RELATION BETWEEN HYDRODYNAMICS OF GOKPINAR SPRINGS AND FAULT ZONES DENIZLI –TURKEY

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Abstract— In this study, it is aimed to determine the relation between the hydrodynamics of the Gokpinar and Derindere drinking water springs and fault mechanisms in the east of Denizli city center. These springs with average 1,211 m^3/s discharges are the most contributing springs to Denizli city center drinking water. These waters do not require any treatment to meet drinking water standards. This area, which has high ground water capacity, also has high earthquake activity. The intense tectonic forces and active faults that control the regional morphology also play a major role in the formation of natural water springs. There are geological units which have differences in lithology, origin and hydrogeology in the drainage basins of the springs. Within these units, whose original characteristics are generally heterogeneous and anisotropic, weak zones and discontinuities have been formed due to the effects of tectonic stresses over time. This discontinuities, hydrogeologically, mean secondary porosity and high permeability and contribute significantly to the groundwater movement, especially near the main faults. The groundwater movement in the basin and the spring yields depend on the size and location of the tectonic discontinuities rather than the primary porosity of the units. Nearly all of the springs in the region are in the "tectonic springs" class. Along the slopes of the mountainous areas within the basin are many large and small springs. The majority of the water springs in the study area are located at the intersection of fault zones. The best examples are Gokpınar and Derindere springs.

Index Terms— Denizli, Gokpinar, Derindere, Groundwater.

I. INTRODUCTION

The research area is located in the basin of intersection of the Buyuk Menderes and Gediz grabens in the Aegean region, one of the most active seismic regions of Turkey and dominated by expansion tectonics. Babadag and Denizli faults in the south and Pamukkale - Karahayıt faults in the north. The Denizli Basin as a whole is bounded in the north by the Cokelez Horst and in the south by the Babadag Horst and in the east by the Honaz Horsts [1]. This region has great ground water capacity and high earthquake activity. According to the geographical coordinate system, it covers an area of approximately 350 km^2 between $29^0.04'.30'' - 29^0.18'.42''$ east longitudes and $37^0.37'.30''$ $37^0.46'$ $30''$ northern latitudes (Fig. 1). The region is currently experiencing an approximately N–S continental extension. The elevation of the investigation area, which has a rough topographical structure, varies between 350 and 2570 meters. The intense tectonic forces and active faults that control the regional morphology also play a major role in the formation of natural water springs ranging from 1 to 1100 l / s. The water springs in this region are the most contributing sources to Denizli city center drinking water.

This study presents an approach for defining the areas of drinking water supply springs in Denizli. The approach is based on the use of available data and limited geological, geophysical and hydrogeological field investigation. In the approach, data from different springs were compiled and analyzed and field studies were conducted to develop a standing of the spring's hydrodynamic properties. For this purpose, firstly geological features of the region and its immediate surroundings were examined and a geological map and cross section with a scale of 1/25000 was prepared (Fig. 2) [2]. Then, using hydrogeological data and by applying geophysical methods (Resistivity profiles, multiple electrode arrays, seismic refraction and ground radar) the effect of faults on groundwater flow and transport investigated.

II. REGİONAL TECTONİCS AND GEOLOGY

The West Anatolian Horst-Graben System (WAHGS) extends from the Aegean Sea to central Anatolia (Fig. 1, 2) and it is one of the most rapidly deforming regions [1], [3]–[27]. It is characterized mainly by E–W trending major horsts and grabens, and NW–SE to NE–SW oriented relatively short and locally suspended cross-grabens [21], contained within the major E–W trending horsts. The lithostratigraphic units that outcrop in the study area range in age from upper Palaeozoic to the Holocene (Fig. 2). The basement rocks are represented by metamorphic rocks, Mesozoic marine carbonate sequences of the Lycian Nappes, ophiolitic mélange and Oligocene continental sedimentary rocks. Graben fill consists mainly the alluvial-colluvial fan, fluvial deposits and travertines, overlies the Neogene ancient graben fill [28].

III. HYDROGEOLOGY

There are geological units in the drainage basins of the Gokpinar Springs, which are different in terms of

lithology, origin and hydrogeology. Within these units, whose original characteristics are generally heterogeneous and anisotropic, weak zones and discontinuities have been formed due to the effects of tectonic stresses over time. This discontinuities, hydrogeologically, mean secondary porosity and high permeability and contribute significantly to the groundwater movement, especially near the main faults. Geological and geophysical studies have shown that the groundwater movement in the basin and the spring yields depend on the size and location of the tectonic discontinuities rather than the primary porosity of the units. Nearly all of the springs in the region are in the "tectonic springs" class.

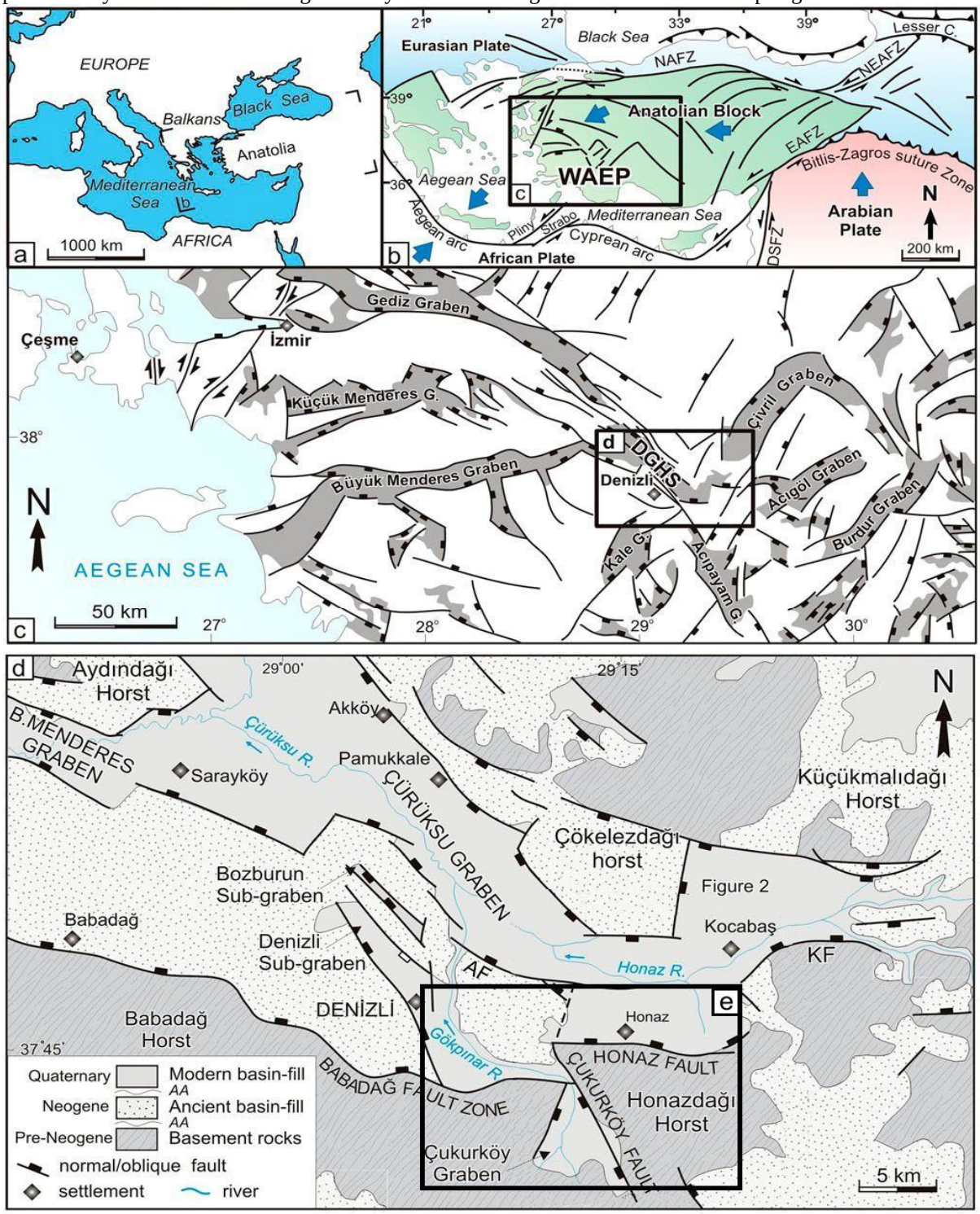


Fig. 1. (a) Tectonic outline of eastern Mediterranean area (compiled from Kaymakci, 2006). (b) Simplified map showing the major active basins in western Anatolia (compiled from Kaymakci, 2006). Abbreviations: WAEP, West Anatolian Extensional Provinces; DSFZ, Dead Sea Fault Zone; EAFZ, East Anatolian Fault Zone; NAFZ, North Anatolian Fault Zone; (c) West Anatolian Extensional Provinces (compiled from Kaymakci, 2006). Abbreviations: DGHS, Denizli Graben Horst System; (d) Simplified Geologic map showing the Denizli Graben Horst System (compiled from Kocyigit, 2005). Abbreviations: AF, Akkale fault; KF, Kaklik Fault [29]. (e) Study Aarea.

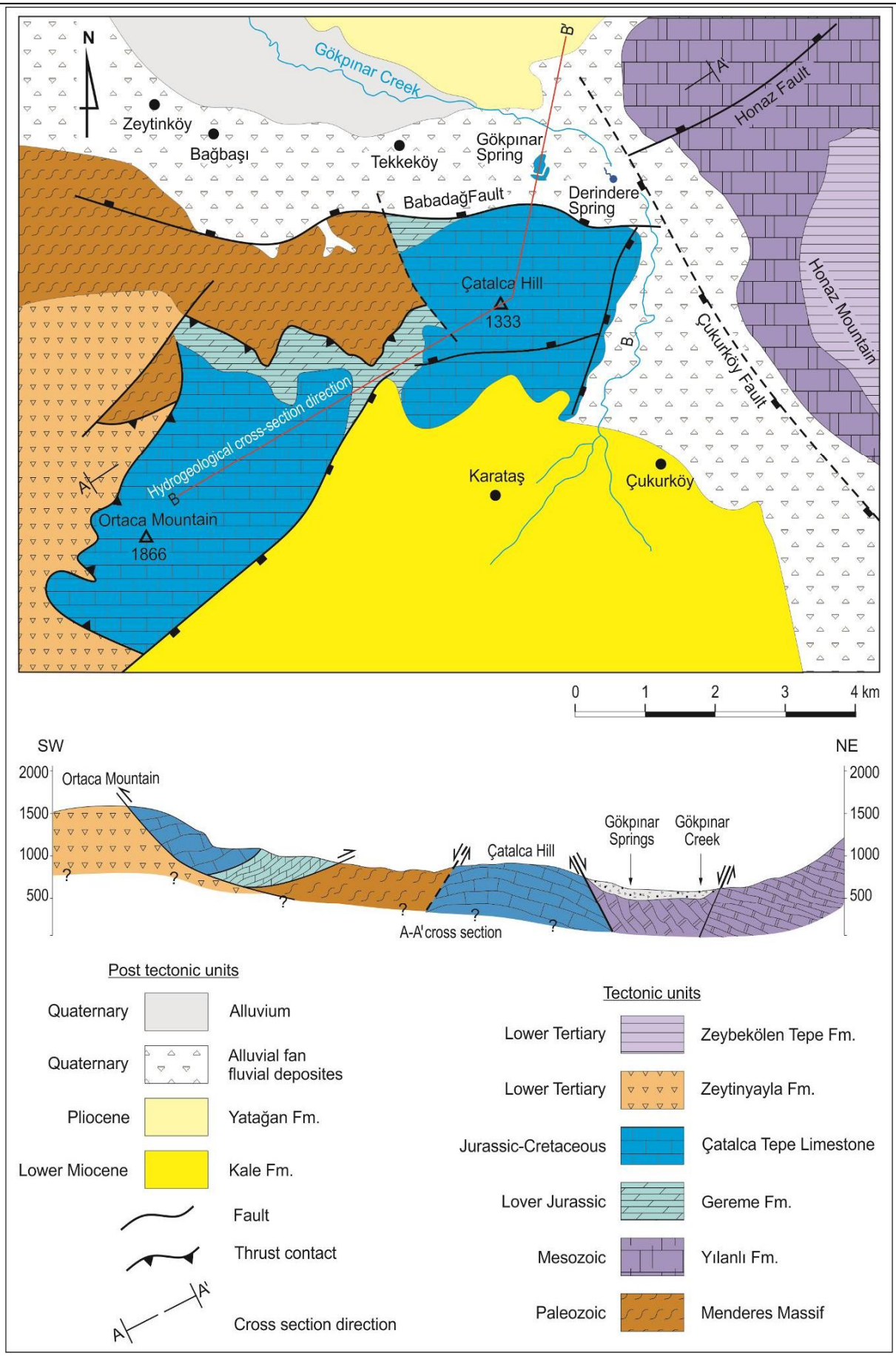


Fig. 2. Geological map and cross section of the study area (modified from Okay, 1989) [31].

Along the slopes of the mountainous areas within the basin are many large and small springs. Some of these springs dries up in the summer months, depending on natural and artificial reasons. Others flow all seasons. Yields of some major springs as m^3/s: Gokpinar 0,849; Derindere 0,362; Yukari santral 0,04; Bentpinari 0,130; Kozlupinar 0,100; Pinarbasi 1,131; Mesut Pinari 0,012; Gokcen Pinari 0,030; Turgut Pinari 0,070 [30], [31]. Gokpinar and Derindere springs are located in the catchment area of Gokpinar Dam, north of the Catalca Hill. Waters of these springs flow to Gokpinar Creek.

Tectonic structures, specifically faults, influence the distribution and movement of groundwater in the geological units and so can be one of the important component of groundwater and hydrogeological processes [32]. Hydrogeological properties are believed to be highly anisotropic in fault zones. Vertical or near-vertical faults are generally may be described as being a barrier in to horizontal flow direction throughout the fault [32], [33]. The faulting mechanism and movement type is a significant parameter in the hydrogeological behavior. Normal tension faults have a greater capacity for groundwater flow, according to reverse faults and strike-slip faults with compressive conditions [32], [34]. Because fault zones in the region are generally vertical with hydraulic gradients, faults tend to aggregate groundwater. Groundwater is thus flow along faults to their near intersections. The groundwater collected by different trending and high permeability fault zones (e.g. Babadag, Honaz and Cukurkoy Faults) is transported along their margins towards the topographic depressions (Gokpinar and Derindere Springs). These intersection areas normally have relatively high permeability. Thus, the most important springs of the region are located at this intersection (Gokpinar and Derindere Springs).

Babadag Fault, which its location and boundaries determined in detail with the geophysical profiles, forms the southern boundary of the Buyukmenderes Graben. The aquifer units, which extend to much wider areas outside the study area, are located in mountainous areas (Catalca Tepe, Ortaca Dagi) on the south side of Babadag Fault. This extension fault, which is east-west oriented, has brought the aquifers in the south and the impervious units in the north to level. On the footwall block, due to the erosion of the impermeable units above, the karstic lime stones below have been directly recharged from the precipitation. On the other hand, the impermeable units on the hanging block form a horizontal barrier against the flow of groundwater from the limestone to the north. With this tectonic structure, ground waters within the limestone, which obtained confined aquifer characteristics around the fault plane, flowed to the surface and formed the most efficient drinking water springs of the region. The ground waters of all the sedimentary formations in the plain areas to the north of Babadag Fault are recharged from ground waters of the high mountains in the south. The springs are located where the ground water reaches to the surface in the plain near the hillside, in other words where the surface and the water table intersect.

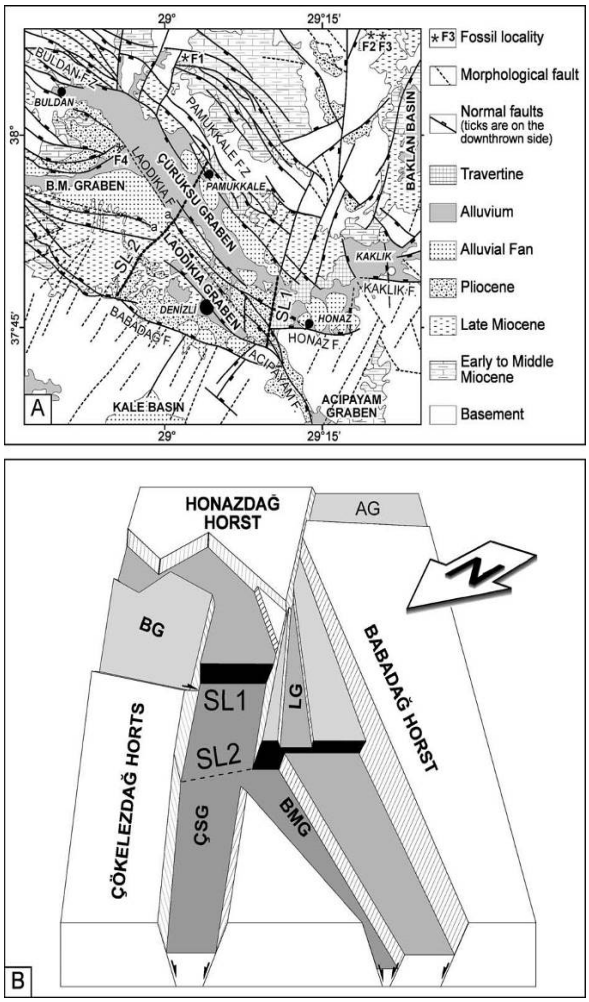


Fig. 3. (A) Geological map of Denizli Basin prepared from 500,000 scale Geological Map of Turkey (General Directorate of Mineral Research and Exploration-MTA, Ankara/Turkey), Landsat ETMC image and SRTM data. a–a^0: 1.5 km displacement along SL2, B.M.Graben: Buyukmenderes Graben, F1–F4: fossil localities, F.Z.: Fault Zone,.SL1 and SL2: subsurface structures. Numbers around the map are UTM coordinates (Zone 35, Map Datum: WGS84). (B) simplified block diagram of the Denizli Basin. Basin infill is not drawn. AG: Acıpayam Graben, BG: Buyukmenderes Graben, CSG: Curuksu Graben, LG: Laodikia Graben [1].

Total discharge of Gokpinar and Derindere springs is 1,211 m3/s. The average annual precipitation of Denizli Province between years of 1981-2010 is 583.8 mm. [35]. About 60 percent of annual precipitation (350,3 mm) is returned to the atmosphere via evapotranspiration. The remaining amount of precipitation water after evaporation is 233,5 mm. In limestone, which are reserves of springs, the estimated rate of infiltration from rainfall is between 35% and 45%. This means an average of 81,7-105,0 mm per year. With this infiltration rate, the required area for

the springs is 467-363 km^2. However, the surface area of these limestone is about 40 km^2. This is a natural situation. The hydrological and hydrogeological divides of a catchment may be different from each other. This area is very inadequate for springs with a discharge of 1,211 m^3/s. In this case, it is obvious that other permeable and semi-permeable units higher than the spring elevation and located on the footwall block of the Babadag fault also contribute to the spring aquifers. Likewise, Cukurkoy and Honaz Faults are estimated to have contributed significantly to both springs, especially Derindere Spring.

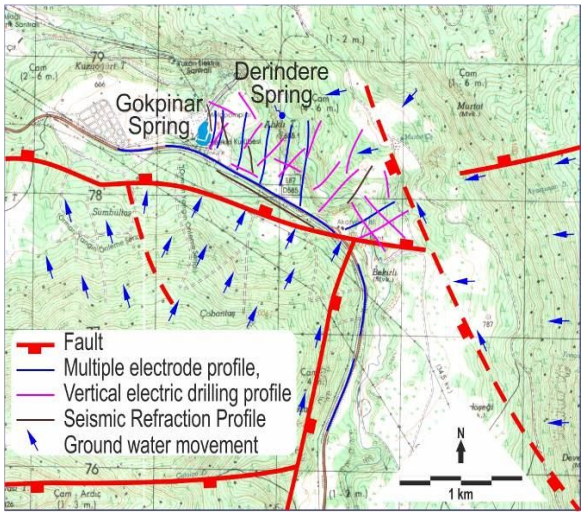


Fig. 4. Locations of geophysical methods profiles which multiple electrode, vertical electric drilling and seismic refraction.

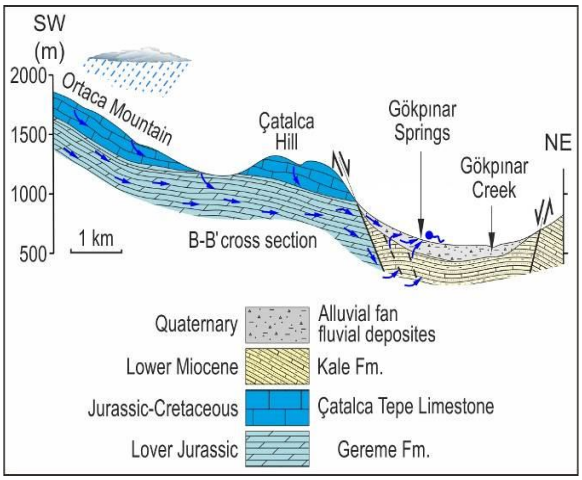


Fig. 5. Hydrogeological cross section of the study area

CONCLUSION

The study area is a seismically active region that has experienced destructive earthquakes that have occurred in both historical and instrumental periods. The distribution of springs fields in study area, closely follow the tectonic patterns. All of the springs in study area are clearly related to the block faulting. The lithostratigraphic units outcropted in the area range in age from upper Palaeozoic to the Holocene. Total discharge of Gokpinar and Derindere springs is 1,211 m^3/s. The average annual precipitation of Denizli Province between years of 1981-2010 is 583.8 mm. The annual evapotranspiration is about 60 percent of the precipitation. The remaining precipitation is 233,5 mm. The infiltration ratio into the aquifer rocks is between 35% and 45%. With this infiltration rate, the required area for the springs is 467-363 km^2 though the surface area of these limestone is about 40 km^2. This area is insufficient for present discharge. It shows that other permeable and semi-permeable units higher than the spring elevation and located on the footwall block of the Babadag fault also contribute to the spring aquifers. Likewise, Cukurkoy and Honaz Faults are estimated to have contributed significantly to both springs, especially Derindere Spring.

REFERENCES

[1] N. Kaymakci, "Kinematic development and paleostress analysis of the Denizli Basin (Western Turkey): implications of spatial variation of relative paleostress magnitudes and orientations," Journal of Asian Earth Sciences, 27 (2006) 207–222, 2006.

[2] A.İ. Okay, "Geology of the Menderes Massif and Lycian nappes in the South of Denizli," M.T.A. Dergisi 109, 45-58, (in Turkish), 1989.

[3] J.F. Dewey, A.M.C. Sengor, "Aegean and surrounding regions: complex multiple and continuum tectonics in a convergent zone," Geological Society America Bulletin 90, 84–92. Donath, F.A., 1962. Analysis of Basin-Range structure, south-central Oregon. Geological Society America Bulletin 73, 1–16, 1979.

[4] X. Le Pichon, J. Angelier, "The Aegean arc and trench system: a key to the neotectonic evolution of the Eastern Mediterranean area," Tectonophysics 60, 1–42, 1979.

[5] M.A. Alessio, S.J. Martel, "Fault terminations and barriers to fault growth," Journal of Structural Geology 26, 1885–1896, 2004.

[6] J.A. Jackson, D.P. McKenzie, "Active tectonics of the Alpine–Himalayan Belt between western Turkey and Pakistan," Geophysical Journal of the Royal Astronomical Society 7, 185–264, 1984.

[7] H. Eyidogan, J.A. Jackson, "A seismological study of normal faulting in the Demirci, Alasehir and Gediz earthquake of 1969–1970 in western Turkey: implications for the nature and geometry of deformation in the continental crust," Geophysical Journal of Royal Astronomical Society 81, 569–607. 1985.

[8] A.M.C. Sengor, "Cross-faults and differential stretching of hanging walls in regions of low-angle normal faulting: examples from western Turkey," In: Coward, M.P., Dewey, J.F., Hancock, P.L. (Eds.), Continental Extensional Tectonics. Geological Society London, Special Publications 28, pp. 575–589, 1987.

[9] T. Taymaz, J.A. Jackson, D.P. McKenzie, "Active tectonics of the north and central Aegean Sea," Geophysical Journal International 106, 433–490, 1991.

[10] G. Seyitoglu, B.C. Scott, "Late Cenozoic crustal extension and basin formation in west Turkey," Geological Magazine 128, 155–166, 1991.

[11] G. Seyitoglu, B.C. Scott, "The cause of N–S extensional tectonics in western Turkey: tectonic escape vs back-arc spreading vs. orogenic collapse," Journal of Geodynamics 22, 145–153, 1996.

[12] G. Seyitoglu, B.C. Scott, C.C. Rundle, "Timing of Cenozoic extensional tectonics in west Turkey," Journal of Geological Society London 149, 533–538, 1992.

[13] R. Westaway, "Evidence for dynamic coupling of surface processes with isostatic compensation in the lower crust during active extension of western Turkey," Journal of Geophysical Research 99, 20203–20223, 1994.

[14] C. Straub, H.-G. Kahle, C. Schindler, "GPS and geologic estimates of the tectonic activity in the Marmara Sea region, NW

Anatolia," Journal of Geophysical Research 102, 27587–2760, 1997.
[15] A.L.W. Lips, "Temporal constraints on the kinematics of the destabilization of an orogen: syn-to post-orogenic extensional collapse of the Northern Aegean region," PhD Thesis, Utrecht University, The Netherlands. Geologica Ultraiectina No.166, 222 pp, 1998.
[16] C.R. Walcott, S.H. White, "Constraints on the kinematics of postorogenic extension imposed by stretching lineations in the Aegean region. Tectonophysics," 298, 155–175, 1998.
[17] A. Kocyigit, H. Yusufoglu, E. Bozkurt, "Evidence from the Gediz Graben for episodic two-stage extension in western Turkey," Journal of Geological Society London 156, 605–616, 1999.
[18] R.E. Reilinger, S.C. McClusky, "GPS constraints on block motions in western Turkey and the Aegean: implications for earthquake hazards. Proceedings of Symposium on Seismotectonics of the NW AnatoliaAegean and Recent Turkey Earthquakes," Istanbul, May 8, 2001.
[19] E. Bozkurt, "Timing of extension on the Buyukmenderes Graben, western Turkey, and its tectonic implications," In: E. Bozkurt, J.A. Winchester, J.D.A. Piper, (Eds.), Tectonics and Magmatism in Turkey and the Surrounding Area. Geological Society London, Special Publication 173, pp. 385–403, 2000.
[20] E. Bozkurt, "Neotectonics of Turkey—a synthesis," Geodinamica Acta 14, 3–30, 2001.
[21] E. Bozkurt, "Origin of NE-trending basins in western Turkey," Geodinamica Acta 16, 61–81, 2003.
[22] C.E. Duermeijer, M. Nyst, P.Th. Meijer, C.G. Langereis, W. Spakman, "Neogene evolution of the Aegean arc: paleomagnetic and geodetic evidence for a rapid and young rotation phase," Earth and Planetary Science Letters 176, 509–525, 2000.
[23] O.F. Gurer, N. Kaymakci, S. Cakır, M. Ozburan, "Neotectonics of Southeast Marmara Region (NW Anatolia Turkey)," Asian Journal of Earth Sciences 21, 1041–1051, 2003.
[24] A.L.W. Lips, D. Cassard, H. Sozbilir, Y. Yılmaz, "Multistage exhumation of the Menderes Massif, western Anatolia (Turkey)," 2001.
[25] S.C. McClusky, S. Balassanian, A.A. Barka, C. Demir, S. Ergintav, L. Georgiev, O. Gurkan, M. Hamburger, K. Hurst, H.G. Kahle, K. Kastens, G. Kekelidze, R. King, V. Kotzev, O. Lenk, S. Mahmoud, A. Mishin, M. Nadariya, A. Ouzounis, D. Paradissis, Y. Peter, M. Prilepin, R.E. Reilinger, I. Sanli, H. Seeger, A. Tealeb, M.N. Toksoz, G. Veis, "Global positioning system constraints on plate kinematics and dynamics in the Eastern Mediterranean and Caucasus," Journal of Geophysical Research 105, 5695–5720, 2000.
[26] R.E. Reilinger, S.C. McClusky, "GPS constraints on block motions in western Turkey and the Aegean: implications for earthquake hazards," Proceedings of Symposium on Seismotectonics of the NW AnatoliaAegean and Recent Turkey Earthquakes. May 8, 2001. Istanbul, 2001.
[27] A-S. Provost, J. Che´ry, R. Hassani, "3D mechanical modeling of the GPS velocity field along the North Anatolian fault," Earth and Planetary Science Letters 209, 361–377, 2003.
[28] A. Koçyiğit, "Denzili Graben-Horst System and the eastern limit of the west Anatolian continental extension: Basin fill, structure, deformational mode, throw amount and episodic evolutionary history, SW Turkey," Geodinamica Acta, 18, 167–208, 2005.
[29] C. Ozkaymak, "Tectonic analysis of the Honaz Fault (western Anatolia) using geomorphic indices and the regional implications," Geodinamica Acta, 27:2-3, 110-129, 2015.
[30] The Scientific and Technological Research Council of Turkey TUBITAK MAM Environmental Institute, "Preparation of Watershed Protection Action Plans - Buyukmenderes Basin," (in Turkish), 2012.
[31] Denizli Governorate Environment and Urban Province Directorate, "Provincial environmental situation report," (in Turkish), 2012.
[32] H. Rajabpour, A. Vaezihir, M. Hasanpour Sedghi, "The North Tabriz Fault, a barrier to groundwater flow in an alluvial aquifer northwest of Tabriz, Iran," Environ Earth Sci (2016) 75:849, 2016.
[33] E. Anderson, M. Bakker, "Groundwater flow through anisotropic fault zones in multi-aquifer systems," Water Resour Res 44: W11433, 2008.
[34] N. Goldscheider, D. Drew, "Method sinkarst hydrogeology," Taylor & Francis, International contributrions to hydrogeology, p 279, 2007.
[35] https://www.mgm.gov.tr/veridegerlendirme/yillik-toplam-yagis-verileri.aspx?m=DENIZLI#sfB (17.03.2017).

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