Intraplate Seismicity in China and North America: A New View

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There is great interest in determining the likely locations of future continental intraplate earthquakes. The usual approach is to either use past seismicity as a guide, or to undertake laborious paleoseismic investigations of suspected fault zone to determine if these faults have generated recent earthquakes. Neither approach is entirely satisfactory. It is well known that instrumental earthquake locations present an inadequate view of the seismic potential of intraplate regions where earthquake recurrence intervals commonly exceed 500 years. Likewise, historic records of seismicity inevitably contain gaps, particularly for North America. Paleoseismology has made great strides in recent years, but due to practical limitations, it will require many more decades of field work before the majority of suspected faults can be investigated.

Given these limitations, it is not surprising that many approaches have been suggested to determine the seismic potential of continental intraplate regions. For example, it has been suggested that regions with higher seismic potential are those locations with intersecting faults, regions of elevated heat flow, or along geophysical lineaments observable in aeromagnetic and gravity maps. In this paper we introduce a new approach to estimating the seismic potential of continental intraplate regions based on the deep properties of the lithosphere as determined by seismology and calibrated by geochemistry.

Intraplate China and North America have relatively sparse seismicity in comparison with their plate boundaries, the western Pacific subduction zone and the San Andreas transform fault and eastern Pacific subduction zone. Nevertheless, significant earthquakes have occurred, notably the 1976 Tangshan earthquake and the 1811-1812 earthquake sequence in New Madrid, Missouri. Schulte and Mooney (GJI, 2005) discuss the seismicity of intraplate regions and note that these earthquakes can be sub-divided into three tectonic settings: (1) extended (rifted) continental margins; (2) continental interior rifts; and (3) non-extended regions. While the identification of these three tectonic settings is valuable, their identification does not explain why some extended margins and continental interior rifts are historically aseismic. Likewise, the third tectonic setting, non-extended crust, essentially says that these earthquakes have no tectonic explanation.

Our hypothesis is that higher integrative lithospheric strength correlates with lower rates of continental crustal seismicity and with lower earthquake magnitudes, also known as Mmax. Integrative lithospheric strength is controlled by lithospheric composition and the geotherm. Positive mantle S-wave velocity anomalies are indicative of mantle composition and temperatures, and are available on a global scale from seismic tomography. In contrast, heat flow measurements, which also reflect the mantle geotherm, are lacking in many continental intraplate regions.

We have created new global maps of lithospheric S-wave velocity anomalies (delta Vs) at a depth of 175 km and quantitative compared the values of these mantle anomalies with the locations and moment magnitudes of earthquakes in the overlying crust. These S-wave anomalies are with respect to a global average velocity model. As is
well known, positive delta Vs anomalies correlate with Precambrian cratonic lithosphere, and we have selected a depth of 175 km to ensure that we are within the cratonic lithospheric root. We seek to demonstrate a correlation of cold, strong mantle lithosphere with lower seismicity rates and lower moment magnitudes. Our earthquake catalog is described by Schulte and Mooney (GJI, 2005) and contains about 1,300 events.

Our catalog contains 740 continental intraplate earthquakes with moment magnitude in the range 4 to 5. We find only 7% (50) crustal earthquakes occur above mantle lithosphere with delta Vs greater than 4.5. The number of events is nearly uniform for values of delta Vs between 0.5 to 4.5. There are 460 continental intraplate events with moment magnitude in the range 5 to 6. We find that only 10% of all events occur above mantle lithosphere with delta Vs greater than 3.5. Most events occur above mantle lithosphere with delta Vs values between 0.5 and 3.5.

There are 110 events with moment magnitude in the range 6 to 7. We find that 14% (16) events occur above mantle lithosphere with values of delta Vs greater than 3.5%. There are no events above mantle lithosphere with delta Vs greater than 4.5%. There are 14 events with moment magnitude greater than 7. There are no events that occur above mantle lithosphere with values of delta Vs greater than 3.5%. The 14 events are roughly evenly distributed above mantle lithosphere with delta Vs values between -1.5% to 3.5%.

In summary, for moment magnitude of 5 or greater, there is a significant decrease in the number of intraplate crustal earthquakes above mantle lithosphere with values of delta Vs greater than 3.5. No earthquakes with moment magnitude greater than 7 occur above mantle lithosphere with delta Vs values greater than 3.5%. An X-Y plot of moment magnitude versus delta Vs at a depth of 175 km yields a linear trend that defines the upper bound on moment magnitude for a given value of the lithospheric mantle seismic anomaly at a depth of 175 km. This trend places a limit on the maximum moment magnitude for a given mantle lithospheric anomaly. The most significant result is the clear trend that limits larger events (moment magnitude greater than 7.0) to mantle lithosphere with delta Vs anomalies less than 3.5%. In China, geochemical studies and seismic tomography indicate that the mantle lithospheric root beneath the eastern Sino-Korean craton has been removed (delaminated). This implies that this Chinese region of Precambrian crust is more susceptible to large earthquakes than geologically-similar Precambrian crust in North America which is still underlain by cold, strong mantle lithosphere. Thus, seismic hazards are relatively higher in NE China as compared with similar Precambrian regions of North America.