THE CRATON: ITS EFFECT ON THE DISTRIBUTION OF SEISMICITY AND STRESS IN NORTH AMERICA

STEVEN G. WESNOUSKY and CHRISTOPHER H. SCHOLZ
Lamont-Doherty Geological Observatory and Department of Geological Sciences of Columbia University, Palisades, NY 10964 (U.S.A.)

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The gross distribution of seismicity in North America suggests the interior platform and shield provinces are relatively stable and significantly affect the intraplate stress field. Focal mechanisms and in-situ stress measurements indicate the cratonic areas of North America must be relatively immobile with respect to the eastern and western portions of the continent. Simple kinematic models are presented to illustrate the importance of the craton in any attempt to explain the general pattern of intraplate stress and seismicity in North America.

1. Introduction

The distribution of seismicity and stress in intraplate North America has been the subject of several investigations. For example, Sbar and Sykes [1,2] have discussed the general east-trending compressive stress that characterizes eastern North America. Smith, Sbar and others have studied the tectonics of the western Intermountain Seismic Belt and interpreted the general extensional stress of the region in terms of the motion of sub-plates [3,4]. The seismicity patterns of northern Canada have been discussed by Basham et al. [5]. A brief review of the data is used to show that the North American craton must be relatively rigid and immobile. On this basis, kinematic models are proposed to explain the general patterns of stress and seismicity in the intraplate regions of North America.

2. Seismicity and stress in North America

The interior platform and shield (or cratonic) areas of the continent are in general rimmed by Phanerozoic mobile belts (Fig. 1). The majority of intraplate seismicity occurs within the Phanerozoic belts (Fig. 2a, b). Intraplate seismicity in western North America is distributed along the Rocky Mountain Cordillera. Earthquakes in this region appear to be characterized by normal and strike-slip faulting predominantly oriented to suggest a regional extensional stress field that trends approximately east (Fig. 3) [6]. Although seismicity along the Rocky Mountain Seismic Zone appears to end at about 55°N, the zone appears to be roughly associated with the Rocky Mountain Trench, which itself continues northward beyond 60°N. This feature is, along much of its length, defined by a series of block fault valleys which cut early Tertiary and older structures [7], suggesting this region is also characterized by east-west extension.

Seismicity in the eastern portion of the continent is generally distributed along the Appalachians. Focal mechanism and hydrofracture data have been used to suggest that, in contrast to the Rocky Mountain Seismic Belt, the east is characterized by a horizontal stress field that trends approximately east to northeast [1,2]. The compilation of stress measurements in Fig. 3 suggests this east-trending horizontal compression also extends southward along the southern margin of the craton.
The seismicity in northern Canada is diffuse, but appears to be predominantly located along the continental margin and in the Innuitian Orogenic Belt. Focal mechanism data are few and do not appear to suggest the presence of any ambient horizontal stress field (Fig. 3). Even if a regional stress field does exist in this region, it may be radically altered by local loading effects of sedimentation on the continental shelf or crustal movements resulting from glacioisostatic rebound [5,8].

The epicentral distribution of intraplate earthquakes in North America, to a first approximation
then, forms a ring of seismicity around the continent (Fig. 2). Much of the seismicity is concentrated along the Phanerozoic mobile belts which rim the interior platform and shield provinces of the continent. In contrast, the Precambrian shield and platform provinces are comparatively aseismic. Focal mechanism and in-situ stress data further show a flip in the ambient horizontal stress field from an east-trending compression in the east to an east-trending minimum compressive stress or extension. In the west.

3. Discussion

The cratonic areas of continents are characterized by the oldest basement rock. It has been proposed that these ancient Precambrian regions of orogenesis may now be "annealed" and hence act as strong rigid blocks resistant to faulting [9,10]. The majority of intraplate seismicity observed in the world occurs along Phanerozoic mobile belts [10]. These areas have been suggested to act as "pre-existing zones of
Fig. 2. (a) Epicenters of about 6000 earthquakes in Canada and adjacent areas to 1974 (from files of the Earth Physics Branch, Department of Energy, Mines and Resources, Canada; P.W. Basham, written communication to Lynn Sykes, 1977). Coverage was arbitrarily cut off south of 40°N in the United States and in other areas outside Canada. Canadian seismograph stations are shown as small squares with an S enclosed. BB = Baffin Bay, BI = Baffin Island, HB = Hudson Bay, HS = Hudson Strait, LS = Labrador Sea, DS = Davis Strait, MV = Mackenzie Valley and NS = Nares Strait. Tectonic boundaries of Fig. 1 are shown as dashed lines for reference. Note the paucity of seismicity within the interior of the continent. (b) Epicenters from the NOAA files for years 1964 through 1976. Coverage was arbitrarily cut off west of 140°W and south of 35°N. Earthquakes along the San Andreas Fault System are not plotted. This data set has a lower detection threshold for the United States as compared to the Canadian data set. Tectonic boundaries of Fig. 1 are shown as dashed lines for reference. Again, note the low level of activity in the platform and shield provinces.
Fig. 3. Horizontal principal-stress axes inferred from focal mechanisms and hydrofracture measurements in North America. The P-axis is shown by inward-pointing arrows; the T-axis by outward-pointing arrows. Focal mechanism data for the western United States are from a compilation by Smith and Lindh [6]. The remaining mechanisms are labelled with a capital letter corresponding to the source of data: A, Leblanc and Wetmiller [31]; B, Hasegawa et al. [32]; C, Hasegawa [33]; D, Hashizume [34]; E, Hashizume [35]; F, Sykes and Sbar [36]; G, Hashizume [37]; H, Hermann [38]; I, Leblanc and Buchbinder [39]; J, Horner et al. [40]; K, Fletcher and Sykes [41]; L, Dames and Moore [42]; M, Sbar et al. [43]; N, Aggarwal and Sykes [44]; O, Yang and Aggarwal [45]; P, Yang and Aggarwal [46]. If a symbol represents more than one focal mechanism, it is shown by a digit adjacent to the respective P- and/or T-axes. For simplicity of illustration, only T-axes are plotted for earthquakes in the western United States that have a strike-slip focal mechanism. The principal horizontal compressive stress determined from hydrofracture measurements is shown by a solid bar. All hydrofracture data are from Haimson [30], except the one labeled with a Q that is from Dusseault [47].
weakness” where faulting will preferentially occur in the presence of an ambient stress field [10]. These interpretations qualitatively explain the general pattern of seismicity seen in North America. It is, however, also of interest to see what further information or insight might be gained by examining the stress field of North America, as exhibited by focal mechanisms and in-situ stress measurements (Fig. 3) in conjunction with the general pattern of seismicity (Figs. 2).

The flip in the horizontal stress field from compression in the east to extension in the west indicates the interior platform and shield provinces must be relatively immobile, as well as rigid, with respect to the Phanerozoic mobile belts rimming the eastern and western edges of the craton. From the stress data, the simple kinematic model in Fig. 4a may be established. The aseismic, presumably strong shield is impacted by the eastern United States from the east, producing compression along the eastern edge of the shield, and is “left behind” by the western United States, producing extension along the western edge. Presumably the seismicity occurs within the mobile belts because they are zones of crustal weakness.

Minster et al. [11] in a study of instantaneous plate motions, concluded, within observational error, that “hot spots” may be considered a fixed reference frame with respect to the translation of the lithospheric plates. In a “hot spot” reference frame, the North American continent is moving in a westerly direction. Evidence from seismology and heat flow consistently indicate that Precambrian shield and platform areas are characterized by a thicker lithosphere as compared to oceans [12–16] and continental areas of younger age [17–22]. Minster et al. [11] further noted that continental plates move more slowly in the hot spot reference frame than do oceanic plates. They suggested that deep “crustal roots” beneath the continents increase the basal drag and, hence, slow the plate’s lateral movement. If resistive shear at the base of the craton is significant as the North American Plate translates westerly, it may produce a stress field similar to that we see. This idea is illustrated in Fig. 4b. As the plate moves westerly, a relatively increased drag occurs at the base of the thickened portion of lithosphere, impeding its motion relative to the eastern and western portions which, respectively, push into and pull away from the cratonic interior. The seismicity is, again, presumed to occur within the “weak” Phanerozoic orogenic belts. The plate velocity vector is approximately parallel to the northern and southern borders of the cratonic regions of North America and, hence, this model may not be applicable in these regions.

Although the resistive shear drag model is attrac-
tive, it is neither unique nor necessary. For example, if differences in oceanic and continental mantle extend to depths as much as 600 km, as Jordan [14] has argued, it is conceivable that the continental root will have a large effect on mantle convection. Two active cells of convection in the mantle separated by the "root" beneath the craton can conceivably create the stress pattern observed. This is simply illustrated in Fig. 4c. Drag at the base of the lithosphere caused by the convection cells might pull the western portion of the plate away from the craton and the eastern portion of the plate into the craton. The importance of shear forces, it is realized, at the base of the lithosphere is still a matter of contention [11,23–28]. Other plate boundary forces, such as ridge push, and slab pull have also been argued to be the primary cause of stress within intraplate regions [23–25]. Regardless of the mechanism preferred, however, the data constrain any model to have a comparatively rigid and relatively immobile craton.

4. Conclusion

The distribution of seismicity strongly suggests the craton plays an important role in the distribution of seismicity and stress in North America. The epicentral distribution, focal mechanisms, and in-situ stress measurements indicate the craton must be relatively rigid and immobile with respect to the eastern and western United States. Simple kinematic models with this constraint may explain the gross distribution of stress and seismicity in North America.

The models presented do not make the pretense of explaining the finer details of the intraplate seismicity and stress patterns in North America. For example, although seismicity does generally trend along the Appalachian Mountains, one may have to appeal to more local phenomena when trying to explain concentrations of seismicity such as the Boston-Ottawa Seismic Zone, which trends transversely to the general northeast trend of the Appalachians [10]. Effects such as sediment loading, stresses from glacial rebound, or crustal thickness inhomogeneities [29] may well affect the stress field in local areas. The ability of the models to explain the first-order distribution of seismicity and stress in North America does, however, illustrate the craton must be strongly considered in any attempt, either qualitative or quantitative, to explain the distribution of intraplate seismicity and stress.

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