing geological deposits and refute the existence of some of them.

A 3D terrain model was created using ArcScene software and loaded into SAS Planet. As a result, the relief of the area was created and the geological situation was attached to this image. The red line marks the fault that we discovered during the route and interpretation of the collected data (Fig. 22).

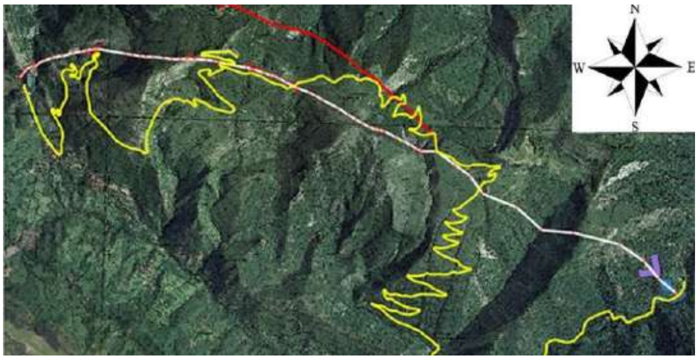

Fig. 21. Superimposed CTR and orthophoto-plan with faults and survey route

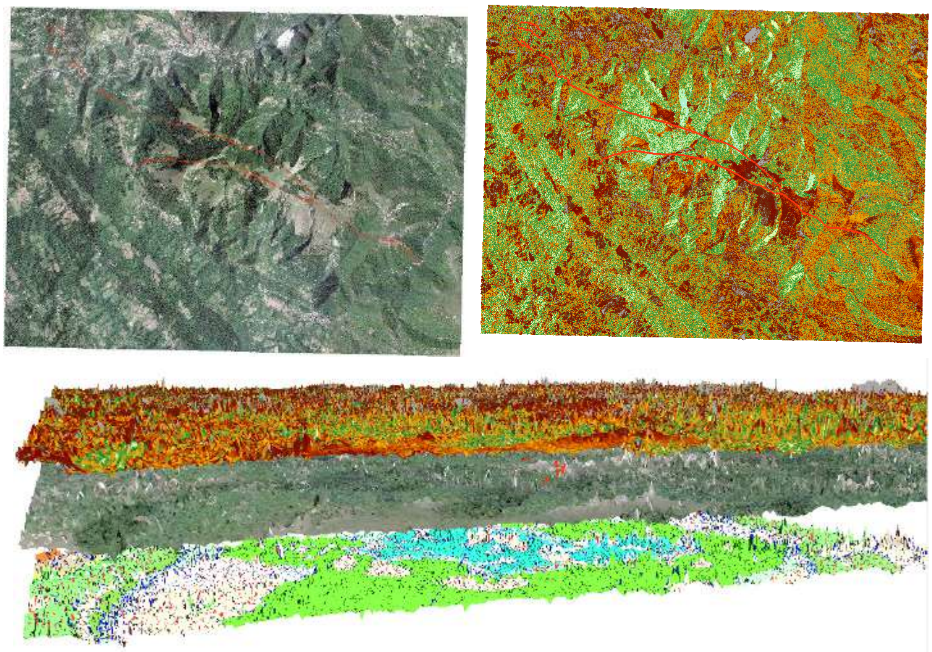
Fig. 22. Creating the image of a land plot in the form of a 3D profile

Conclusions. The conducted research has started a cycle of works to confirm (or disprove) the existence of correlations based on the Monte Nerone fault with the earthquake in the Apennines in March 1781. The fault crosses the Monte Nerone ridge (PU), continues westward north of Serravalle di Cardo, and extends southeastward to Monte La Montagnola.

Research results indicate that this area should be involved in normal kinematics and seismogenic evolution caused by related families of faults.

Signs of recent activity are observed in the studied areas.

With the help of the measurements, a hypothesis was put forward regarding the extension of the Monte Nerone fault from the west, which starts from La Valle, crosses the western, southern and eastern slopes of Monte Nerone and stretches to Monte La Montagnola, continuing to Pietralunga, the length of which is approximately 9–10 kilometers. Taking into account the 54° dip, 90° inclination of the rocks, which were measured along the laid route, it was concluded that the earthquake was shallow, with a maximum depth of about 10 km.

References

Butler, R.W.H., Sveva Corrado, Mazzoli, S., De Donatis, M. (2000). Time and space variability of "hin-skinned" and "thick-skinned" thrust tectonics in the Apennines (Italy). *Rendiconti Lincei. Scienze Fisiche e Naturali,* 11(1), 5–39. DOI:10.1007/BF02904594

Carannante, S., Monachesi, G. Cattaneo, M., Amato, A. (2013). Deep structure and tectonics of the northern-central Apennines as seen by regional-scale tomography and 3-D located earthquakes: STRUCTURE AND TECTONICS OF CENTRAL ITALY. *Journal of Geophysical Research Atmospheres* 118(10), 1–13. DOI:10.1002/jgrb.50371

Castellarin, A., Colacicchi, R., Praturlon, A., Cantelli, C. (1982). The Jurassic-Lower Pliocene history of the Ancona-Anzio line (Central Italy). *Mem. Soc. Geol. It.*, 24, 325–336.

Centamore, E., Catenacci, V., Chiocchini, M., Chiocchini, U., Jacobacci, A., Martelli, G., Micarelli, A., Valletta, M. (1975). Note Illustrative della Carta Geologica d'Italia alla scala 1:50.000. *Foglio 291, Pergola. Serv. Geol. d'It.:* pp. 40.

Centamore, E., Chiocchini, M., Deiana, G., Micarelli, A., Pieruccini, U. (1971). Contributo alla conoscenza del Giurassico dell'Appennino Umbro-Marchigiano. *Studi Geol. Camerti,* 1, 7–89.

Colacicchi, R., Passeri, L. & Pialli, G. (1970). Nuovi dati sul Giurese umbro-marchigiano ed ipotesi per un suo inquadramento regionale. *Mem. Soc. Geol. It.,* 9, 839–874.

Conti, P., Cornamusini, G., Carmignani, L. (2013). Schema tettonico dell'Appennino Settentrionale. Universita di Siena. https://geotecnologie.unisi.it/wp-content /uploads/sites/110/2021/05/Conca-Marecchia_M1.pdf

De Donatis, M., Alberti, M., Cipicchi, M., Guerrero, N.M., Giulio, F. Susini, P.S. (2020). Workflow of Digital Field Mapping and Drone-Aided Survey for the Identification and Characterization of Capable Faults: The Case of a Normal Fault System in the Monte Nerone Area (Northern Apennines, Italy). *International Journal of Geo-Information*. https://www.mdpi.com/2220-9964/9/11/616

De Donatis, M., Pappafico, G.F., Susini, S., Alberti, M., Guerrero, N.M., Ottaviani, F. (2021) A Normal Faults System in the Monte Nerone area and its significance in the recent seismo-tectonic setting of the Northern Umbria-Marche Apennines (Italy). Preprint. Discussion started: 5 July 2021. https://doi.org/10.5194/se-2021-87

Lavecchia, G. *(*1988) The Tyrrhenian-Apennines system: Structural setting and seismotectogenesis*, Tectonophysics,* 147(3), 263-296. DOI:10.1016/0040-1951(88)90190-4

Malinverno, A., Ryan, W.B.F. (1986) Extension in the Tyrrhenian Sea and shortening in the Apennines as result of arc migration driven by sinking of the lithosphere, *Tectonics,* 5 (2), 227-245. https://doi.org/10.1029/TC005i002p00227

Mantovani, E., Viti, M., Babbucci, D., Tamburelli, C., Vannucchi, A., Falciani, F. (2014). Assetto tettonico e potenzialità sismogenetica dell'Appennino Tosco-Umbro-Marchigiano. Dipartimento di Scienze Fisiche, della Terra e dell'Ambiente. Siena, 2014. https://www. dsfta.unisi.it/sites/st01/files/allegatiparagrafo/23-10-2014/assetto_tettonico _e_potenzialita_sismogenetica_appennino_tosco_umbro_marchigiano_parte-1.pdf

Menichetti, M., De Feyter, A.J., Corsi, M. (1991). CROP 02-I 1 tratto Val Tiberina-Mare Adriatico. https://www.researchgate.net/publication/291781641_CROP_02-I_1_tratto_Val_Tiberina-Mare_Adriatico

Michele, M., Chiaraluce, L., Di Stefano, Waldhauser, R.F. (2020). Fine-Scale Structure of the 2016–2017 Central Italy Seismic Sequence From Data Recorded at the Italian National Network. *JGR Solid Earth*, 125, 4. https://doi.org/10.1029/2019JB018440

Mirabella, F., Brozzetti, F., Lupattelli, A., Barchi, M.R. (2011). Tectonic evolution of a low-angle extensional fault system from restored cross-sections in the Northern Apennines (Italy). *Tectonics,* 30, 6. https://doi.org/10.1029/2011TC002890

Pauselli, C., Barchi, M.R., Federico, C., Magnani, M.B. (2006) The crustal structure of the Northern Apennines (Central Italy): An insight by the CROP03 seismic line. *American Journal of Science*, 306(6). DOI:10.2475/06.2006.02

Tozer, R.S.J., Butler, R.W.H., Sveva Corrado (2002). Comparing thin- and thick-skinned thrust tectonic models of the Central Apennines, Italy. Stephan Mueller Special Publication Series 1. DOI:10.5194/smsps-1-181-2002

Надійшла до редколегії 21.01.23

С. Вижва[1], д-р геол. наук, проф.,
E-mail: vyzhvas@gmail.com;
В. Зацерковний[1], д-р техн. наук, проф.,
E-mail: vitalii.zatserkovnyi@gmail.com;
І. Зобнів[1], студ.,
E-mail: ivannazobniv333@gmail.com;
М. Де Донатіс[2], доц.,
E-mail: mauro.dedonatis@uniurb.it;
І. Цюпа, канд. геол. наук,
E-mail: tsyupa@ukr.net;
[1]Київський національний університет імені Тараса Шевченка, ННІ "Інститут геології",
вул. Васильківська, 90, м. Київ, 03022, Україна;
[2]Департамент теоретичних і прикладних наук, Університет Урбіно "Карла Бо",
Урбіно, 61029, Італія

КАРТОГРАФУВАННЯ ГОЛОВНОГО РОЗЛОМУ АНТИКЛІНАЛІ МОНТЕ-НЕРОНЕ (МАРКЕ – ПІВНІЧНІ АПЕННІНИ) ТА ВИКОРИСТАННЯ ТЕХНОЛОГІЇ ГІС У МОНІТОРИНГУ ЗЕМЛЕТРУСІВ

Досліджено головний розлом антикліналі Монте-Нероне (Марке – Північні Апенніни) та результати проведених досліджень з ідентифікації та фіксування розломів: нормальної системи розломів у районі Монте-Нероні та пошук кореляцій на місцевості розлому Монте-Нероні із землетрусом в Апеннінах у 1781 р. Малокутовий східний звичайний розлом, що занурюється під невеликим кутом у структуру великих деформацій, був інтерпретований на основі сейсмічних профілів земної кори. Тому сейсмічні події, зареєстровані в цій тектонічно активній зоні, можуть бути пов'язані із цим розломом, як, наприклад, нещодавні події в районі південних Умбрійсько-Маркійських Апеннін. Основною локальною тектонічною структурою є антиклінорій, орієнтований на північний-західний захід, що відповідає регіональній Апеннінській западині, з повздовжньою протяжністю близько 30 км і довжиною хвилі 5–6 км.

Робота із зондування головного розлому Монте-Нероне проходила в кілька етапів: підготовка проєкту, зйомка місцевості, обробка та синтез даних. Проєкт включав CTR регіону Марке, геодезичну опорну карту на основі міжнародного еліпсоїда з центром Монте-Маріо (Рим 1940 р.), геологічну карту масштабу 1 : 10 000 та супутникові ортофотоплани опорних територій. Довідкові шари створено у форматі шейп-файлів, для можливості каталогізувати та обмінюватися інформацією, отриманою в польових умовах. Ці рівні включали: метадані, дані, що містять вимірювання, анотацію. Під час польових робіт було сплановано маршрут та зупинки, де проводилися більш детальні вимірювання, котрі відігравали роль орієнтирів для звірки з раніше отриманими даними (для підтвердження або спростування гіпотези). У маршруті вибрано дев'ять основних зупинок, на яких проведено розвідку території, визначено геологічні характеристики пласта, проведено вимірювання та фіксацію основного розлому, його напрямку, кутів падіння та простягання, нахилу. Усі вимірювання фіксувалися в програмному середовищі та попередньо створеній базі даних. За допомогою Bluetooth GPS, підключеного до планшетного ПК, було отримано точне відстеження місця, де були проведені вимірювання.

За допомогою проведених вимірювань вдалося виділити гіпотезу про те, що розлом Монте-Неро простягається із заходу, починаючи від Ла Валле, перетинаючи західний, південний і східний схили Монте-Нероне, і простягаючись до Монте-Ла-Монтаньола та Пьетралунга приблизно на 9,9 км. Крім того, маючи CTR з геологічною картою, ми змогли підтвердити певні геологічні поклади. Для повного врахування ситуації на місцевості в програмному забезпеченні ArcScene було створено 3D-модель рельєфу місцевості, а також позначено розлом, інтерпретовано зібрані дані. Враховуючи кут падіння 54° та нахилу 90° скель, які ми виміряли вздовж маршруту, можна припустити, що землетрус був неглибоким, із максимальною глибиною епіцентру до 10 км.

Ключові слова: ГІС, GPS, CTR, структура із руху, 3D-моделювання, історичний землетрус, сейсмічність, тектоніка розтягування.