Turkish Journal of Earth Sciences (Turkish J. Earth Sci.), Vol. 20, 2011, pp. 161–165. Copyright ©TÜBİTAK
doi:10.3906/yer-1002-15 First published online 14 August 2010

Short Note on the Use of Neotectonic and Palaeotectonic Nomenclature

DOUWE J.J. VAN HINSBERGEN

Physics of Geological Processes, University of Oslo, Sem Sælands vei 24, 0316 Oslo, Norway
(E-mail: d.v.hinsbergen@fys.uio.no)

Received 26 February 2010; revised typescript receipt 11 August 2010; accepted 14 August 2010

Abstract: The terms 'palaeotectonic' and 'neotectonic' are entrenched in the literature of Anatolian geology, used to subdivide the tectonic history before and after the last major tectonic change, which is frequently linked to the Arabia-Eurasia collision and the onset of westward Anatolian escape along the North Anatolian Fault Zone. This short note, however, illustrates that many different authors use different definitions for the age and cause of onset, and style of 'neotectonics', leading to needless confusion in Turkish geological literature. In addition, in recent years it has become common practice to use the neotectonic period as a stratigraphic correlation tool, leading to interpretations of the age of sedimentary units ('neotectonic units') based on the inferred tectonic context in which they were deposited. This practice should be abandoned, and authors should in all cases return to classical stratigraphic and structural nomenclature. Based on the wide array of meanings that authors attach to the term 'neotectonic', it is advocated here that this terminology should be abandoned altogether, and replaced by simple description of what is meant. This call is meant to clarify geological literature, and to strictly separate observation and interpretation.

Key Words: neotectonic, palaeotectonic, Anatolia, Turkey, Greece, Aegean

Neotektonik ve Paleotektonik Terimlerinin Kullanılması Üzerene Kısa Not

Özet: 'Paleotektonik' ve 'Neotektonik' Anadolu jeolojisinin terminolojisine yerleşmiş terimler olup, çoğunlukla Arap ve Avrasya levhalarının çarpışması ile Anadolu'nun Kuzey Anadolu Fay Zonu boyunca batıya kaçmasına bağlanan en son büyük tektonik değişim öncesi ve sonrasındaki tektonik tarihçeyi tanımlamakta kullanılmaktadır. Ancak, bu kısa not değişik yazarların neotektoniğin başlangıç yaşı, nedeni ve sitilinin tanımı hakkında Türk jeoloji literatüründe gereksiz karışıklığa neden olan farklı görüşleri ileri sürdüklerini göstermektedir.

Bunlara ilaveten, son yıllarda neotektonik dönem çökeldikleri tektonik ortamlar dikkate alınarak sedimanter birimlerin yaşının yorumlanması (neotektonik birimler) için stratigrafik korelasyon aracı olarak da sıkça kullanılmaya başlandı. Bu yaklaşım terkedilmeli ve her durumda klasik stratigrafik ve yapısal adlama kurallarına geri dönülmelidir. Farklı yazarların neotektonik terimine yükledikleri farklı anlamlar dikkate alındığında, makalede bu terminolojinin terk edilmesi ve bunun yerine ne ifade edilmek isteniyorsa tanımlanarak kullanılması gerektiği savunulmaktadır. Bu çağrının amacı jeolojik literatürü berraklaştırmak, gözlemler ile yorumların kesinlikle ayrılması gerektiğini vurgulamaktır.

Anahtar Sözcükler: neotektonik, paleotektonik, Anadolu, Türkiye, Yunanistan, Ege

Introduction

The use of the adjectives 'neotectonic' and 'palaeotectonic' is common in the geoscientific literature on the Anatolian and Aegean region. However, these terms are only loosely defined, and interpretations on the timing of transition from a palaeotectonic to a neotectonic period vary from author to author. In recent years, the term 'neotectonic' has started to be applied not only to sets of structural features from a certain time period, but has also been used to depict stratigraphic intervals: neotectonic units (as in bodies of rock) (e.g., Koçyiğit & Deveci 2008; Piper *et al.* 2010). Moreover, many papers use this terminology without defining its meaning.

This short note argues that the use of this terminology leads to needless confusion, loss of valuable information and an inevitable mixing of

observation and interpretation. It also argues that applying tectonic interpretation as a dating and correlation mechanism is improper. Hence these terms should be abandoned, with a return to accurate description of observation and interpretation, using conventional stratigraphic and structural nomenclature.

These arguments are illustrated below, citing a series of papers on eastern Mediterranean geology. No questioning or criticism of the validity of the data and interpretations of these authors is intended: their work is merely used to illustrate the confusion that arises from the use of neotectonic and palaeotectonic terminology.

Definition of the Neotectonic Period

The term 'neotectonics' was introduced by Obruchev (1948), to summarise active tectonic processes. Later, the definition was widened to include all tectonic processes since the last major tectonic configuration change, and the establishment of the modern stress field (e.g., Hancock 1986; Slemmons 1991; Stewart & Hancock 1994).

Becker (1993) provided a useful and clear definition of the Neotectonic period that is used as the basis for this paper: "The 'neotectonic period' is the youngest period of tectonic activity and extends up to the present. The beginning of the neotectonic period during the Cenozoic may be regarded as having begun when characteristic changes in the tectonic evolution of a region of interest have occurred for the last time. Changes in the different tectonic facets, which characterise the evolution of a region, need not be simultaneous, and hence the times of the last change may differ between facets. This leads to the definition of a 'transitional time interval' wherein elements of both the 'palaeotectonic' and 'neotectonic' period are present. The length of this transitional time interval depends on the regional geological evolution. Where a broad transitional time interval exists, the beginning of the neotectonic period may be defined as the earliest time marker by when most of the characteristic changes of the tectonic evolution of the region had occurred."

Crucial parts of this definition, addressed below in the context of eastern Mediterranean geology, are (1) the onset of the neotectonic period may be diachronous; (2) the neotectonic period starts at the last tectonic change in a region and (3) the change from Palaeotectonic to Neotectonic periods may be diffuse, and its interpretation may vary from author to author. Most importantly, it is an *interpretation* of geological observations.

On the Use of the Neotectonic Period as Correlation Tool

The geological record is studied to reconstruct a tectonic history. Inference of the style of deformation relies on structural geological observations. Dating the activity of the observed structures relies e.g. on radiometric dating in conjunction with (micro-) structural and petrological observation, or on a combination of sedimentological analysis with stratigraphic dating tools such as bio-, magneto-, or cyclostratigraphy. The combination of such observations, which are entirely independent from interpreted tectonic periods or events, can be used for regional correlation, and lead to an *interpretation* of tectonic regimes through time. Dating rock records based on the interpretation of the tectonic regime during which they were deposited ('Neotectonic Units') is based on circular reasoning, and mixes observation with interpretation. This practice should be abandoned.

On the Meaning of the 'Palaeotectonic Period'

According to Becker's definition, the palaeotectonic period comprises the complete Earth History from the Early Archaean to the last tectonic phase, e.g. in the Pliocene. That is not a particularly useful definition. Description of a tectonic event as 'palaeotectonic' has no meaning other than 'old', and should in all cases be replaced by periods as defined in the Geological Time Scale.

On the Definition of the 'Neotectonic Period' in the Eastern Mediterranean

The terminology of neo- vs. palaeo-tectonics became common in the Aegean region in the 1970s (Mercier *et al.* 1972, 1976; Sorel 1976; Le Pichon & Angelier 1979), and was mainly used for brittle tectonic events

associated with Neogene sedimentary basins. The notion of Becker (1993) that the onset of neotectonics may be highly diachronous is illustrated by the fact that in western Greece, on the Ionian islands, the neotectonic period was interpreted to reflect the Plio–Quarternary, when post-compressional sedimentary basins developed (Mercier *et al.* 1976), whereas on Crete, where extensional basin formation started earlier, Le Pichon & Angelier (1979) considered neotectonics to start 13 Ma ago, based on the onset of Cretan sedimentation according to the stratigraphy of Drooger & Meulenkamp (1973) (which has been redated to ~11 Ma in recent years (van Hinsbergen & Meulenkamp 2006; Zachariasse *et al.* 2010). Although several authors (e.g., Kissel & Laj 1988) used 'neotectonics' to depict the post-13 Ma expansion of the Aegean arc, nobody considers the metamorphic core complexes of the central Aegean region, with exhumation ages as young as 8–4 Ma (Hejl *et al.* 2002, 2008; Kumerics *et al.* 2005; Brichau *et al.* 2006) as neotectonic features, again illustrating the confusion arising from the use of this terminology as a regional correlation tool.

The Aegean definition of neotectonics is not applicable to Anatolian geology. Here, the widespread application of neotectonic terminology became common since Şengör (1980), and is usually referred to as the period during which the North and East Anatolian fault zones were active, accommodating westward extrusion of Anatolia (Koçyiğit & Beyhan 1998; Bozkurt 2001). Although the inception of Anatolian extrusion undeniably has a profound effect on Turkish geology, the timing of onset of this process is subject to widely differing interpretations. These stem, for instance, from the interpretation of the cause of extrusion, now generally seen as mainly the result of the collision between Arabia and Anatolia. For instance, Wong *et al.* (1995) preferred an early Miocene age for this collision and hence for the onset of the neotectonic period, whereas, in more recent years, estimates have suggested a younger collision age of ~12–11 Ma (Keskin 2003; Şengör *et al.* 2005; Hüsing *et al.* 2009; Okay *et al.* 2010), used by e.g. Piper *et al.* (2010) as the onset of the 'neotectonic era'. Even if the definition of the neotectonic period is not based on the Arabia-Anatolia collision, but on reconstructions of the age of activity of the North Anatolian Fault Zone, such as suggested by Bozkurt (2001), the diachronous growth of that fault zone from ~11 Ma in the east to ~5 Ma in the west (Armijo *et al.* 1999; Şengör *et al.* 2005; Hubert-Ferrari *et al.* 2009) inevitably leads to confusion: in western Turkey, most authors consider only the Plio–Pleistocene as 'neotectonic' (e.g., Barka & Reilinger 1997; Straub *et al.* 1997; Koçyigit *et al.* 1999; Bozkurt 2003).

One could argue that the inception of Anatolian extrusion as the start of the neotectonic period is in line with Becker's definition as the 'last tectonic change'. However, several authors advocate several 'neotectonic episodes': ten Veen *et al.* (2009), for instance, proposed 3 neotectonic stages since the early Miocene, and Koçyigit *et al.* (1999) suggested alternating phases of neotectonic extension and compression in the Pliocene. This is clearly at odds with Becker's definition.

Although Bozkurt (2001)'s widely cited paper ascribed the formation of the North Anatolian Fault Zone to the interplay between Arabia-Anatolia collision and extension in the Aegean arc, in recent years the general consensus has moved to a causal relationship with the Arabia-Anatolia collision (Şengör *et al.* 2005; Faccenna *et al.* 2006; Hubert-Ferrari *et al.* 2009), mainly because Aegean extension has been active since at least the late Oligocene (Gautier *et al.* 1999; Forster & Lister 2009; Tirel *et al.* 2009; Jolivet & Brun 2010). The connection of the definition of neotectonics to the NAFZ and hence the Arabia-Anatolia collision (e.g., Wong *et al.* 1995; Piper *et al.* 2010) therefore induces a kinematic and geodynamic interpretative flavour to the term. A wealth of international research has focused its attention on testing which geological elements can or cannot be ascribed to the extrusion tectonics of Turkey, and by introducing their study to focus on 'neotectonics', they, intentionally or not, already suggest an interpretation well before the observations are presented.

Finally, there is of course no problem in using interpretative terms in discussions and interpretations. However, given the very different understandings of the term by different authors, defining a period as 'neotectonic' remains vague, and would require every author to give a very clear definition, that probably changes from paper to paper. It therefore seems best to abandon this term

altogether, and give simply a description of the age, and style of the tectonic regime that is proposed.

Conclusion

Based on the confusion arising from the subdivision of Earth history into a neotectonic and palaeotectonic period, as illustrated above, and the improper use of these terms as stratigraphic correlation tools, the Neotectonic-Palaeotectonic terminology should be abandoned altogether, with a return to common geological nomenclature, defined in the Geological Timescale and structural geological and sedimentological textbooks. Interpretation of observations in terms of tectonic regimes and episodes should return to where it belongs: in the discussion.

Acknowledgements

I thank Aral Okay and an anonymous reviewer, and editor Erdin Bozkurt for their fruitful comments. This work was supported by StatOil (SPlates Project).

References

Armijo, R., Meyer, B., Hubert, A. & Barka, A. 1999. Westward propagation of the North Anatolian fault into the northern Aegean: timing and kinematics. *Geology* **27**, 267–270.

Barka, A. & Reilinger, R. 1997. Active tectonics of the Eastern Mediterranean region: deduced from GPS, neotectonic and seismicity data. *Annali di Geofisica* **XL**, 587–610.

Becker, A. 1993. An attempt to define a 'neotectonic period' for central and northern Europe. *Geologische Rundschau* **82**, 67–83.

Bozkurt, E. 2001. Neotectonics of Turkey - a synthesis: *Geodinamica Acta* **14**, 3–30.

Bozkurt, E. 2003. Origin of NE-trending basins in western Turkey. *Geodinamica Acta* **16**, 61–81.

Brichau, S., Ring, U., Ketcham, R.A., Carter, A., Stockli, D. & Brunel, M. 2006. Constraining the long-term evolution of the slip rate for a major extensional fault system in the central Aegean, Greece, using thermochronology. *Earth and Planetary Science Letters* **241**, 293–306.

Drooger, C.W. & Meulenkamp, J.E. 1973, Stratigraphic contributions to geodynamics in the Mediterranean area: Crete as a case history. *Bulletin of the Geological Society of Greece* **10**, 193–200.

Faccenna, C., Bellier, O., Martinod, J., Piromallo, C. & Regard, V. 2006. Slab detachment beneath eastern Anatolia: a possible cause for the formation of the North Anatolian Fault. *Earth and Planetary Science Letters* **242**, 85–97.

Forster, M.A. & Lister, G.S. 2009. Core-complex-related extension of the Aegean lithosphere initiated at the Eocene–Oligocene transition. *Journal of Geophysical Research* **114**, B02401, doi:10.1029/2007JB005382.

Gautier, P., Brun, J.-P., Moriceau, R., Sokoutis, D., Martinod, J. & Jolivet, L. 1999. Timing, kinematics and cause of Aegean extension: a scenario based on a comparison with simple analogue experiments. *Tectonophysics* **315**, 31–72.

Hancock, P.L. 1986. Neotectonics. *Journal of the Geological Society, London* **143**, 325–326.

Hejl, E., De Grave, J., Riedl, H., Weingartner, H. & Van den haute, P. 2008. Fission-track thermochronology of the Middle Aegean Island Bridge – implications for Neogene geomorphology and palaeogeography. *Zeitschift Deutsche Geselschaft fur Geowissenschaften* **159**, 495–512.

Hejl, E., Riedl, H. & Weingartner, H. 2002, Post-plutonic unroofing and morphogenesis of the Attic–Cycladic complex (Aegea, Greece). *Tectonophysics* **349**, 37–56.

Hubert-Ferrari, A., King, G., van der Woerd, J., Villa, I., Altunel, E. & Armijo, R. 2009. Long-term evolution of the North Anatolian Fault: new constraints from its eastern termination. *In*: van Hinsbergen, D.J.J., Edwards, M.A. & Govers, R. (eds), *Collision and Collapse at the Africa-Arabia-Eurasia Subduction Zone.* Geological Society, London, Special Publications **311**, 133–154.

Hüsing, S.K., Zachariasse, W.J., van Hinsbergen, D.J.J., Krijgsman, W., İnceöz, M., Harzhauser, M., Mandic, O. & Kroh, A. 2009. Oligo–Miocene foreland basin evolution in SE Anatolia: constraints on the closure of the eastern Tethys gateway. *In*: van Hinsbergen, D.J.J., Edwards, M.A. & Govers, R. (eds), *Collision and Collapse at the Africa-Arabia-Eurasia Subduction Zone.* Geological Society, London, Special Publications **311**, 107–132.

Jolivet, L. & Brun, J.-P. 2010. Cenozoic geodynamic evolution of the Aegean. *International Journal of Earth Sciences* **99**, 109–138.

Keskin, M. 2003. Magma generation by slab steepening and breakoff beneath a subduction-accretion complex: An alternative model for collision-related volcanism in Eastern Anatolia, Turkey. *Geophysical Research Letters* **30**, 8046, doi: 10.1029/2003GL018019.

Kissel, C. & Laj, C. 1988. The tertiary geodynamical evolution of the Aegean arc: a paleomagnetic reconstruction. *Tectonophysics* **146**, 183–201.

Koçyiğit, A. & Beyhan, A. 1998. A new intracontinental transcurrent structure: the Central Anatolian Fault Zone, Turkey. *Tectonophysics*, **284**, 317–336.

Koçyiğit, A. & Deveci, S. 2008. Ankara orogenic phase, its age and transition from thrusting-dominated palaeotectonic period to the strike-slip neotectonic period, Ankara (Turkey). *Turkish Journal of Earth Sciences* **17**, 433–459.

Koçyiğit, A., Yusufoğlu, H. & Bozkurt, E. 1999. Evidence from the Gediz Graben for episodic two-stage extension in western Turkey. *Journal of the Geological Society, London* **156**, 605–661.

Kumerics, C., Ring, U., Bricheau, S., Glodny, J. & Monié, P. 2005. The extensional Messaria shear zone and associated brittle detachment faults, Aegean Sea, Greece. *Journal of the Geological Society, London* **162**, 701–721.

Le Pichon, X. & Angelier, J. 1979. The Hellenic arc and trench system: a key to the neotectonic evolution of the Eastern Mediterranean area. *Tectonophysics* **60**, 1–42.

Mercier, J., Bousquet, B., Delibasis, N., Drakopoulos, I., Kéraudren, B., Lemeille, F. & Sorel, D. 1972. Déformations en compression dans le Quarternaire des rivages ioniens (Céphalonie, Grèce). Données néotectoniques et séismiques: *Comptes Rendus Acadademie Science Paris* **275**, 2307–2310.

Mercier, J.-L., Carey, É., Philip, H. & Sorel, D. 1976. La néotectonique plio-quarternaire de l'arc égéen externe er de la mer Égée er ses relations avec la séismicité. *Bulletin de la Societe Geologique de France* **18**, 355–372.

Obruchev, V.A. 1948. *Osnovnyje certy kinetiki i plastiki neotectoniki*. Izvestiya Akademii Nauk UzSSR Sertiya Geologicheskaya, **5**.

Okay, A.I., Zattin, M. & Cavazza, W. 2010. Apatite fission-track data for the Miocene Arabia-Eurasia collision. *Geology* **38**, 35–38.

Piper, D.J.W., Gürsoy, H., Tatar, M., Beck, M.E., Rao, A., Koçbulut, F. & Mesci, B.L. 2010. Distributed neotectonic deformation in the Anatolides of Turkey: a palaeomagnetic study. *Tectonophysics* **488**, 31–50.

Şengör, A.M.C. 1980. *Türkiye'nin Neotektoniğinin Esasları [Fundamentals of the Neotectonics of Turkey]*. Publication of Geological Society of Turkey [in Turkish].

Şengör, A.M.C., Tüysüz, O., İmren, C., Sakinç, M., Eyidoğan, H., Görür, N., Le Pichon, X. & Rangin, C. 2005. The North Anatolian Fault: a new look: *Annual Reviews in Earth and Planetary Sciences* **33**, 37–112.

Slemmons, D.B. 1991. Introduction. *In*: Slemmons, D.B., Engdahl, E.R., Zoback, M.D. & Blackwell, D.D. (eds), *Neotectonics of North America*. Geological Society of America, Boulder, Co., 1–20.

Sorel, D. 1976. Tectonique et néotectonique de la zone préapulienne. *Bulletin de la Societe Geologique de France* **1976**, 383–384.

Stewart, I.S. & Hancock, P.L. 1994. Neotectonics. *In*: Hancock, P.L. (ed), *Continental Deformation*. Pergamon Press, London, 341–399.

Straub, C., Kahle, H.-G. & Schindler, C. 1997. GPS and geologic estimates of the tectonic activity in the Marmara Sea region, NW Anatolia. *Journal of Geophysical Research* **102**, 27587–27601.

ten Veen, J.H., Boulton, S.J. & Alçiçek, M.C. 2009. From palaeotectonics to neotectonics in the Neotethys realm: the importance of kinematic decoupling and inherited structural grain inSW Anatolia (Turkey). *Tectonophysics* **473**, 261–281.

Tirel, C., Gautier, P., van Hinsbergen, D.J.J. & Wortel, M.J.R. 2009. Sequential development of metamorphic core complexes: numerical simulations and comparison to the Cyclades, Greece. *In*: Van Hinsbergen, D.J.J., Edwards, M.A. & Govers, R. (eds), *Collision and Collapse at the Africa-Arabia-Eurasia Subduction Zone:* Geological Society, London, Special Publications **311**, 257–292.

Van Hinsbergen, D.J.J. & Meulenkamp, J.E. 2006. Neogene supra-detachment basin development on Crete (Greece) during exhumation of the South Aegean core complex. *Basin Research* **18**, 103–124.

Wong, H.K., Ludmann, T., Uluğ, A. & Görür, N. 1995. The Sea of Marmara: a plate boundary sea in an escape tectonic regime. *Tectonophysics* **244**, 231–250.

Zachariasse, W.J., van Hinsbergen, D.J.J. & Fortuin, A.R. 2011. Foundering and demise of a Tortonian supradetachment basin (central Crete, Greece). *Basin Research*, in press.