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Mutlu ZEYBEK, Alican KOP

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Research Article

Geological and Geostatistical Modeling of Geogenic Radon Potential of Minarets in Muğla Province (SW Turkey)

Mutlu Zeybek[1,*], Alican Kop[2]

[1] Muğla Sıtkı Koçman University, Faculty of Engineering, Department of Geological Engineering, Muğla, TURKIYE
[2] Kahramanmaraş Sütçü İmam University, Faculty of Engineering, Department of Geological Engineering, Kahramanmaraş, TURKIYE

* Corresponding author: M.Zeybek
E-mail: mutlu505@gmail.com

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Abstract

Radon (222Rn), derived from the Uranium (^{238}U) series and emitted from Geological Formation (soil, rock) (Qg), Fault (Qf) and Construction Material (Qm), which cannot be detected by the five senses, is an inert radioactive gas. Radon negatively affects people's health (such as lung cancer) as a result of excessive (>200 Bq/m^3) accumulation in buildings. The aim of this study is to measure the radon emission concentrations of the components (Qg, Qf, Qm) that make up the Total Radon Gas Concentration (Qt) in the building (for the purpose of this study, mosque minarets) close to the fault or the possible fault in Muğla province (SW Turkey) and order their sizes. The Indoor Radon Concentration (IRC) of 841 minarets in Muğla province was measured with a portable RadonEye device (made in South Korea). At least 5 Soil Radon Concentration (SRC) measurements were made perpendicular to the fault lines near 14 minarets with a portable Markus 10 device (made in Sweden). About 10% of the 841 minarets were found to be above the European Indoor Radon Reference Value (EIRRV) (200 Bq/m^3). When evaluated according to the 13 districts, it is seen that the district with the highest IRC in the 841 minarets is Marmaris (Çetibeli town, 2809 Bq/m^3), and the district with the lowest is Ula (Armutçuk town, 217 Bq/m^3). The highest IRC was measured inside a minaret made of volcanic rocks in the Marmaris district (Çetibeli town, 2809 Bq/m^3). The lowest SRC was obtained in Datça district (Kızlan town, 5830 Bq/m^3) where serpentinites outcropped, and the highest SRC was found in Bodrum district (Gürece town, 120000 Bq/m^3) where volcanic rocks outcropped. It has been determined that there is a Qf>Qg>Qm relationship between the magnitudes of the factors (Qg, Qf, Qm) affecting Qt in the minarets close to the fault and possible faults. As a result, IRC measurements in all buildings where people live should be done periodically and regularly by the relevant institutions.

Keywords: Markus 10, Minaret, Muğla, RadonEye

Introduction

Radon (^{222}Rn), derived from the radioactive Uranium (^{238}U) series, is an inert, noble gas and has a half-life of 3.82 days (UNSCEAR, 1958, 1977). Radon (^{222}Rn), which cannot be detected by the five senses, negatively affects human health (contributing to such ailments as lung cancer) as a result of its excessive (>200 Bq/m^3) accumulation in buildings (WHO, 2009; Durrani et al., 1999; Scheib et al., 2009; Demoury et al., 2013; UNSCEAR, 2016; Ravina et. al., 2017). When exposed to IRC, tens of thousands of people die on average worldwide from lung cancer each year (Bossew and Petermann, 2022). For every 100 Bq/m^3 increase inside the building, the risk of lung cancer increases by approximately 16% (Darby et al. 2005). Indoor radon reference values from country to country were determined as World Health Organization (WHO) (100 Bq/m^3) (WHO, 2009), USA (148 Bq/m^3) (CELA, 2014), Europe (200 Bq/m^3) (Ravina et. al., 2017) and Turkey (400 Bq/m^3) (Çelebi et al., 2014). The sources of IRC are Geological Formation (soil, rock) (Qg) (Coletti et al., 2022), Fault (Qf) (Neri et al., 2019) and Building Material (Qm) (Frutos et al., 2021; Wang et al., 2022).

According to previous studies, although the IRC was measured in various buildings such as homes (Park et al., 2018), workplaces (Moreno et al., 2008), schools (Bossewa et al., 2014; Madureira et al., 2016; Stojanovska et al., 2019), it was not measured in mosque minarets. The Qt was measured in 841 minarets in faulted and passive zones in Muğla province (in all 13 districts). At least 5 SRC measurements were made perpendicular to the faults located around the 14 minarets with the highest radon gas in these districts.

Why was radon gas in minarets measured with a radon sensor?

(1) Compared to other structures (house, workplace, school, etc.), it allows 360^0 examination of the building blocks of the minaret, due to its uniform and cylindrical shape.
(2) Minarets are largely uniform in terms of building materials, making them an ideal location for the placement of the radon sensor compared to other structures.

(3) Minarets are generally empty structures and they are not entered by people as the daily call to prayer is made with loudspeakers.
(4) Many minarets in the region were positioned without consideration for the presence of faults.
(5) There are many minarets in each of the 841 mosques (Muslim places of worship).
(6) The building materials of minarets are of critical importance in determining and understanding the source of radon gas emissions.

According to the radon measurement results, the following sets of hypotheses were formed:

1.Hypothesis: If there is no Qf and Qg and is only Qm, then Qt is equal to Qm (Figure 1).

2.Hypothesis: If there is no Qf and is Qg and Qm, then Qt is equal to Qm and Qg (Figure 2).

3.Hypothesis: If there is Qf, Qg and Qm, then Qt is equal to Qm, Qg and Qf (Figure 3).

The aim of this study is to reveal the magnitude relationship between the parameters (Qg, Qf, Qm) that cause Qt accumulation. As a result, all radon data obtained were modeled as geological and geostatistical, and the sources (Qg, Qf, Qm) of Qt were visualized.

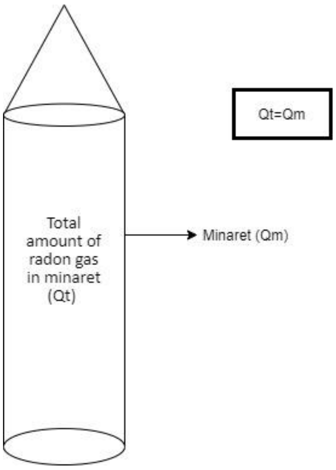

Fig. 1. The influencing factor (Qm) affects the total amount of radon gas in the building (minaret) (Qt).

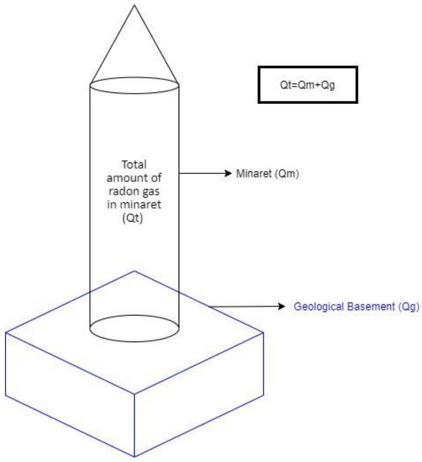

Fig. 2. The influencing factors (Qm, Qg) affect the total amount of radon gas in the building (minaret) (Qt).

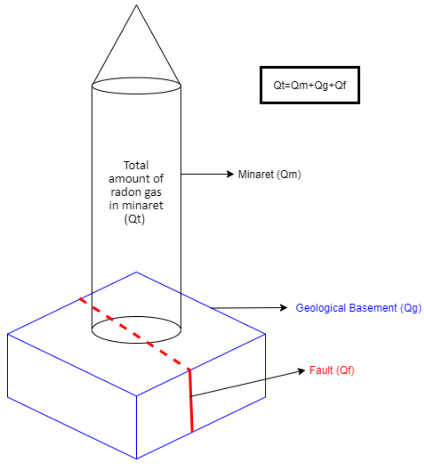

Fig. 3. The influencing factors (Qm, Qg, Qf) affect the total amount of radon gas in the building (minaret) (Qt).

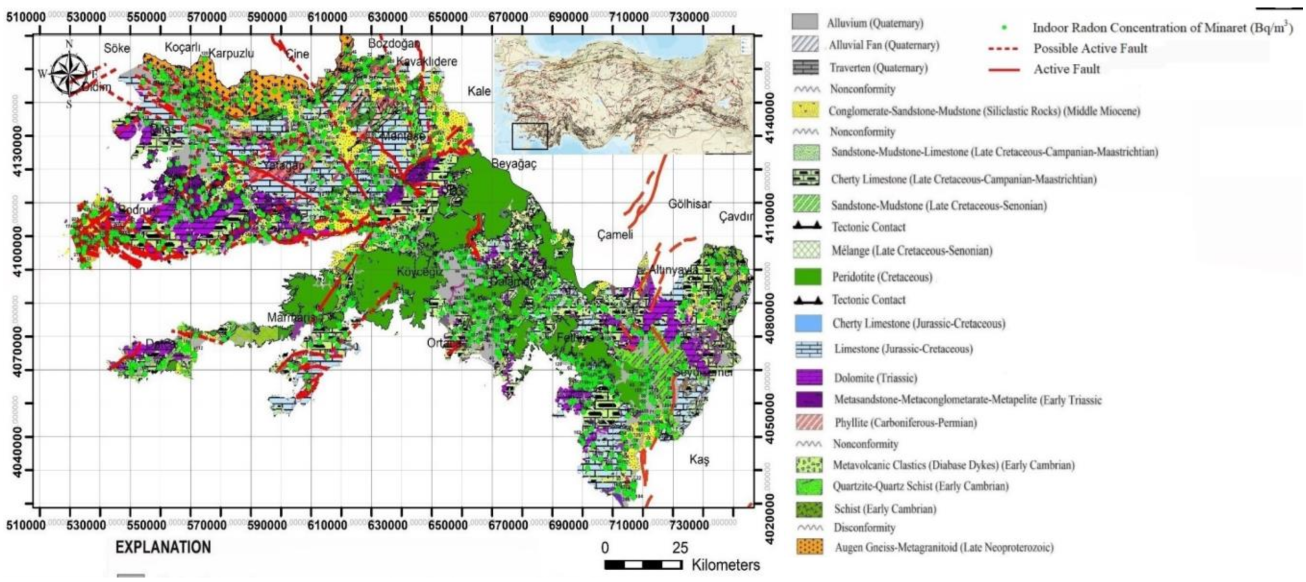

Fig. 4. Geological Map of Muğla Province (Geology and Fault Maps are modified from MTA, 2002, 2011a, 2011b).

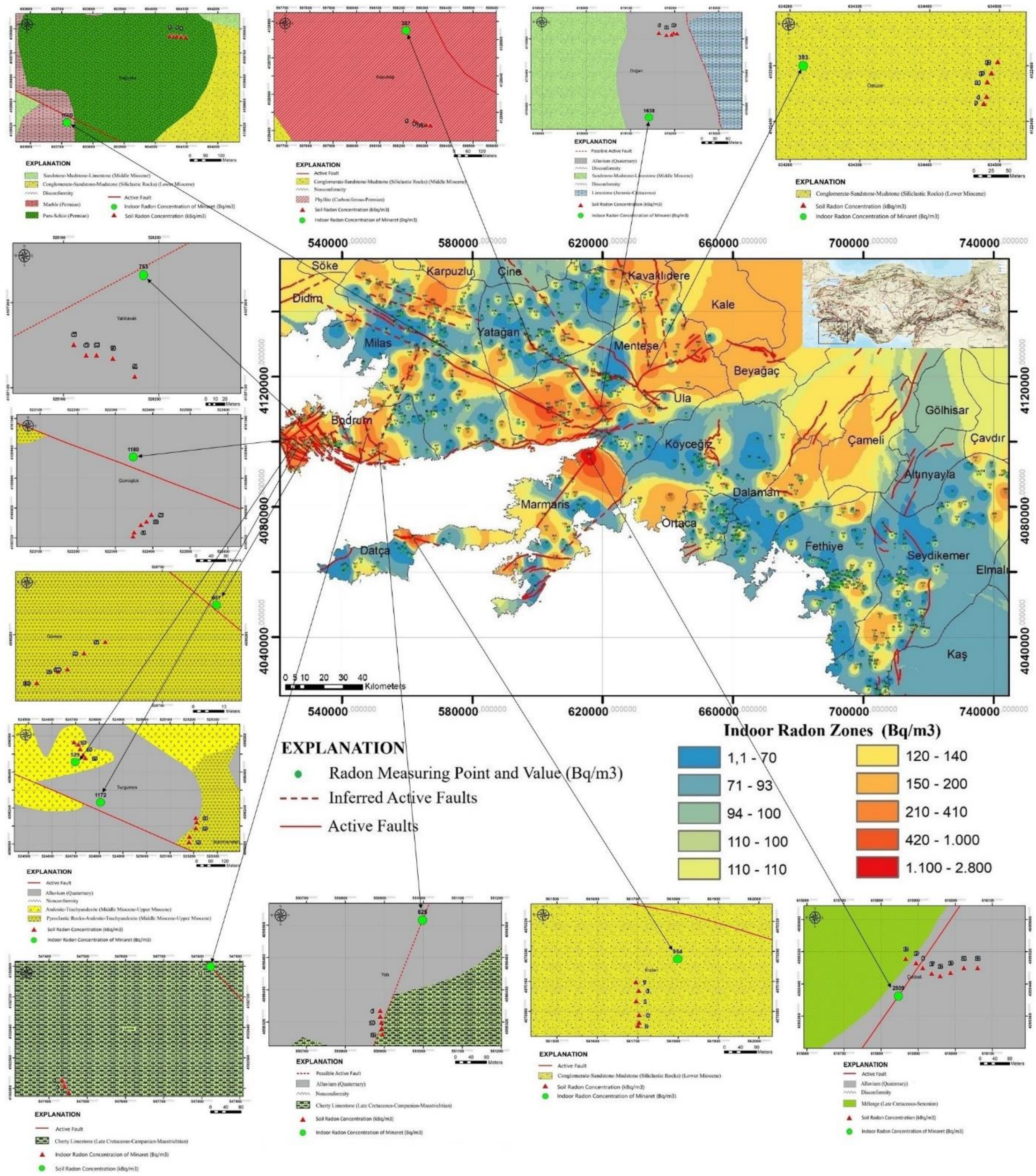

Fig. 5. IRC of Minarets and SRC near them in the Muğla Province (Southwestern Turkey) (Geology and Fault Maps are modified from MTA, 2002, 2011a, 2011b).

Geological Setting

The study area is located in the province of Muğla (all 13 districts) in the southwest of Turkey. In the Muğla province, volcanic rocks in the west, metamorphic rocks in the north, ophiolites and limestones in the south and east are dominant (Figure 4). Bodrum Peninsula in Muğla consists of metamorphic and volcanic rocks with strike-slip and normal faults (Pişkin and Bertrand, 1980; Ercan et al., 1984). There are metamorphic rocks associated with oblique-slip fault systems in Milas and Yatağan districts (Gürer and Yılmaz, 2002). Menteşe and Ula districts were formed from metamorphic rocks (marbles) with normal faults (Gürer et al., 2013). In Datça, Marmaris, Köyceğiz, Ortaca, Dalaman, Fethiye and Seydikemer districts, there are predominantly composed of peridotites and limestones due to the effect of reverse faults (Collins and Robertson, 1998). The IRC of 841 mosque minarets in active tectonic and passive zones in Muğla province (in all 13 districts) was measured between September 2018 and December 2019 with a portable RadonEye device (made in South Korea). In particular, at least 5 SRC measurements perpendicular to the faults near each of the 14 minarets with the highest IMRC in the active tectonic zones were made between October 2021 and November 2021 by a portable Markus 10 device (made in Sweden). Each IRC and SRC were measured in situ with the active method for an average of 20 minutes. These radon concentration measurements, geological formations and faults are visualized on a map (Figure 4-13).

Results

In Muğla Province (in all 13 districts), IRC of 841 minarets was modeled geostatistically with active faults

(Figure 5). In this model, 14 minarets with the highest radon concentration and associated with active faults were geologically mapped (Figure 5). IRCs and SRCs in very different sizes have been found where there are different geological basement rocks (volcanic rocks, peridotites (serpentinites), limestones, etc.). When evaluated according to the 13 districts, it is seen that the district with the highest IRC in minarets is Marmaris (Çetibeli town, 2809 Bq/m^3), and the district with the lowest is Ula (Armutçuk town, 217 Bq/m^3) (Figure 6).

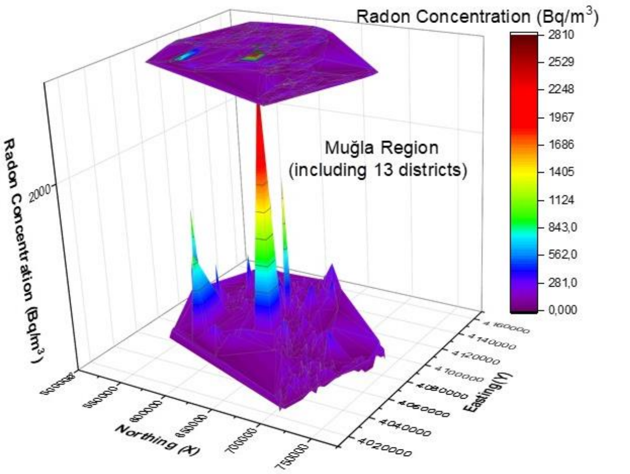

Fig. 6. Graph of 2D and 3D Colormap Surface Model of IRC (Bq/m^3) for all minarets (841 units) in the Muğla Province.

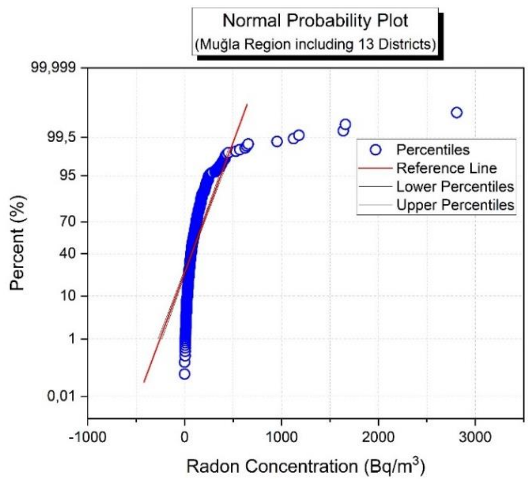

Fig. 7. Graph of Normal Probability Plot of IRC for all minarets (841 units) in Muğla Province.

Table 1. Database of the IRCs of 14 minarets and the SRCs near them in the Muğla province (SW Turkey)

Code Name	Northing (X)	Easting (Y)	Elevation (Z) (metres)	IRC of Minaret (Bq/m^3)	Building Material(s) of Minaret	Mean SRC (Bq/m^3)	Basement Rock	Mosque Minaret Name	Town Name	District Name
M60	622455	4114254	650	657	Concrete	94600	Volcanic Rock	Gürece Camii	Gürece Mah.	Bodrum
M59	622869	4114699	625	753	Concrete	69000	Volcanic Rock	Gökçebel Yemiş Camii	Dirmil Mah.	Bodrum
M63	619616	4101966	24	529	Concrete, Volcanic Rock	49400	Volcanic Rock	Akçalan Camii	Akçaalan Mah.	Bodrum
M50	621217	4116305	695	1180	Concrete	42600	Volcanic Rock	Gümüşlük Camii	Gümüşlük Mah.	Bodrum
M61	618030	4102360	48	625	Concrete, Red Tiles	27600	Limestone	Yalıçiftlik Camii	Yalıçiftlik Mah.	Bodrum
M53	615007	4121899	647	1172	Volcanic Rock	26400	Volcanic Rock	Turgutreis Cuma Camii	Akçaalan Mah.	Bodrum
M45	636472	4110810	715	2809	Volcanic Rock	15500	Serpentinite	Çetibeli Camii	Çetibeli Mah.	Marmaris
M64	712200	4055036	121	453	Volcanic Rock	12500	Limestone	Belen Camii	Çaltık Mah.	Milas
M74	620914	4119927	680	383	Concrete	11600	Limestone	Özlüce Camii	Özlüce Mah.	Menteşe
M48	625899	4107435	611	1638	Cement, Limestone	11000	Limestone	Doğanköy Camii	Doğanköy Mah.	Menteşe
M84	579297	4098688	6	324	Concrete, Iron	10400	Limestone	Çamlık Camii	Çamlık Mah.	Bodrum
M47	625933	4107357	611	1660	Volcanic Rock	6200	Limestone	Çatakbağyaka Camii	Çatakbağyaka Mah.	Menteşe
M80	589540	4099627	400	357	Concrete, Limestone, Red Tiles	6000	Schist	Kapubağ Camii	Kapubağ Mah.	Yatağan
M58	624625	4114379	638	954	Concrete	5830	Serpentinite	Kızlan Camii	Kızlan Mah.	Datça

Only about 0.5% of the radon gas concentrations measured in all the minarets in Muğla Province (841 units) are above 1000 Bq/m^3, and also overall about 10% were found to be above EIRRV (200 Bq/m^3) (Figure 7). Although the average highest SRC was found in Bodrum district (Gürece town, 120000 Bq/m^3) where the foundations were formed by volcanic rocks, and the lowest SRC was obtained in the Datça district (Kızlan town, 5830 Bq/m^3) where the serpentinites outcropped in the Muğla province. The highest ICR was measured in a minaret made of volcanic rocks in Marmaris district (Çetibeli town, 2809 Bq/m^3) (Table 1).

Discussion

Approximately 10% of the IRCs, which were carried out in 841 minarets in Muğla Province and 50 houses in Bitlis province, was found to be above the EIRRV (200 Bq/m^3) (Kuluöztürk et al., 2019). Although the highest IRC was found to be 2809 Bq/m^3 according to the measurement result of IRCs made in 841 minarets in Muğla province, the highest IRC was 130.2 Bq/m^3 for the measurement result of the ICRs made in 37 houses in Kahrizak, a city in Iran (Askari et al., 2019). The main reason for the difference in the IRCs of these two structures may be due to the differences in the building materials (volcanic rock, brick, concrete, etc.), geological formation and fault activities. The minaret with the highest ICR (2809 Bq/m^3) in the Marmaris district is made of volcanic rocks, despite the fact that the Tower of Hercules, built in the Roman Period in the city of Corunna in Spain, is made of granites and has a very high IRC (149.7 mBq/m^2.s) (Frutos et al., 2021). Minarets are generally built with such building materials as concrete, volcanic rock, red brick, limestone, etc., even though there are different geological basement rocks (predominantly volcanic rocks, peridotites, limestones, etc.) in Muğla province.

In Romania, SRC ranged between 0-500000 Bq/m^3 (Burghele et al. 2019), but in Muğla province it was found between 0-120000 Bq/m^3. Alluvial deposits of volcanic rocks have the highest SRC (Vilcapoma et al., 2019). The highest SRC was measured as 120000 Bq/m^3 since the basement rock is volcanic rock in the Bodrum district of Muğla province. However, the lowest SRC was determined as 5830 Bq/m^3 in the Datça district of Muğla province where the basement rock is peridotite (serpentinite). Granitic and igneous rocks have very high radon concentrations, compared to other rock types (Kemski et al., 2009; Tositti et al., 2017).

SRC reaches its highest level at the fault line (Al-Tamimi and Abumurad, 2001; Ioannides et al., 2003; Sun et al., 2018). Measurements made in the soil perpendicular to the fault lines near the 14 minarets in Muğla province revealed that there may be quite high radon concentrations on the lines. The fault lines deform the base of minarets with earthquakes. The radon gas in the soil enters the minarets and increases the IRC as a result of porosity, permeability, fracture, crack, etc. formed by this deformation.

Limitations

There are some deficiencies and limitations in our studies. Since the minarets are historical and belong to the state, no samples could be taken from the building materials of the minarets, so a detailed geochemical and petrographic study could not be carried out. Due to the limited budget of the project, IRC measurement of 841 minarets could be made for a short time (average 20 minutes) instead of long-term (1 year). In addition, soil gas permeability measurements could not be made in SRC measurement areas. It makes it difficult to correlate with each other due to the fact that the building blocks and architectures of many minarets differ.

Conclusion

The qualitative presence of the factors (Qm, Qg, Qf) affecting Qt in the faulted zones was determined according to the IRC carried out at 841 minarets and SRC performed on the faults nearby 14 minarets in Muğla Province. In the radon gas measurements made from minarets with faults or possible faults in their vicinity and the areas where these minarets are located, it has been determined that the factors (Qm, Qg, Qf) affecting Qt have a relationship in the form of Qf>Qg>Qm between their sizes. The minaret with the highest IRC (2809 Bq/m^3) was made of volcanic rocks in Marmaris district (Çetibeli town). However, the basement rock under the minaret with the highest SRC (120000 Bq/m^3) is volcanic rock in Bodrum district (Gürece town). As a result, in all buildings where people live, IRC measurement should be made periodically and regularly by the relevant institutions, and it should be monitored whether it is over EIRRV (200 Bq/m^3).

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References

Al-Tamimi, M.H., Abumurad, K.M. (2001). Radon anomalies along faults in North of Jordan. *Radiation Measurements* 34, 397–400.

Askari, M., Hassanvand, M.S., Naddafi, K., Zarei, A., Yousefi, M., Alimohammadi, M. (2019). Assessment of indoor radon concentration in residential homes and public places in south of Tehran, Iran. *Environmental Earth Sciences*, 78(10), 1-10.

Bossew, P., Petermann, E. (2022). Radon hazard vs. radon risk – consequences for radon abatement policy, *EGU General Assembly 2022*, Vienna, Austria, 23–27 May 2022, EGU22-3145, doi.org/10.5194/egusphere-egu22-3145.

Bossew, P., Zunic, Z.S., Stojanovska, Z., Tollefsen, T., Carpentieri, C., Veselinovic, N., Komatina, S., Vaupotic, J., Simovic, R.D., Antignani, S., Bochicchio, F. (2014). Geographical distribution of the annual mean radon concentrations in primary schools of Southern Serbia - application of geostatistical methods. *Journal of Environmental Radioactivity* 127, 141-148.

Burghele, B., Ţenter, A., Cucoş, A., Dicu, T., Moldovan, M., Papp, B., Szacsvai, K., Neda, T., Suciu, L., Lupulescu, A., Maloş, C., Florică, Ş., Baciu, C., Sainz, C. (2019). The FIRST large-scale mapping of radon concentration in soil gas and water in Romania. *Science of the Total Environment* 669, 887–892.

CELA, (2014). Radon in Indoor Air: A Review of Policy and Law in Canada.

Coletti, C., Ciotoli, G., Benà, E., Brattich, E., Cinelli, G., Galgaro, A., Massironi, M., Mazzoli, C., Mostacci, D., Morozzis, P., Mozzi, P., Nava, J., Ruggiero, L., Sciarra, A., Tositti, L., Sassi, R. (2022). The assessment of local geological factors for the construction of a Geogenic Radon Potential map using regression kriging. A case study from the Euganean Hills volcanic district (Italy), *Science of The Total Environment*, Volume 808, 152064, ISSN 0048-9697, https://doi.org/10.1016/j.scitotenv.2021.152064.

Collins, A.S., Robertson, A.H.F. (1998). Processes of Late Cretaceous to Late Miocene episodic thrust-sheet translation in the Lycian Taurides, SW Turkey. *Journal of the Geological Society*, 155(5), 759–772. doi:10.1144/gsjgs.155.5.0759.

Çelebi, N., Ataksor, B., Taşkın, H. (2014). Konutlarda Radon Ölçümleri (Teknik Rapor). Türkiye Atom Enerjisi Kurumu (TAEK) (In Turkish).

Darby, S., Hill, D., Auvinen, A., Barros-Dios, J.M., Baysson, H., Bochicchio, F., Deo, H., Falk, R., Forastiere, F., Hakama, M., Heid, I., Kreienbrock, L., Kreuzer, M., Lagarde, F., Makelainen, I., Muirhead, C., Oberaigner, W., Pershagen, G., Ruano-Ravina, A., Ruosteenoja, E., Rosario, A.S., Tirmarche, M., Tomasek, L., Whitley, E., Wichmann, H.E., Doll, R. (2005). Radon in Homes and Risk of Lung Cancer: Collaborative Analysis of Individual Data from 13 European Case-Control Studies. *British Medical Journal*, 330, 223. doi.org/10.1136/bmj.38308. 477650.63.

Demoury, C., Ielsch, G., Hemona, D., Laurent, O., Laurier, D., Clavel, J., Guillevic, J. (2013). A statistical evaluation of the influence of housing characteristics and geogenic radon potential on indoor radon concentrations in France. *Journal of Environmental Radioactivity* 126, 216-225.

Durrani, S.A. (1999). Radon concentration values in the field: correlation with underlying geology. *Radiation Measurements* 31, 271-276.

Ercan, T., Günay, E., Türkecan, A. (1984). Geology of Bodrum peninsula. *Bull. Miner. Res. Explor. Inst. Turk*, 97(98), 21-32.

Frutos, B., Martín-Consuegra, F., Alonso, C., Perez, G., Peón, J., Ruano-Ravina, A., Barros, J.M., Santorun, A.M. (2021). Inner wall filler as a singular and significant source of indoor radon pollution in heritage buildings: An exhalation method-based approach. *Building and Environment*, 201, 108005.

Gürer, Ö.F., Yılmaz, Y. (2002). Geology of the Ören and surrounding areas, SW Anatolia. *Turkish Journal of Earth Sciences*, 11(1), 1-13.

Gürer, Ö.F., Sanğu, E., Özburan, M., Gürbüz, A., Sarica-Filoreau, N. (2013). Complex basin evolution in the Gökova Gulf region: implications on the Late Cenozoic tectonics of southwest Turkey. *International Journal of Earth Sciences*, 102, 2199-2221.

Ioannides, K., Papachristodoulou, C., Stamoulis, K., Karamanis, D., Pavlides, S., Chatzipetros, A., Karakala, E. (2003). Soil gas radon: a tool for exploring active fault zones. *Applied Radiation and Isotopes* 59, 205–213.

Kemski, J., Klingel, R., Siehl, A., Valdivia-Manchego, M. (2009). From radon hazard to risk prediction-based on geological maps, soil gas and indoor measurements in Germany. *Environ Geol* (2009) 56:1269–1279 doi.10.1007/s00254-008-1226-z.

Kuluöztürk, M.F., Büyüksaraç, A., Özbey, F., Yalçin, S., Doğru, M. (2019). Determination of indoor radon gas levels in some buildings constructed with Ahlat stone in Ahlat/Bitlis. *International Journal of Environmental Science and Technology*, 16(9), 5033-5038.

Madureira, J., Paciencia, I., Rufo, J., Moreira, A., Fernandes, E.O., Pereira, A. (2016). Radon in indoor air of primary schools: determinant factors, their variability and effective dose. *Environ Geochem Health*, 38:523–533 doi.10.1007/s10653-015-9737-5.

Moreno, V., Baixeras, C., Font, L., Bach, J. (2008). Indoor radon levels and their dynamics in relation with the geological characteristics of La Garrotxa, Spain. *Radiation Measurements* 43, 1532–1540.

MTA, (2002). 1:500.000 scale Geological Inventory map Series of Turkey, DENIZLI, Maden Tetkik Arama Genel Mudurlugu, Ankara, Turkey.

MTA, (2011a). 1:250.000 scale Active Fault Map Series of Turkey, AYDIN (NJ35-11) quadrangle, serial no:7, Maden Tetkik Arama Genel Mudurlugu, Ankara, Turkey

MTA, (2011b). 1:250.000 scale Active Fault Map Series of Turkey, MARMARIS (NJ35-15) quadrangle, serial no:8, Maden Tetkik Arama Genel Mudurlugu, Ankara, Turkey

Neri, M., Giammanco, S., Leonardi, A. (2019). Preliminary Indoor Radon Measurements Near Faults Crossing Urban Areas of Mt. Etna Volcano (Italy). *Front. Public Health* 7:105. doi: 10.3389/fpubh.2019.00105.

Park, T.H., Kang, D.R., Park, S.H., Yoon, D.K., Lee, C.M. (2018). Indoor radon concentration in Korea residential environments. *Environmental Science and Pollution Research* 25:12678–12685, doi.org/ 10.1007/s11356-018-1531-3.

Pişkin, Ö., Bertrand, J. (1980). Les minéralisations de plomb, zinc et cuivre de Kadikalesi (Presqu'île de Bodrum - Turquie). In: *Schweizerische mineralogische und petrographische Mitteilungen*, 60(1), 45-68. doi: 10.5169/seals-46657.

Ravina, A.R., Kelsey, K.T., Villar, A.F., Dios, J.M.B. (2017). Action levels for indoor radon: different risks for the same lung carcinogen, doi.org/10.1183/13993003.01609-2017

Scheib, C., Appleton, J.D., Miles, J.C.H., Green, B.M.R., Barlow, T.S., Jones, D.G. (2009). Geological controls on radon potential in Scotland. *Scottish Journal of Geology*, 45, 147-160, 1.

Stojanovska, Z., Boev, B., Zunic, Z.S., Ivanova, K., Ajka, S., Boev, I., Curguz, Z., Kolarz, P. (2019). Factors Affecting Indoor Radon Variations: A Case Study in Schools of Eastern Macedonia. *Romanian Journal of Physics*, 64 (1-2). Art. No.-801. ISSN 1221-146X.

Sun, X., Yang, P., Xiang, Y., Si, X., Liu, D. (2018). Across-fault distributions of radon concentrations in soil gas for different tectonic environments. Vol. 22, No. 2, p. 227-239, http://dx.doi.org/10.1007/s12303-017-0028-2, pISSN 1226-4806 eISSN 1598-7477.

Tositti, L., Giorgia Cinelli, G., Brattich, E., Galgaro, A., Domiziano Mostacci, D., Mazzoli, C., Massironi, M., Sassi, R. (2017). Assessment of lithogenic radioactivity in the Euganean Hills magmatic district (NE Italy). *Journal of Environmental Radioactivity* 166, 259-269.

UNSCEAR, (1958). Report of The United Nations Scientific Committee on the Effects of Atomic Radiation. General Assembly, Official Records: Thirteenth Session, Supplement No.17 (A/3838), Newyork, USA.

UNSCEAR, (1977). Sources and Effects of Ionizing Radiation. United Nations Scientific Committee on the Effects of Atomic Radiation, Report to the General Assembly, with annexes, New York, USA.

UNSCEAR, (2016). Sources, Effects And Risks Of Ionizing Radiation. Report to the General Assembly, with annexes, New York, USA.

Vilcapoma, L.L., Herrera, M.E.L., Pereyra, P., Palacios, D.F., Bertin Pérez, B., Rojas, J., Sajo-Bohus, L. (2019). Measurement of radon in soils of Lima City - Peru during the period 2016-2017. *Earth Sci. Res. J*. Vol. 23, No. 3: 171-183.

Wang, H., Zhang, L., Gao, P., Guo, Q. (2022). A pilot survey on indoor radon concentration in Beijing, *Radiation Medicine and Protection*, ISSN 2666-5557, doi.org/10.1016/j.radmp.2022.01.003.

WHO, (2009). Handbook on Indoor Radon: a Public Health Perspective. WHO Press, Geneva.

Appendixes

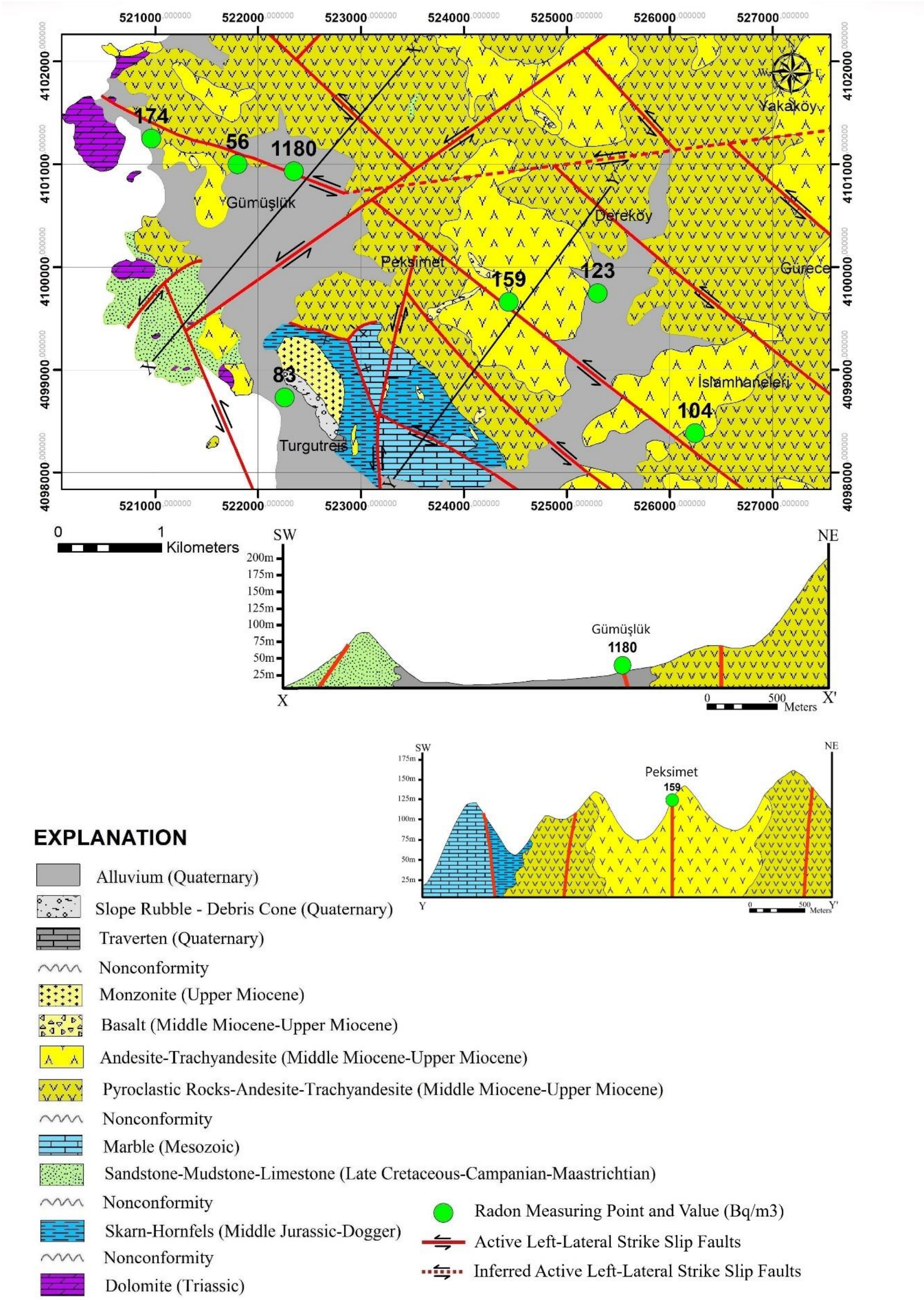

Fig. 8. Associating the IRC of the minarets with the Geological Model (GM) (Bodrum district) (Geology and Fault Maps are modified from MTA, 2002, 2011a, 2011b).

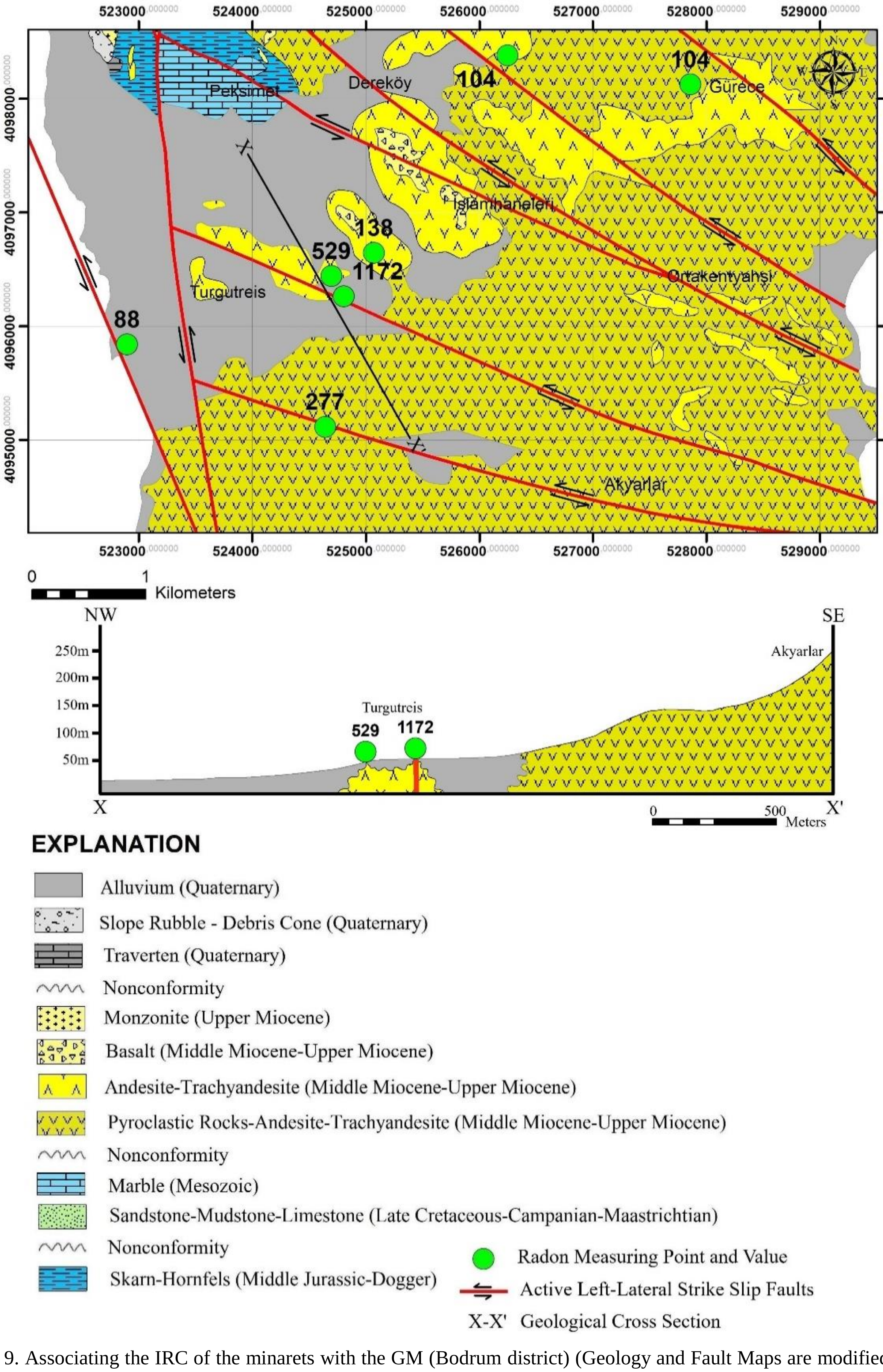

Fig. 9. Associating the IRC of the minarets with the GM (Bodrum district) (Geology and Fault Maps are modified from MTA, 2002, 2011a, 2011b).

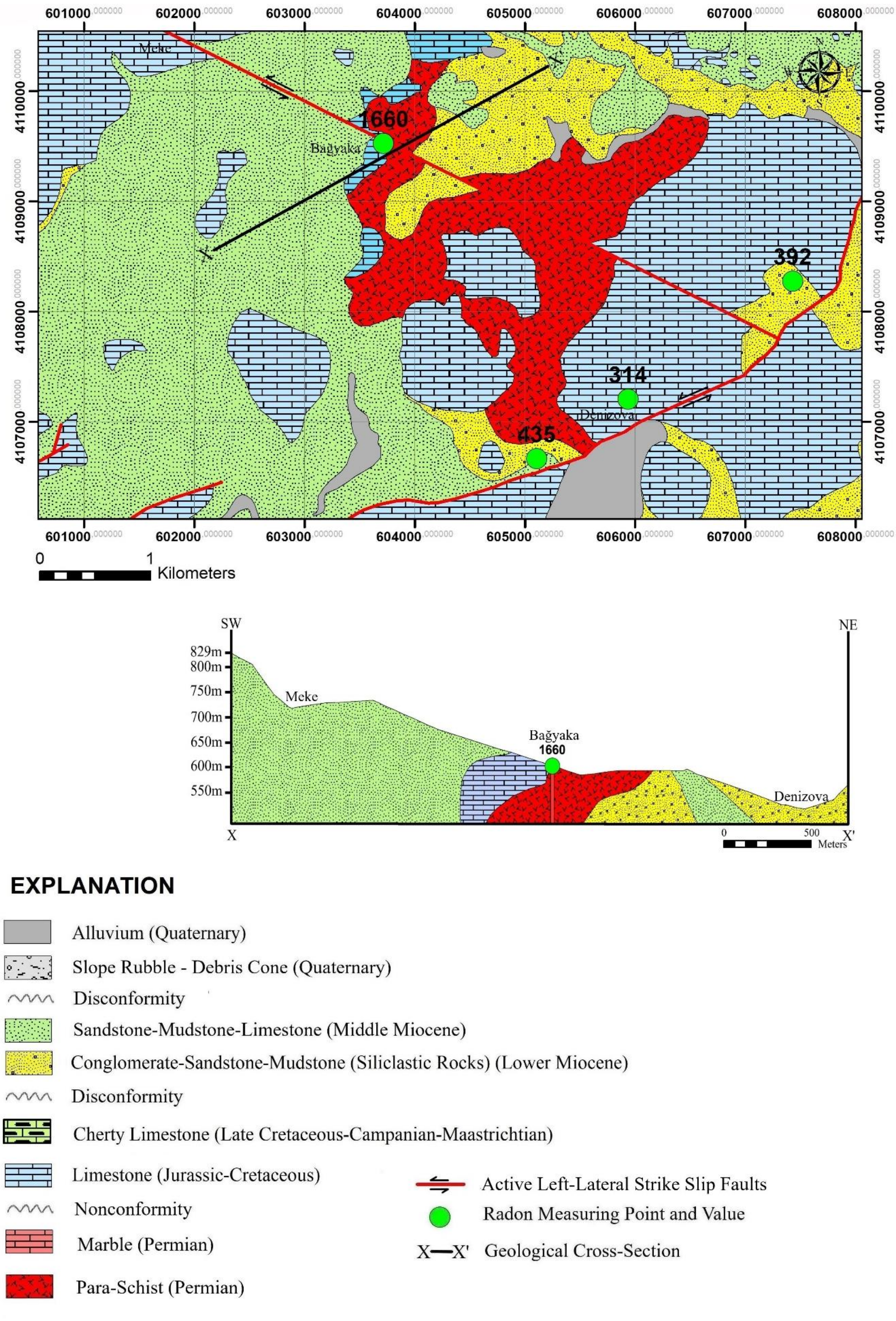

Fig. 10. Associating the IRC of the minarets with the GM (Menteşe district) (Geology and Fault Maps are modified from MTA, 2002, 2011a, 2011b).

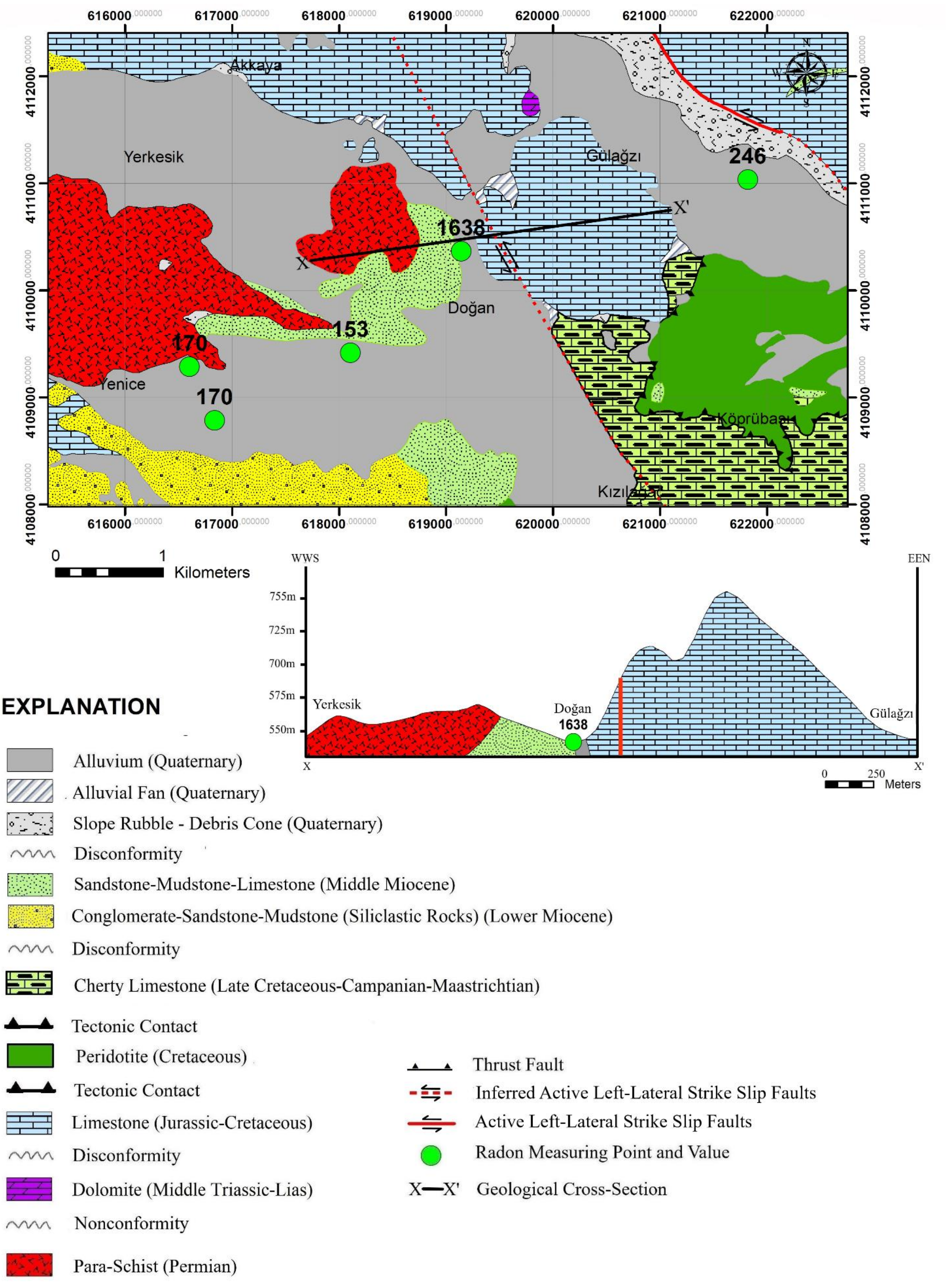

Fig. 11. Associating the IRC of the minarets with the GM (Menteşe district) (Geology and Fault Maps are modified from MTA, 2002, 2011a, 2011b).

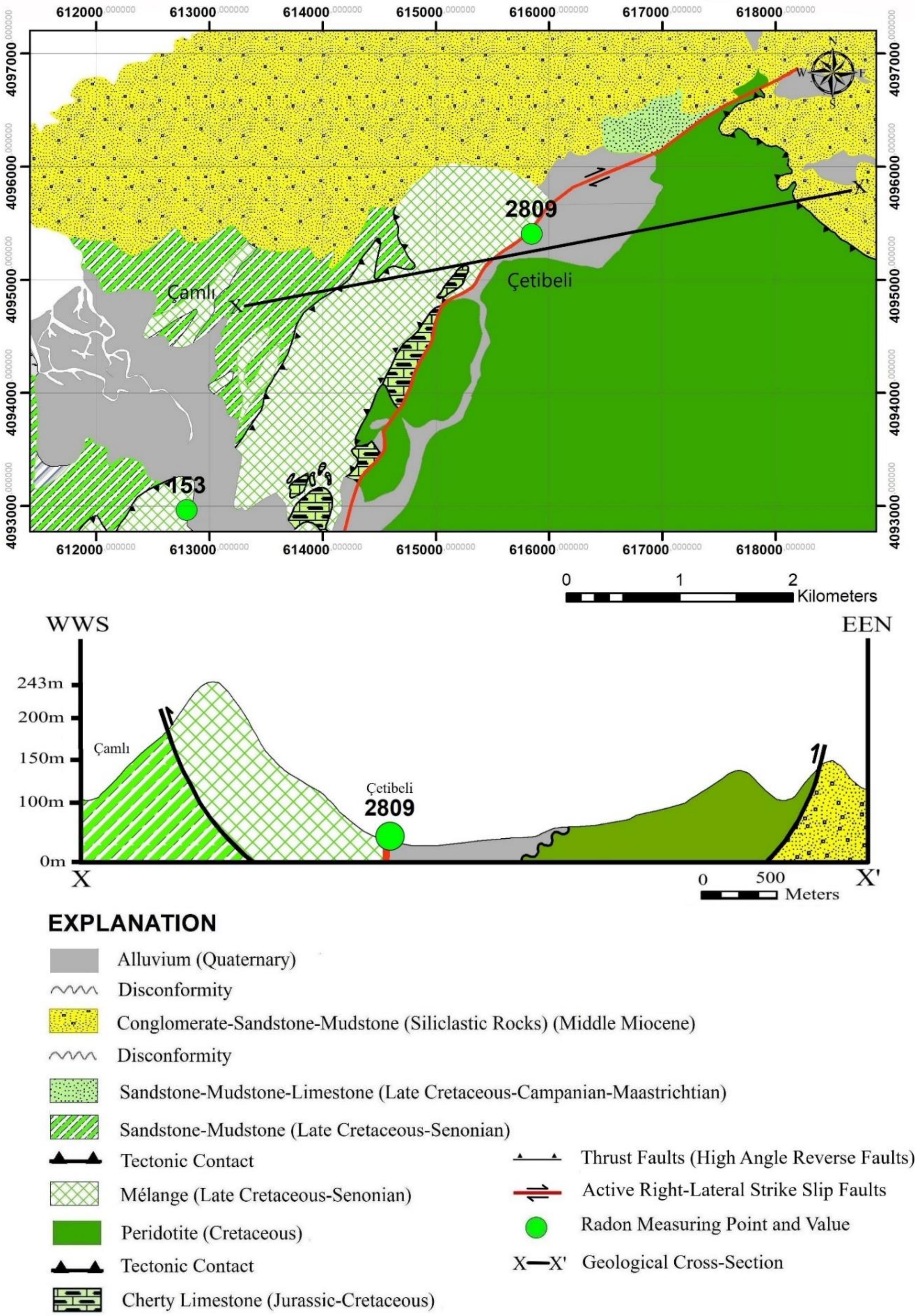

Fig. 12. Associating the IRC of the minarets with the GM (Marmaris district) (Geology and Fault Maps are modified from MTA, 2002, 2011a, 2011b).

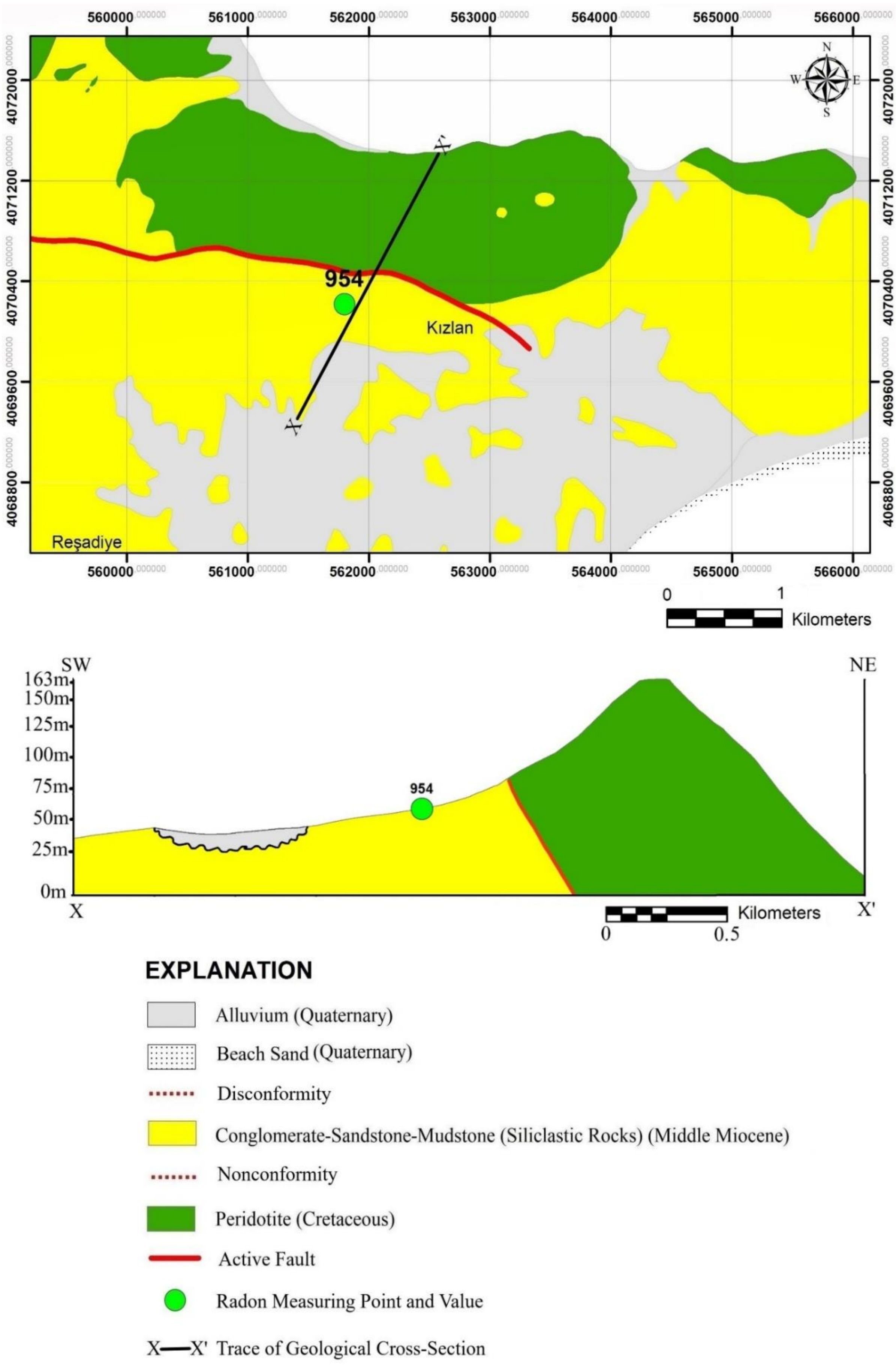

Fig. 13. Associating the IRC of the minarets with the GM (Datça district) (Geology and Fault Maps are modified from MTA, 2002, 2011a, 2011b).