Palaeoseismic records and instrumental data from continental interiors increasingly show that these areas of slow strain accumulation are more subject to seismic and associated natural hazards than previously thought (Tuttle & Schweig 1995; Johnston 1996; Johnston & Schweig 1996; Crone et al. 1997, 2003; Camelbeeck & Meghraoui 1998; Camelbeeck et al. 2000; Rastogi et al. 2001; Singh et al. 2004; England & Jackson 2011). This book explores some of the key issues arising in attempts to understand slowly deforming areas.

Earthquakes in slowly-deforming areas behave quite differently in space and time from those at plate boundaries, owing to the geometry of faults and the rate at which they are loaded (Fig. 1). Faults at plate boundaries are loaded at constant rates by steady relative plate motion. Consequently, earthquakes concentrate along the plate boundary faults, and show quasi-periodic occurrences, although the actual temporal patterns are often complicated. The apparent ‘gaps’ that appear will be filled in over time. However, in midcontinents, the tectonic loading is shared by a complex system of interacting faults spread over a large region, such that a large earthquake on one fault could increase the loading rates on remote faults in the system. Because the low tectonic loading rate is shared by many faults in midcontinents, individual faults may remain dormant for a long time and then become active for a short period. The resulting earthquakes are therefore episodic and spatially migrating (Li et al. 2009; Stein et al. 2009).

As a result, the precise future spatiotemporal behavior of large mid-continental earthquakes may be unpredictable, as is typically the case for complex dynamic systems. In particular, some of our instincts developed for plate boundaries may not apply within plates. In Australia, Clark et al. (2012) note that ‘periods of earthquake activity comprising a finite number of large events are separated by much longer periods of seismic quiescence, at the scale of a single fault and of proximal faults’. As a result, ‘assigning an “active/inactive” label to a fault in a slowly deforming area based upon the occurrence (or non-occurrence) of an event in the last few thousands to tens of thousands of years is not a useful indicator of future seismic potential’ (Clark et al. 2011). Moreover, ‘it is debatable whether a “recurrence interval” on individual faults applies’ (Clark 2003), so if the term is used to describe the idea that large earthquakes are separated by long time intervals, it does not imply that these intervals are similar and that the earthquakes are quasi-periodic. At the deepest level, it may not be useful to think in terms of a classic seismic cycle in which strain accumulates steadily and is released by quasi-periodic earthquakes. In other words, ‘the fundamental assumption of earthquakes occurring due to progressive strain build-up, and thus being in some way predictable in their periodicity, is not satisfied’ (Clark et al. 2015).

Where ‘recurrence intervals’ of ground-rupturing earthquakes are on the order of thousands to tens of thousands of years, slip rates on individual faults are below or barely at geodetic measurability. Consequently, decadal geodetic or seismicity records may not reflect long-term deformation and seismicity (Friedrich et al. 2003; Stein & Liu...
Even in areas with dense space-geodetic coverage, the relationship between strain accumulation and strain release is poorly understood. Furthermore, records of historical seismicity in these environments are too short to constrain the size of the largest possible earthquakes or their recurrence intervals (Schmedes et al. 2005; Fäh et al. 2009). Even in densely populated regions with long historical records, such as China or central Europe, earthquake catalogues do not cover more than 1000 or 2000 years and thus, are not sufficient to correctly assess how the seismicity and associated hazards vary in time and space (Stein & Mazotti 2007; Stein & Liu 2009; Liu et al. 2011). Liu et al. (2011) show that earthquakes in Central China have migrated over the past 2000 years, and that no fault in this region has ruptured twice in this time span. Accordingly, one of the most pressing and enigmatic problems in earthquake geology is assessing the spatiotemporal distribution of large earthquakes in low-strain (intraplate) regions. To extend the short records of seismicity, palaeoseismological and historical data are being used.

Although some seismicity occurs in cratonic interiors (Crone et al. 1997; Clark et al. 2014), more occurs in extensive, tectonically active intra-continental mountain belts or continental rift zones (Camelbeeck & Meghraoui 1996; McCalpin 2005; Zielke & Strecker 2009). If the resulting motion and deformation are large enough, such areas are treated as diffuse plate boundary zones (Gordon & Stein 1992). Relatively recent historic occurrences of major earthquakes, some exceeding magnitude 8, in low-strain regions of Central Asia or Mongolia (e.g. Bogdanovich et al. 1914; Baljiinyam et al. 1993; Schlupp & Cisternas 2007; Kalmetieva et al. 2009), provide the opportunity for detailed studies because they were reported, their effects were partly investigated only months afterwards and the ruptures are still well preserved in the landscape. Understanding these events that occurred unexpectedly 150 and more years ago may lead to better assessment of where such earthquakes might strike in the future.

Although seismic events in the interior of continents and low-strain regions represent a small fraction of the total number of earthquakes and have lower magnitudes than the highest at plate boundaries, they pose a significant hazard to societies (England & Jackson 2011). Part of the reason is

Fig. 1. Conceptual models for the difference between interplate (a) and intraplate or mid-continental (b) earthquakes. The plate boundary fault is loaded by steady relative plate motion, causing earthquakes are concentrated along the boundary. In mid-continents, slow far-field tectonic loading is shared by a complex system of interacting faults. Large earthquakes roam across widespread faults, as rupture of one fault zone may affect the loading on a distant fault. Modified from Liu et al. (2011).
that many seismogenic sources in such settings were unknown prior to rupture owing to a lack of exposure and thus were not included in hazard estimates. For example, the 2010 Canterbury (New Zealand) earthquake occurred on an unknown fault in a region where no large historical earthquakes were known (Gledhill et al. 2010), as did the 2012 Emilia earthquake in the Bologna region, northern Italy (Alessio et al. 2010) and the 2012 Pernik earthquake in Western Bulgaria (Radulov 2012). Accordingly, the numbers of fatalities reported from unexpected, moderate to large events in low-strain regions often exceed the death toll from earthquakes in high-strain areas by multiples (Fig. 2). Where earthquake recurrence is short enough to be in human memory, prepared communities and safer infrastructure often reduce fatalities. Learning more about earthquakes in continental interiors and low-strain regions should hopefully improve hazard assessments and achieve similar results.

Types of slowly deforming regions

Papers in this volume address earthquakes and deformation in slowly deforming regions worldwide. Such regions can be classified in several groups. One is stable continental regions of continental crust, including shelf regions, slopes and attenuated continental crust, which show no orogenic activity younger than early Cretaceous (Johnston 1989). Another is intraplate regions distant from plate boundaries, including ‘stable’ cratons and intracontinental rifts that are deforming too slowly (less than c. 1 mm a$^{-1}$) to be regarded as diffuse plate boundaries (e.g. European Cenozoic Rift System, Reelfoot Rift, Rio Grande Rift). Here, deformation rates on individual faults are usually smaller than geodetic measurability and earthquakes along these faults are characterized by long recurrence intervals that are in the order of thousands to tens of thousands of years. Faster-deforming regions can be regarded as diffuse plate boundaries, for instance the Basin-and-Range province, the Tien Shan mountains, Baikal Rift or East African Rift.

Limitations of instrumental, historic, and palaeoseismic catalogues

The short time span of instrumental seismology, i.e. about 120 years, is insufficient to characterize the seismicity of low-strain regions. Moreover, for events in the early period of analog seismic recordings, data coverage is usually poor and only few records are available or face uncertain near-future maintenance (e.g. Kulikova 2016). These valuable records, many of them on thermal paper, will be lost soon if not systematically collected and digitized. Modern analyses have been performed on some historic seismograms (e.g. Schlupp & Cisternas 2007; Kulikova & Krüger 2015; Kulikova et al. 2016), yielding estimates of magnitude, focal mechanism or other source parameters. Interestingly, a new archive, reaching a few more centuries back, may be available. In this volume, Krüger et al. (2015) combine magnetograms with seismic records from 1889 and 1911 for new estimates of the previously debated magnitude for an earthquake in Central Asia. For yet older seismic events, macroseismic observations provide useful data. However, such observations are limited or might be biased by population density, cultural and political changes, and other issues (e.g. Berberian 2014).

Stein et al. (2015) and Zöller et al. (2015) note the resulting difficulty in estimating how large the largest earthquakes to expect may be, which gives rise to uncertainties in hazard estimates. Zöller et al. (2015) analyse the earthquake catalogue of Central Asia, derived from historically reported and instrumentally measured data in the magnitude range between 4 and 8.3. They find high probabilities for occurrence of large magnitude events in short time intervals, even if such events are rare in the catalogue and probably have not occurred within the past c. 400 years. Although palaeoseismology can enhance the database, it also faces challenges. Clark et al. (2015) note that palaeoseismic studies in low-strain regions are hampered by complexities, related to the interplay of deformation, sedimentation, and surface processes.

Inherited structures

Deformation in low-strain settings is often guided by inherited structures and results from fault reactivation or rupture propagation along pre-existing zones of weakness (e.g. Sykes 1978). Such reactivated faulting does not fulfil Andersonian faulting criteria that apply to a homogeneous, isotropic medium. The resulting faulting need not occur along the most favourably oriented planes (e.g. Célérier 2008). Consequently, weak planes with a wide range of orientations can be activated by the same applied stresses, making ruptures more complex and less predictable for earthquake-hazard assessment. Subsequently, a large network of pre-existing structures in which faults were reactivated casually and infrequently may leave less reliable traces of cumulative displacements in the landscape. This effect may be even more pronounced if deformation rates are low with respect to landscape decay.

Examples of earthquakes associated with inherited zones of weakness abound. The New Madrid earthquake sequence occurred within a failed rift
Inverted Mesozoic rift-related normal faults guide thick-skinned deformation in the Andean broken foreland (e.g. Johnston & Schweig 1996). Changes in orientation of the maximum horizontal shortening direction can reactivate dip-slip faults as obliquely slipping or pure strike-slip faults (Strecker et al. 1990), or nearly reverse the sense of lateral motion. Remnants of the earlier phase that is unrelated to present-day tectonic conditions may then still be manifested in the landscape (Landgraf et al. 2009, 2013).

Fig. 2. Global seismicity and resulting earthquake fatalities. (a) Cartographic view of the world overlain with plate boundaries (red) and a five-year record of earthquakes with magnitudes above five. Seismicity is from the ANSS catalogue for 2010–14. Most earthquake occurrence reflects the locations of the plate boundaries. (b) Earthquake fatalities between 1900 and today based on NOAA catalogue (without tsunami). Data are plotted on a NASA view of the earth at night that illustrates heavily populated areas. Some of the deadliest earthquakes did not occur along plate boundaries, but in areas characterized by low present-day seismic activity.
Other examples have been described worldwide. The 2002 Molise earthquake sequence in Italy that included two shocks with M 5.7 was related to deformation within the Adriatic plate; prior to this sequence, no historical earthquakes had been reported in the epicentral area (Di Bucci & Mazzoli 2003). Inherited structural grain might control coseismic surface-deformation patterns, as demonstrated for the 2013 Balochistan earthquake (Val-lage et al. 2016), where inherited structures may have caused geometric complexities in the surface slip. Reactivation of inherited structures after distinct, but repeated phases of orogeny, occurs in the Tien Shan mountains of Central Asia (e.g. Selander et al. 2012; Macaulay et al. 2013). In this volume, Walker et al. (2015) discuss a case from Mongolia, where the low ratio of recently accumulated slip to the full length of the fault suggests modern reactivation of a pre-existing structure.

Recognition of active faults

The main problem in detecting potentially hazardous fault structures in the landscape of low-strain regions is the long time between individual rupture events (up to 10^2 years) and the many surface processes that can disguise a past rupture.

Anthropogenic and meteorological overprint

Research in palaeoseismology and tectonic geomorphology developed and advanced initially in remote arid regions (Wallace 1977, 1986; Sieh 1978; Schwartz & Coppersmith 1984; Sieh et al. 1989; Crone et al. 1997). In such areas, seismogenic surface structures are exposed over several kilometres and preserved over long periods of time, owing to low erosion rates and negligible anthropogenic landscape modification. Thus even low-strain intraplate fault systems usually preserve fault scarps or offset gullies, such that they are easily recognizable in the field and on remote sensing data such as orthophotos and digital elevation models.

In contrast to those in remote arid regions, fault scarps in humid and densely populated regions are subject to much greater degradation by meteorological and anthropogenic processes. Urbanization and farming may lead to rapid degradation of fault scarps, as ‘sharp edges’ produced by surface ruptures are often flattened shortly after the earthquake. Meteorologically induced effects degrading and/or obliterating fault scarps include solifluction (down-slope movement of water-saturated soil in periglacial environments), fluvial erosion and formation of dense vegetation cover. In low-strain regions with tectonic deformation rates well below 1 mm a^-1, the effects of seismogenic deformation are often barely distinguishable from fluvial and erosion processes and in many cases are entirely obliterated. Mining-induced subsidence may also disguise surface effects of tectonic deformation. In the coal and lignite mining areas of Central and Western Germany and Western Poland, mining induced subsidence rates are on the order of cm a^-1 – up to three orders of magnitude higher than tectonic slip rates (Perski 1998; Görres et al. 2006; Görres 2008; Kratzsch 2012). Consequently, the worst environments for preservation of fault scarps are densely populated low-strain fault systems in humid or moderately humid climate zones, as exemplified by the tectonically active areas in Central Europe, South America and parts of China.

Glacial and periglacial overprint

Most areas in intraplate Europe experienced periglacial climatic conditions during the Last Glacial Maximum. Therefore, potential records of faulting in trenches might be overprinted by or confused with features related to the annual freezing and thawing of permafrost soils (van Vliet-Laenoè et al. 2004). Ice veins are easily confused with smaller tension cracks, while normal faults might be mixed up with the steep orientation at periglacial wedges. Distorted sedimentary layers and flame structures might be caused by either cryoturbation or soft-sediment deformation during co-seismic liquefaction. Finally, even if a fault is identified, colluvial wedges might be misinterpreted as periglacial wedges or vice versa, resulting in different surface displacement values (e.g. Vanneste et al. 2001).

The deglaciation of wide regions in Northern Europe and North America after the Last Glacial Maximum has been recognized to reactivate faults by glacial isostatic adjustment that affects also areas south of the former ice shield (e.g. Steffen & Wu 2011). Intraplate regions therefore could have experienced a short-lived impulse of high seismicity during deglaciation that might not be reflected in recent instrumental seismicity, which seems to be dominated by the effects of the ‘ridge push’ from the Atlantic oceanic lithosphere (Bungum et al. 2010). In this volume, Mörner (2015) discusses such differences between long-term and recent seismicity.

Regional settings

Classic intraplate region discussed in this volume include Central and Northern Europe (Mörner 2015; Stein et al. 2015; Kübler et al. 2016; Shipton et al., this volume, in press), Mongolia (Walker et al. 2015), Inner Mongolia (Rudersdorf et al. 2015), and the Tien Shan mountains of Central Asia (e.g. Selander et al. 2012; Macaulay et al. 2013). In this volume, Walker et al. (2015) discuss a case from Mongolia, where the low ratio of recently accumulated slip to the full length of the fault suggests modern reactivation of a pre-existing structure.
part of a diffuse plate boundary zone. Considered as an intracontinental mountain belt or Tien Shan mountains in Central Asia that should be discussed by Krüger et al. (2015) and Zöller et al. (2015) discuss the Tien Shan mountains in Central Asia that should be considered as an intracontinental mountain belt or part of a diffuse plate boundary zone.

Central Europe

Most present-day seismicity in Central Europe is related to the reactivation of inherited zones of crustal weakness in the Late Variscan, Permocarboniferous and Mesozoic fault systems (Ziegler 1992; Schumacher 2002; Dézes et al. 2004). Cenozoic intraplate deformation in Central Europe has been attributed to far-field stresses from the continent–continent collision in the Alps and Pyrenees and the opening of the Atlantic Ocean (Illies 1975; Şengör et al. 1978; Ziegler 1992; Reichert et al. 2008), and to effects of rising mantle plumes (Hoernle et al. 1995; Goes et al. 1999; Ritter et al. 2001; Cloetingh et al. 2005).

One of Central Europe’s most tectonically and seismically active features is the European Cenozoic Rift System (ECRS). During the Late Eocene to Oligocene, ESE–WNW-directed extension led to the formation of the ECRS, which extends more than 1100 km from the North Sea to the western Mediterranean (Ahorner 1975; Illies 1975; Ziegler 1992; Reichert et al. 2008). It includes the Rhine and Rhône Valley Rift Systems, which are linked by the Burgundy and the eastern Paris Basin transfer zones with the grabens of the Massif Central. The southern part of the rift system consists of the Bresse Graben, the grabens of the Lower Rhône Valley, and their prolongation into the Western Mediterranean (Ziegler 1992, 1994; Jolivet et al. 1999; Michon et al. 2003; Dézes et al. 2004). The northern part of the ECRS is the Rhine Rift System including the Upper Rhine Graben, Lower Rhine Graben and the Hessian Graben system. The seismically active shallow Eger Graben of the Bohemian Massif is the ECRS’s easternmost graben (Ziegler 1992). The Upper and Lower Rhine Grabens are an active seismic zone. The largest historical earthquake in the region, and one of the largest known earthquakes in Central Europe, was the 1356 $M_t \approx 6.5$ Basel earthquake near the southern end of the Upper Rhine Graben. The earthquake severely damaged the city of Basel, causing several hundred fatalities (Mayer-Rosa & Cadiot 1979). For the Lower Rhine Graben, the largest historical earthquake is the $M_t \approx 6.2$ Düren earthquake of 1756 (Meidow 1994; Hinzen & Reamer 2007). This event occurred only a few weeks after the $M \approx 9$ Lisbon earthquake of 1755 (Babtista et al. 1998) – the largest historical earthquake of the European continent.

Central Asia (Kyrgyz and Kazakh Tien Shan and Mongolia)

Despite their distance from nominal plate boundaries, Central Asia’s northern Tien Shan mountains and the deformation belts in Mongolia have suffered a series of large-magnitude earthquakes, some exceeding M 8, in the past 150 years (e.g. Ignatiev 1886; Mushketov 1891; Bogdanovich et al. 1914; Khil’ko et al. 1985; Baljiinyam et al. 1993; Krüger et al. 2015; Arrowsmith et al. 2016). Such events are rare, given the slow slip rates – less than a few millimetres per year – of single active faults in those areas.

Both the Tien Shan and most of the Mongolian ranges were reactivated during renewed orogenic pulses between the Precambian and the Palaeozoic, and to a limited extent in Mesozoic time. Phases of deformation alternated with quiescence, yielding several zones of weakness (Tapponnier & Molnar 1979; Baljiinyam et al. 1993). Although they are more than a 1000 km north of the India–Eurasia plate boundary, they are affected by far-field strain from the ongoing collision. Thus, most areas in Kyrgyzstan and Mongolia experience roughly north-directed shortening at present. In Kyrgyzstan, active faults are mainly east–west striking, perpendicular to the main horizontal shortening direction; so most recent and historic earthquakes show thrusting and reverse-faulting mechanisms with minor strike-slip components or few strike-slip events (e.g. Nelson et al. 1987; Molnar & Ghose 2000; Thompson et al. 2002; Arrowsmith et al. 2016; Landgraf et al. 2016). However, major right-lateral strike-slip faults accommodate part of the north–south shortening in the northern Tien Shan (e.g. Korjenkov et al. 2010; Campbell et al. 2013, 2015). Reactivation of several inherited faults may result in complex ruptures, incorporating segments with different mechanisms (Abdrakhmatov et al. 2016). Interestingly, the known historical events seem to be located along the northern and southern borders of the Tien Shan (Kalmetieva et al. 2009; Landgraf et al. 2016), despite comparable Quaternary single-fault slip rates across the Tien Shan (Thompson et al. 2002) and continuously northward-decreasing GPS-velocities (Zubovich et al. 2010). In Mongolia, the mechanisms of active faulting vary between provinces, with dextral strike-slip in the Altay and left-lateral as well as oblique-slip faulting in combination with thrusting in the Gobi–Altay and Hangay Dome. Walker et al. (2015) document that active normal faulting is common in the Hangay area. Nevertheless, virtually all of these provinces have experienced large earthquakes in historical time.
distributed across the mountainous areas of the entire country (e.g. Khil’ko et al. 1985).

North America

Earthquakes are widespread within this presumably stable continent. The New Madrid seismic zone is best-known for its 1811–12 earthquakes, which include three or four large shocks \( (M \geq 7.0) \) (Stein 2010; Hough & Page 2011). Other intraplate seismic zones include the Wabash Valley zone in southern Illinois and Indiana, a northeastern extension of the New Madrid zone, where palaeoliquefaction deposits indicate the past occurrence of large earthquakes (Obermeier 1999) that may have been comparable to those that occurred in the New Madrid zone in 1811–12. Moderate seismicity has been recorded in the southern Oklahoma and the Texas panhandle. Holocene \( (c. \ 1.2 \text{ kyr ago}) \), and younger fault scarp deposits on the Meers Fault indicate earthquakes of magnitude greater than 6.5 (Madole & Rubin 1985; Crone & Luza 1990). The Eastern Tennessee seismic zone includes seismicity in the Valley and Ridge province of the southern Appalachians. The central Virginia seismic zone also shows clusters of seismicity, including the 2011 Mw 5.8 earthquake near Mineral. The Carolina seismic zone is best known for the destructive \( (M \approx 6.5–7.0) \) event near Charleston, South Carolina. Palaeoseismic studies indicate at least seven prehistoric earthquakes in the past 6000 years (Obermeier et al. 1985; Talwani & Cox 1985). The entire east coast, including Charleston, Virginia and New England, can be viewed as a single seismic zone, consistent with the observation that seismicity occurs along many passive continental margins (Stein et al. 1979; Stein et al. 1989; Schulte & Mooney 2005; Wolin et al. 2012). Further north in the St Lawrence River Valley, numerous events with magnitude 6–7 have been recorded, including the 1663 M 7.3–7.9 Charlevoix earthquake in Quebec (Ebel 2011). Agurto-Detzel et al. (2015) give an overview of intraplate seismicity and tectonics in South America.

Australia

Clark et al. (2015) give an overview of intraplate seismicity and tectonics in Australia.

Topics/approaches

The papers in this volume are grouped into two sections: (1) Seismology and Hazard; and (2) Earthquake Geology. Areas discussed include North and South America, Central and Northern Europe, Central Asia, Mongolia and China, and Australia.

The first section deals with instrumental and historical earthquake data and associated hazard assessments. Three papers explore the limitations of seismic catalogues for hazard assessments. Focusing on challenges of the short instrumental record with respect to expected earthquake recurrence times in intraplate regions, Stein et al. (2015) consider the consequences of low-probability events for hazard evaluation in intraplate Europe. Zöller et al. (2015) use the regional earthquake catalogue for Central Asia to estimate the largest expected magnitude in a predefined time window. The authors use statistical methods, combined with a probabilistic consideration of magnitude errors, to infer that, for future periods of a few hundred years, earthquakes of \( M \geq 8.5 \) are possible. For the same region in Central Asia, Krüger et al. (2015) consider one of the earliest teleseismically recorded earthquakes (the 1889 Chilik earthquake), together with magnetostratigraphic evidence of this and a better known earthquake in the region, to constrain the large magnitude that was previously debated.

The other two papers in the first section focus on physical processes and their relation to the distribution of intraplate seismicity. Agurto-Detzel et al. (2015) consider possible lithospheric factors controlling the occurrence or non-occurrence of seismicity in intraplate South America. They argue that the most important factors are elastic thickness and heat flow, but also that Neoproterozoic fold belts show significantly higher seismicity, possibly owing to inherited zones of weakness. Costain (2016) discusses intraplate earthquakes and their aftershocks, triggered by groundwater recharge, with an example from North America. He provides a two-step model for the physical processes that influence crustal stress changes and might affect aftershock distributions.

The second section covers methods from structural geology, palaeoearthquake and tectonic geomorphology and incorporates field evidence. The transition between the two sections is given by Mörner (2015), who explores the compatibility of short-term seismic catalogues and long-term palaeoseismic records, a highly debated topic in seismological and palaeoearthquake communities, for Scandinavia. Kübler et al. (2016) report on geophysical, geological and morphological data indicating earthquake ground rupture in the Lower Rhine Graben and outline challenges in recognizing coseismic deformation in a densely populated low-strain region. Shipton et al. (this volume, in press) investigate the microstructures of cataclastic deformation in unconsolidated sand deposits related to deformation along the active Riedselz fault that is part of the northern Upper Rhine Graben in France. Clark et al. (2015) show a record of episodic faulting with temporally clustered
earthquakes from the Cadell Fault in southeast Australia, where fault slip rates averaged over a clustered period can be more than an order of magnitude higher than the long-term average. Moreover, they suggest that the assumption of earthquakes occurring owing to progressive strain build-up, and thus being in some way predictable in their periodicity, is not satisfied. Walker et al. (2015) investigate a newly initiated normal fault in the Hangay mountains of intraplate Mongolia that shows an approximately 80 km-long scarp and slipped during mid-Holocene time in a rare large-magnitude event. Rudersdorf et al. (2015) analyse seismically induced soft-sediment deformation structures in palaeo-lakebeds of the northeastern Ejina Basin in Inner Mongolia, and show that these structures can record palaeoearthquake where the present-day seismicity is low and the geomorphology does not indicate active tectonics. Finally, Arrowsmith et al. (2016) investigate the rupture of the 1911 Kebin earthquake that occurred near an 1889 earthquake studied by Krüger et al. (2015). Their field surveys, using slip measurements, indicate a segmented rupture incorporating large step-overs and a switch in fault vergence. Interestingly, the seismic moment calculated from the observed slip at the surface is lower than seismological estimates.

Outlook/implications for future work

Assessing seismic hazard in slowly deforming areas is challenging, and how well we do heavily depends on our ability to assess the spatiotemporal distribution of past large earthquakes and draw implications for the future. Even considering the long record of historical events in some populated areas, their time-span of about 1000 years probably fails to capture the activity of some faults with typical large-event recurrence intervals that are in the order of tens of thousands of years. To extend the short instrumental and historical records, palaeoearthquake data are increasingly being used. Although the precise spatiotemporal behavior of large midcontinental earthquakes may be unknowable, an intrinsic limitation of complex dynamic systems, the steady improvement of palaeoseismic methods is improving our knowledge of what has happened and giving insight into what may happen.

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