

## A TEST OF THE HYPOTHESIS THAT IMPACT-INDUCED FRACTURES ARE PREFERRED SITES FOR LATER TECTONIC ACTIVITY

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*Introduction.* Because impact cratering has been such an important process on the solid objects of the solar system and because the cratering event is generally accompanied by faulting in adjacent terrain, impact-induced faults are nearly ubiquitous over large areas on the terrestrial planets. The suggestion has frequently been made in the planetary geology literature that these fault systems, particularly those associated with the largest impact features [e.g., 1,2] are preferred sites for later deformation in response to lithospheric stresses generated by other processes. Much of the evidence in support of this view is circumstantial, such as a perceived clustering of orientations of tectonic features either radial or concentric to the crater or basin in question.

An opportunity exists to test this suggestion more directly on Earth. The terrestrial continents contain more than 100 known or probable impact craters [3], with associated geological structures mapped to varying levels of detail. Prima facie evidence for reactivation of crater-induced faults would be the occurrence of earthquakes on these faults in response to the intraplate stress field. Either an alignment of epicenters with mapped fault traces or fault plane solutions indicating slip on a plane approximately coincident with that inferred for a crater-induced fault would be sufficient to demonstrate such an association. As a first step toward testing this hypothesis on Earth, we have examined published catalogs of earthquakes for evidence of seismic activity near terrestrial impact craters.

*Procedure.* We began with Grieve's [3] list of 25 probable impact craters with diameter  $D$  greater than or equal to 20 km. We then searched standard seismicity catalogs [4-6] for earthquakes having epicenters in the vicinity of each crater, taking care to compare the rate of activity around each crater with the background seismicity in the region. The earthquake catalogs have magnitude thresholds that vary spatially and with time; these must be taken into account when interpreting the results. Local or microearthquake studies have also been performed with temporary seismic stations near a few craters; the findings from such surveys are also incorporated.

*Crater-Earthquake Associations.* The 25 craters with  $D > 20$  km are all located in the stable interiors of continents, distant from plate boundaries [3]. The lithosphere in the vicinity of these craters is nonetheless subject to the intraplate stresses generated by plate tectonic forces [7], topographic and density variations [8], and the effects of vertical loading and unloading [9].

For 8 craters with  $D = 25$  to  $40$  km (Araguainha Dome, Clearwater Lake West and East, Slate Is., Mistastin, Kamensk, Steen River, and St. Martin), the standard earthquake catalogs [4-6] list no earthquakes within  $2^\circ$  in latitude or longitude of the crater. For an additional 10 craters with  $D = 20$  to  $100$  km (Popigai, Puchezh-Katunki, Kara, Carswell, Manson, Teague, Boltys, Strangways, Gosses Bluff, and Haughton), fewer than 5 earthquakes have occurred within  $2^\circ$ - $3^\circ$  in latitude or longitude in the last two decades [4], rates of seismicity that are comparable to or below background levels. It should be noted, however, that the magnitude threshold for regions near craters in the Soviet Union is generally higher than for North America or Australia.

Five craters with  $D = 23$  to  $140$  km (Sudbury, Manicouagan, Siljan, Ries, and Rochechouart) have seen one to several earthquakes occur within two crater radii of the crater center during the last 20 years [4]. These earthquakes are relatively small ( $m_b < 5$ ), however, and the level of seismic activity in the vicinity of the crater is not noticeably higher than the regional background level.

Two large terrestrial craters are associated with high levels of recent seismic activity. During the last 20 years, several thousand small to moderate earthquakes occurred within one to two crater radii from the center of the Vredefort structure ( $D = 140$  km) in South Africa [4,10]. All or nearly all of these earthquakes, however, are rock bursts resulting from deep level gold mining operations in the Witwatersrand [10].

Finally, the Charlevoix impact structure ( $D \cong 50$  km) is centrally located in La Malbaie seismic zone in Quebec, one of the most seismically active areas of North America east of the Rocky Mountains [11]. Modern seismicity is concentrated near the conjunction of the St. Lawrence rift system and the 360-m.y.-old crater [12]. Earthquake epicenters [13] and focal mechanisms obtained from first motion and surface wave studies [14], however, indicate that it is the NE-striking, moderately to steeply dipping, rift-related faults that are slipping rather than those created by the impact. The coincidence of the zone of most intense activity with the impact/rift intersection has led to the suggestion that the impact has somehow "weakened" the older fault systems of the rift [e.g., 11,13], but this suggestion is not testable with the seismic data available.

*Conclusion.* Modern intraplate seismicity does not show any general correlation with fault structures associated with the largest terrestrial impact craters. For the two craters with higher than normal levels of nearby seismic activity, other

factors appear to control earthquake occurrence. We conclude that terrestrial analogs offer little support for the hypothesis that impact-induced fractures remain preferred sites for the release of lithospheric stress long after the impact event.

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