Usage of Geological Features in Seismic Hazard Evaluation- A Critical Review of Various Methods

Praseeda E.

Raja Reddy Institute of Technology,
Chikkabanavara, Bangalore, India

ABSTRACT

Seismic hazard analysis represents an evaluation of the probability that an area will be affected by the potential earthquakes generated at a given distances and during future time intervals. In recent decades, significant investigations are done to find the possibility that a region will be subjected to potential earthquakes, produced within the area or from some distances and also the possibility of future seismicity. This paper presents a comprehensive review of various research works, where geologic tools used for seismic hazard evaluation. An attempt has been made to discuss the usage of numerous morphometric parameters in seismic hazard analysis by identifying the nearby active weaker zones. Finally, some important conclusions and the suggestions for future directions of research in this area are presented. It is felt that this review paper will serve the interests of all the academicians, researchers and engineers involved in the seismic hazard evaluation.

Keywords: Seismic hazard evaluation; Geologic tools; Earthquakes; Weaker zones

INTRODUCTION:

Mapping potentially active faults and gathering information about their capability to produce destructive earthquakes became essential in assessing seismic hazard during the last couple of decades. A precise assessment of these threats mainly depends on its generation and distribution with their recurrence interval in space and time. The prime evidence required for any work related to earthquake hazard estimation, management and mitigation is the identification and understanding of the present condition of the seismic sources (faults /shear zones), and evaluating their role in the historical seismicity of the area. Seismic shaking, the dislocations and distortion along pre-existing structures like faults and shear zones, are having greater influence on the locations, where major infrastructural projects such as nuclear project plants, huge dams and underground crude oil storages (John and Rao, 2014) are located. For many tectonic settings, history of earthquake recording is proved to be alone insufficient to calculate continuing activity of the faults (John, 2018). The highly dynamic periods of damaging earthquakes in many tectonic settings leads to huge damages due to unpredictability. To overcome this challenge, earthquake geologists concentrate on past earthquakes to stretch the seismic catalogue through geology related records (Fig. 1.1). Such a study begins with the identification of signatures of faults in satellite images through geomorphic analysis and to site specific fault identification and evaluation. In many tectonic settings, it was observed that active structures were either hidden or its surface signatures were removed by various agents (John, 2018). Generally active faults show complicated structures with several breaks, varying displacement, style and rupture length. Further, to differentiate between faults, which are recently active and inactive for a long time, is difficult, because the evidences obtained will be far from precise. After identifying the active structure using geomorphological studies, geologist may suggest trenching methods to collect stratigraphic and chronologic data of the region. To identify past seismic events, geologists may use the techniques in various fields of geology like geomorphological studies, structural features, geochronological studies, samples related to sedimentological studies, various soil data etc.

The first step toward quantitative seismic hazard analysis for the area is the recognition and identification of active faults in the region of interest. However, the identification of faults, that are active with low-relief and in highly populated areas become a difficult task due to limited availability of applicable methods especially those areas with less recorded seismicity (Singh et al., 2016). Based on the findings of researchers like John and Rajendran (2008), Cox (1994), and Keller and Pinter (2002) in such areas, the most suitable tool to identify the signature of active tectonism, is analyzing the morphometry of drainage basins Therefore, in the present article an attempt has been made to discuss the usage of morphometric tools in seismic hazard analysis by identifying the nearby active weaker zones. Each sub sections are distinctly classified based on the methods followed as active fault studies, delineation of lineaments, Fault zone characterization and morphometric studies. Historical developments and findings of various researchers were discussed in detail.

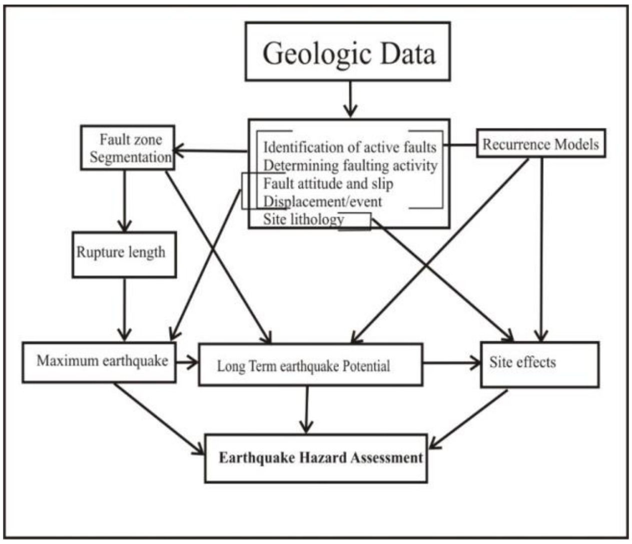

Fig. 1. Figure displays role of various geological data in seismic hazard evaluation process (John, 2018)

Various geological methods followed:

Active fault studies:

The trend of investigation and characterization of active faults were started way behind the year 1916. It was Wood (1916) who gave the first definition of an active fault, in terms of "Living zones of geological faulting". Later this was modified in the California fault map, by adding 2 types of fault viz Alive fault and Dead fault (Willis, 1923). A fault in which slip is likely to occur is called as active fault and a dead fault is one on which no movement is expected.

Fixing the time in geological time scale for characterizing the active fault was done by Bonilla (1970;1967), based on the surface rupturing associated with the faults in United States and Mexico. According to the study, any fault with traces of activity in Holocene Epoch (10000 years approximately) may be classified as active. In addition, there were genuine attempts by the author to set the criteria for the investigations in relation with active faults, in other words, a leaning towards more accurate seismic event assignment to a fault was shown by the studies, marking of episodes of rupturing, elastic and inelastic strain evidences and structural component.

Another important research attempt made in the same line is the study conducted by International Atomic Energy Agency (1968). The major objective of the study was to evaluate the threat posed by the active faults to the nuclear establishments. The emphasize was on gathering the information about how the faults have moved recently and how often in past. The study further suggests that that regional seismological, geodetic and geological consideration may also be taken into before classifying a fault as active. Also, proper attention may be given to the associated branches of fault along with the main fault for a proper assessment.

U.S Atomic Energy Commission (1971) had given three major guidelines for the characterization of active fault viz., Shows movement or surface rupture at a minimal rate of once in 35,000 years or more than once in past 50,000 years, Well defined macro seismic activity along, Coherency between the above-mentioned conditions.

Further it is important to mention that International Atomic Energy Agency's (1972) suggestion that if a fault is associated with the creep movement along with topographic evidences related to surface rupture, offset and wrapping may be classified as active. According to the mentioned study, active faults are further divided into four classes, based on their geomorphology such as, Class A fault–rate of movement will be very high, more than one meter per thousand years, Distinct traces of topographic displacement, Indications of topographic dislocation, Absence of amount or rate of dislocation or quantitative assessment could be built, the fault may be classified as the one of which may cause surface faulting.

Collating the above-mentioned modifications, which were made time to time by different sources, also helps in defining and characterizing the active faults. Association of Engineering Geologists, California (1973) had presented a broad classification of the active faults. According to which the faults broadly fall in three categories viz., active, potentially active and inactive as per the geological time scale. Also, those faults which have shown historical activities might be considered as active. Those faults in absence of any known historical or seismological record but with robust geological indication of recent faulting might be taken as potentially active.

This category is sub-divided in to two. The first group consists of those faults which has affected the Holocene deposits (with an age factor less than 10-11 ka), having robust geomorphic expressions, caused ground water anomalies, occurrence of micro seismic activity across the faults are coined as high potential. The second group consists of those faults which have shown similar activity, same as the first group, except the occurrence of micro seismic activity across the feature along with the evidences of movement in Pleistocene deposits (with an age factor less than 1,650,000 years) and called them as low potential. That fault which shows nil activity in Holocene and Pleistocene offsets are called as inactive fault.

Mines and Geology Division of California (1976) presented a definition for Active faults as "Faults are considered as active faults only if they subjected to surface dislocation within the last eleven thousand years (Holocene). Faults are considered as active and hence as constituting a potential hazard." Accordingly, any fault with a distinct signature of slipping in the present tectonic regime and likely to re-occur in future is termed as an active one. The historical, geological, seismological, geodetic, and geophysical evidences of activity should also be considered for the same classification.

In the span of 1973-1976 several researchers such as Grant Taylor *et al*., (1974), Nichols and Buchananbanks (1974), Wesson *et al*., (1975) attempted modifying the definition of active faults on order to provide enhanced safety factor. However, the classification by Association of Engineering Geologists California (1973) and the one by Mines and Geology Department, California (1976), are commonly been accepted in classifying the faults into three major categories as Active, Potentially active and Inactive faults (Fig. 2).Majority of the work related to active fault studies in India were mainly concentrated on two fields, as geological or geomorphological studies. Geological Survey of India, later compiled all the results from their studies and published them as seismotectonic atlas (GSI, 2000).

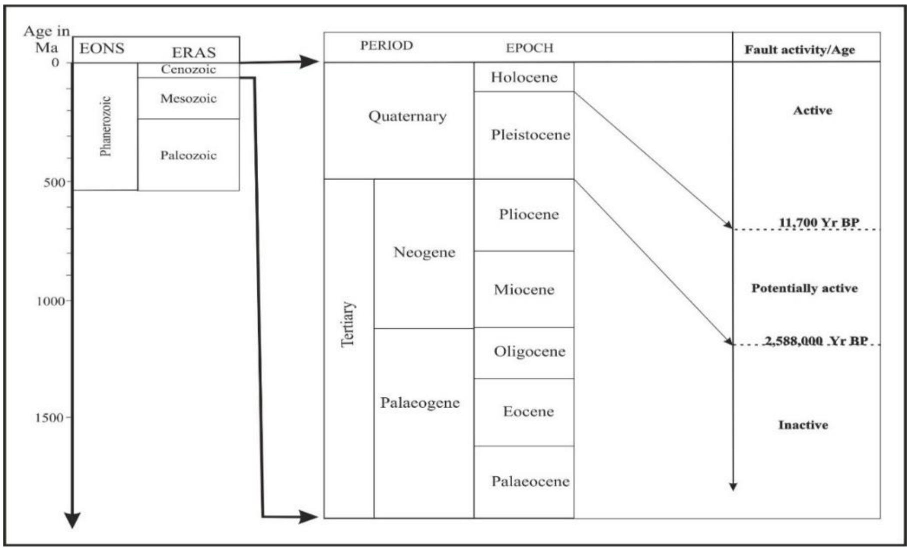

Fig.2. Terms related to fault classification. Based on international commission on stratigraphy, the ages are stated (John 2018)

Delineation of lineaments:

Faults are initially identified regionally as lineaments. The study of lineaments was first initiated in Great Britain during 19th century by the mapping the fractures systematically. Hopkins (1841) was the first geologist who prepared a lineament map which describe d the relation between the structural and topographical features. This systematic mapping of fractures was incorporated in topographic maps during geological mapping by Daubree (1879) and also in geomorphological maps of south and central Norway (Kjerulf, 1880). The outcome of the Kjerulf (1880) study was reinterpreted by Hobbs. In 1904, Hobbs defined lineament as a linear geological structure which may observe in straight line or a curved pattern with a simple or complex structure. Lineaments will vary clearly in pattern and structure from the surrounding formations and highlight some activities which lead to its formation. Linear surface feature may include rivers, coastlines, boundary line of rock formation, fracture zones valleys, etc. In 1912 he come up with another definition of the lineament as, these are the substantial linear lines observed over the land which discloses the secreted structure of the underground.

Aerial photo was first utilized by Latterman (1958), for the mapping of the lineaments. He noticed out that the resolution of the structure and the area covered in photo has significant importance in the demarcation of the lineaments. However, due to the lack of continuity, an aerial photographic survey would also be unable to define the continuity of the lineaments having regional/ larger extent (Suzen and Toprak, 1998). Since the satellite images are having relatively high coverage and resolution than any other data / method, it is highly utilized in the lineament analysis (Suzen and Toprak, 1998). Generally, the method for the identification of the lineament using the remote sensing can be divided into two categories viz., visual extractions and automatic extraction. In this study visual extraction method is utilized for the delineation of the lineaments.

In areas of extensive mapping associated with high slopes, abrupt changes in vegetative cover and unexpected turns along stream channels, remote sensing technology was immensely helpful. It gives effective general view of the whole region and thus provides vast information on structure and geology of the surface features. The capability of remote sensing such as multispectral and high-resolution data and a number of digital image-processing techniques to enhance the available images, increase its importance in demarcating the contacts of various litho- units and structures related to geology, in depth and with increased precision.

Remote-sensing studies remain capable of demarcating those faults which are linear or curvy linear on the earth surface as linear faults. These contrasting linear zones covering some meters or kilometers are generally termed as lineaments Also, the boundaries between lands that are used for different purposes, lithological boundaries and drainage lines are considered as lineaments. The spatial correlation of remote sensing images of geological objects along with the available geological–geophysical data and its density make the interpretation of lineaments easy. Remote-sensing techniques acts as cost effective and faster tool for fault detection compared to the field work / investigations. However, remote-sensing studies cannot replace field investigation as suggested by Praseeda *et al*., (2015) and Singh *et al*., (2016) are not alone sufficient, but can only work in tandem each other.

Fault zone characterization:

The fault related deformation at higher layers of the crust, in crystalline terrains is characterized by cataclasis. This process comprises the brittle disintegration of minerals with alternation of mineral grains followed by slipping leads to dilatant condition of frictional grain boundary (Fig.3). To recognize such earthquake generating faults in the shield areas few studies were conducted by analyzing geology of the bedrock (e.g., Dawers and Seeber, 1991; John and Rajendran, 2009). The advanced integration and assimilation of recently formed and established secondary ruptures of variable dimensions and alignment lead to the development of brittle faults (John and Rajendran, 2009). The powdered rock obtained as an output during faulting is called as gauge. According to the findings of Anderson *et al*., (1983) and Mawer & Williams (1985), the mineral composition of the parent rock is conserved in some cases, however the processes which lead to this modification are obliterated by the alteration of gouge to clay in some environments. The movement and principal stress directions in brittle faults can be identified from careful study of slickensides (Marshak and Mitra, 1988). To find out the earthquake potential from field-based data, several studies used these relations (John and Rajendran, 2009) and observed that the surface rupture length and amount of fault movement could be determined from the fault related field data.

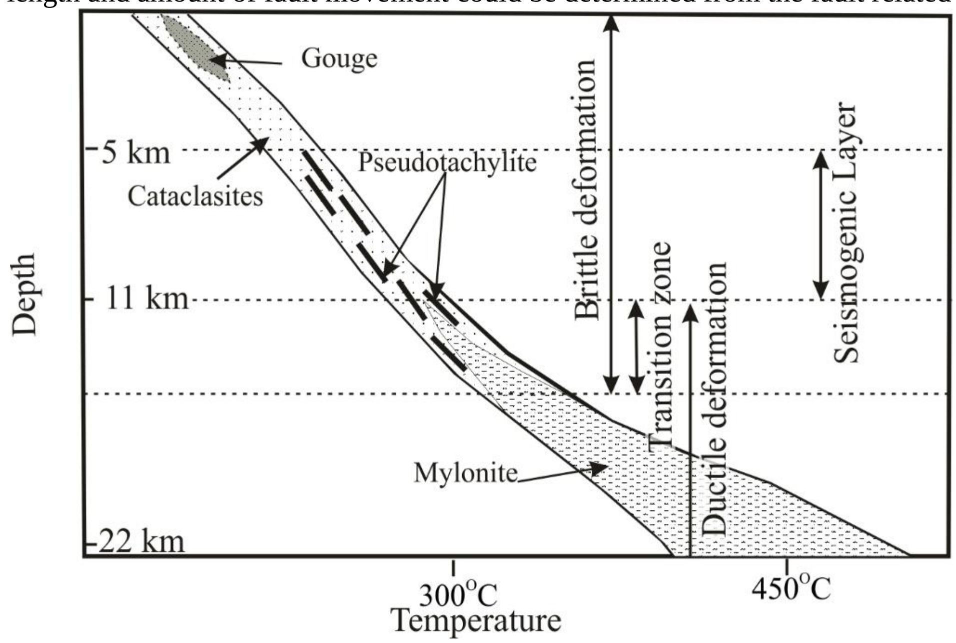

Fig. 2.2 Representation of the faulted rocks with respect to depth (based on fault zone model). Clay gouge is observed on the tip of the zone. (John, 2018)

Crystalline rocks associated with brittle faults are always characterized with slip planes surrounded by a mass of powdered or brecciated rocks. Three lithological units are available in this structure, they are parent rock, a zone of damaged rocks and a fault core, may be characterized with gouge, mylonite or breccia (Fig.3). The portion of the parent rock without any alteration surrounding the damaged zone and fault core is called as Protolith (Fig.4). The comparative movement between the fractured rock situated on both side of the fault will be observed as offsets in some cases. The system of fault related structures like sudden offset of rocks, small veins in rocks, presence of fracture planes and cleavage planes (Bruhn *et al*., 1994) that bound the fault zone are considered as damage zone. Fractures of varying orientations are observed in damage zones. Depending on the age of the fault, these fractures may be filled with secondary minerals. Sometimes the gouge may also inject to fracture zone. Lin (1997) reported similar structures from Nagano Prefecture region located in Japan, where the veins are formed by the rapid injection of gauge in to fracture zone during seismic slip. The alteration of fault gouge to a fluid state during the process might have resulted this injection (Otsuki *et al*., 2003). Based on the findings of Caine (1996), part of the faulted structure where maximum dislocation accommodated is called as fault core. The host rock will be crushed, and its actual texture and structure will completely be altered within the principal slip plane. Chester, *et al*., (1993) reported this kind of narrow zone, comprising composite slip planes from faults located at San Gabriel, similar one reported again by Chester & Chester (1998) from Punchbowl of USA and also by Boullier *et al*., (2004) from Nojima located at Japan.

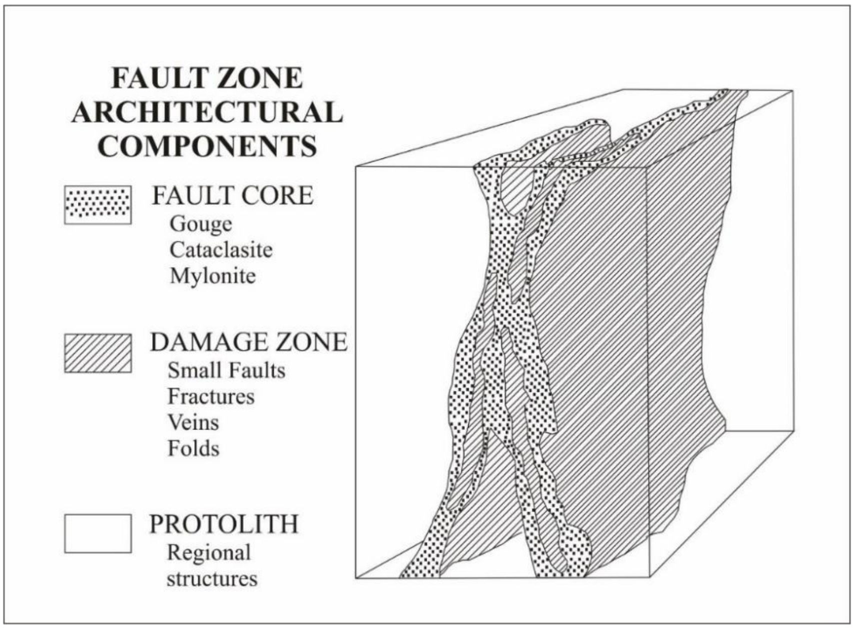

Fig.4. Model of continental fault zone, after Carine (1996)

Morphometric studies:

It is not easy to identify active fault in those areas which are characterized with low seismicity, less relief and thick population, because the methods applicable to these areas are very less (Singh *et al*., 2016). Evaluating basin morphometry using morphometric parameters and geomorphic indices is the suitable tool to assess the signatures of active tectonism in these areas (Cox, 1994; John and Rajendran, 2008).

The term Morphometry denotes the measurement of shape. Basin morphometry refers the quantitative analysis of the drainage basin of a fluvial system. In 1945, Horton introduced the method of analyzing a drainage basin quantitatively. This method is followed by Strahler (1952;1957) in the field of hydrology. Morphometry is used as a principle to calculate active tectonism because most of the landforms are formed by erosional and depositional activities and the shape of the resultant terrain will completely be depending on the processes which controls them. Several researchers have utilized this method for the study of Morphometric characteristics of various basins and sub basins (Leopold and Miller, 1964; Shreve, 1966; Bull & MacFadden, 1977; Abrahams, 1984; Murthy *et al.*, 1996; Burrbank and Andereson, 2001; Reddy *et al*., 2004; Peter and VanBalen, 2007; Kumar *et al*., 2009 and Altin and Altin, 2011). Geomorphic variables like, drainage density, Form factor ratio, constant of channel maintenance, basin relief, bifurcation ratio, Ruggedness number (Schumn, 1956), Circularity ratio (Miller, 1953), relief ratio, Elongation ratio (Schumn, 1956) have been used for the analysis (both qualitative and

quantitative) of land forms (Table 1). Geomorphic indices have been developed as basic reconnaissance tool to identify areas experiencing rapid tectonic deformation. These indices are useful in tectonic studies for quick evaluation of larger areas from topographic maps and/or aerial photographs. Some of the geomorphic indices that are widely used for studies of active tectonics are Hypsometric integral (Strahler, 1952), Drainage basin asymmetry (Hare and Gardner, 1985), Stream length gradient index (Hack, 1973), Valley floor valley height ratio (Bull and McFadden, 1977), Mountain front sinuosity (Bull and McFadden, 1977), Sinuosity of river (Leopold et al., 1964), Transverse topography symmetry factor (Cox, 1994).The results of several indices need to be combined with the other geological information to classify the areas as being very active, moderately active, or inactive
The relationship between tectonics and landscape can examine by geomorphology or morpho tectonics. (Caputo and Pavlides, 2008). Based on the findings of Cox (1994) and Keller and Pinter (2002), a quick judgment on active tectonics of an area could be possible by studying a drainage system, and its pattern qualitatively and quantitatively and measurable parameters can also use as an exploration tool to interpret relative tectonic activities. Over the years, different areas are classified as very active, moderately active and inactive by various workers based on quantitative parameters. The effect of various topographical elements and parameters like drainage density, form factor ratio, etc. in relation with rate of sediment production of sub water sheds of the Damodar Valley, were being examined by Mishra *et al*., (1984) and found out that the rate of sediment production and form factor ratio are inversely related. This same observation by Mishra et al has relevance to the 20 watersheds found in Nilgiri region because of different form factors witnessed here in the region.

Table 1. Equations Applied to Compute Various Parameters of Morphometry

Sl. No	Morphometric Parameters	Formulae	References
1	Bifurcation Ratio (BR)	BR = Nu/Nu+1 Where, Nu = Total number of stream segments of order ‘U, Nu+1 = Number of stream segments of next higher order.	Horton (1945)
2	Stream frequency (SF)	SF= Nu/A Where, Nu = Total number of streams, A = Area of basin.	Horton (1945)
3	Drainage Density (DD)	DD = L/A Where, L = Total length of streams of all orders, A = Area of basin.	(Horton 1932)
4	Infiltration Number (IN)	IN= DD × SF Where DD = Drainage density and SF = Stream frequency	Faniran (1968)
5	Length of Overland flow (LF)	LF = ½ (DD) Where DD = drainage density	Horton (1945)
6	Constant of channel maintenance (CCM)	CCM = A/ ΣL or 1/DD Where DD = drainage density	Schumm (1954)
7	Texture Ratio / Drainage Texture (TR)	TR = (ΣN / P) Where ΣN= total number of stream segments of all order and P = perimeter	Smith (1950)
8	Elongation Ratio (ER)	$ER=(2/L) \times (A/\pi)^{0.5}$ where A is the area and L is length of the basin.	Schumm (1956)
9	Circulatory ratio (CR)	$CR=4\Pi A/P^2$ Where A is the area and P is the perimeter of the basin	(Strahler,1964; Miller, 1953).

Sl. No	Morphometric Parameters	Formulae	References
10	Form factor (FF)	$FF=A/LP^2$ Where A is the area and P is the perimeter and L is the length of the basin	Horton (1932)
11	Relief Ratio (RR)	RR = R/L Where R is maximum basin relief and L maximum basin length	Schumm (1963)
12	Ruggedness number (RN)	RN = H × DD; where, H= Basin relief, DD = Drainage density.	Strahler (1968)
14	Asymmetry factor (AF)	AF = 100× (Ar/At); Where, Ar = Right half of area of basin while facing downstream, At = Total area of the basin.	Keller and Pinter (2002)
13	Valley floor width to height ratio (VR)	$VR = 2V_{fw}/(E_{ld}-E_{sc}) +(E_{rd}-E_{sc})$ V_{fw} = the width of valley floor E_{ld} and E_{rd} = elevations of the left and right valley divide respectively, Esc- the elevations of the valley floor.	Bull and McFadden (1977)
15	Transverse Topography Symmetry Factor (TTS)	$TTS=(D_a/D_d)$, where D_a = distance from the stream channel to the middle of its drainage basin and D_d = distance from the midline to the basin divide.	(Cox, 1994)

CONCLUSION:

The significance of the paper is to highlight the requirement of geological knowledge for a better seismic hazard analysis. The present seismic zoning approach is principally controlled by inadequate database, particularly those regions where earthquake has long recurrence intervals. Thus, for earthquake hazard assessment of an area, combination of geological information like presence of an active or potentially active faults, data on possible earthquake (highest recorded magnitude) of the area, recurrence interval of earthquake, the juxtaposition to shear zones, and lithology of the area are indispensable. This paper concentrated mainly to find out the geological evidences associated with active tectonic processes. Construction of any major civil engineering structures like dams, tunnels etc. giving prime importance to earthquake hazard assessment, for their location of interest. Liquefaction, shaking of the ground, fracture and cracks developed on the earth surface and earthquake related landslides are the hazards related to earthquake. But required historic and instrumental data to assess long-term earthquake potential were insufficient in most of the cases. To improve these earthquake catalogue beyond historic period, geological information of the area can be helpful. Disparities in ground vibration, amplitude variation, duration of an earthquake are primarily controlled by the geological and geotechnical characteristics of a terrain. Thus, in any earthquake hazard assessment programme, geological information will be collected and studied both regionally and locally. Thus, a systematic geomorphic, morphometric study including the remote sensing study and field investigation is required to estimate the nature of fault in any study area. So, this paper is a supplementary effort to recognize the effect of vigorous tectonic activity in an area using various geologic tools. In addition to that, an attempt has been made to develop a methodology, for the identification and evaluation of any seismogenic feature in an area of similar cratonic region. This would be a first step for earthquake hazard assessment in an area.

REFERENCES:

Abrahams, A. D. (1984), 'Channel networks: a geomorphological perspective', Water Resour Res. 20, 161 – 168.

Anderson, J.G. and Luco, J.E. (1983). 'Consequence of Slip Rate Constraints on Earthquake Occurrence Relations', Bull. Seism. Soc. Am. 73, 471-496.

Bonilla, M.G. and Buchanon, J.M. (1970). 'Interim Report on World-Wide Historic Surface Faulting', Open-File Report 70-34, U.S. Geological Survey.

Bonilla, M. G. (1967), 'Historic surface faulting in continental United States and adjacent parts of Mexico', U. S. Geological Survey open file report: also, Atomic Energy Commission Report TID-24124, pp.36.

Bruhn, R. L., Parry, W. T., Yonkee, W. A., and Thompson, T. (1994), 'Fracturing and Hydrothermal Alteration in Normal Fault Zones, Pure Appl', Geophys. 142, 609–644.

Boullier, A.M., Fujimoto, K., Ohtani, T., Roman-Ross, G., Lewin, E., Ito, H., Pezard, P., Ildefonse, B. (2004), 'Textural evidence for recent co-seismic circulation of fluids in the Nojima fault zone, Awaji island, Japan', Tectonophysics 378, 165-181.

Bull, W.B & McFadden, L., 1977. Tectonic geomorphology North and South of the Garlock fault, California, In: Dohering, D.O. (Ed.), Geomorphology in Arid Regions. Publ. in Geomorphology, State University of New York, Binghamton, pp. 115–138.

Burbank, D.W., Anderson, R.S. (2001), 'Tectonic Geomorphology', Blackwell Science 43, 105–129.

Caine, J.S., Evans, J.P., Forster, C.B. (1996), 'Fault zone architecture and permeability structure', Geology 24, 1025–1028.

California Division of Mines and Geology (1976), 'Active fault mapping and evaluation program; Ten-year program to implement Alquist-Priola Special Studies Zone Act: CDMG Special Pub. 47

Caputo, R., Pavlides, S.B. (2008), 'Earthquake geology: methods and applications', Tectonophysics 453, 1–6.

Chester, F.M., Evans, J.P. and Biegel, R.L. (1993), 'Internal structure and weakening mechanisms of the San Andreas Fault', J. geophys. Res.98, 771-786.

Chester, F.M., Chester, J.S. (1998), 'Ultra cataclastite structure and friction processes of the Punchbowl fault, San Andreas system, California', Tectonophysics 295, 199-221.

Cox R.T., 1994. Analysis of drainage basin symmetry as a rapid technique to identify areas of possible Quaternary tilt block tectonics: An example from the Mississippi Embayment, Geol. Soc. Am. Bull., 106, pp.571-581.

Daubree, A. (1879) 'Geologie Exprimentale. Libraire des Corps des Points et Chausses', des Mines et des Telegraphes, Paris 2, 828.

Dawers, N. H. and Seeber, L. (1991), 'Intraplate faults revealed in crystalline bedrock in the 1983 Goodnow and 1985 Ardsley epicentral areas, New York', Tectonophysics 186, 115-131.

Grading Codes Advisory Board and Building Code Committee (1973), Geology and earthquake hazards: Planners guide to the seismic safety element, Southern California Section, Association of Engineering Geologists, 44.

Grant Taylor, T.L., Adams, R.D., Hatherton, T., Milne, J.D.G., Northby, R.D., Stephenson, W.R. (1974), 'Microzoning for earthquake effects in Wellington, NZ', New Zealand Department of Scientific and Industrial Research Bulletin 213, 62.

GSI Seismotectonic Atlas of India and its Environs. 2000. Geol. Surv. India Spec. Publ., no.59.

Hack, J.T., 1973. Stream-profile analysis and stream-gradient indices. J. Res. U. S. Geol. Surv. 1, 421–429.

Hare, P.W. and Gardner, T. W. (1985), 'Geomorphic indicators of vertical neotectonism along converging plate margins', Nicoya Peninsula, Costa Rica; In: Tectonic Geomorphology, 75–104.

Hobbs, W.H. (1904), 'Lineaments of the Atlantic border region', Geological Society of America Bulletin 15, 483–506.

Hopkins (1841), 'On the geological structure of the Wealden district and of the Bas Boullonais', Transcription of the Geol. Society of London 7 (2), 1- 51.

Horton R.E., 1945. Erosional development of streams and their drainage basins; hydro physical approach to quantitative morphology, Geol. soc. Am. Bull, 56, pp. 275-370.

International Atomic Energy Agency (1968), 'Aseismic design and testing of nuclear facilities', Technical Report Series No. 88, Vienna, Austria, pp. 49.

International Atomic Energy Agency (1972), 'Earthquake guidelines for reactor siting': Technical Report Series No. 139, Vienna, Austria, pp. 9-10.

John, B. (2018), 'Importance of geological studies in earthquake hazard assessment' Integrating disaster science and management, 27-38.

John, B., Rao, D.T. (2014), 'Seismotectonic evaluation of critical civil engineering facilities: the standard practice', In 'National Seminar on Innovative Practices in Rock Mechanics', pp. 133–138.

John, B. and Rajendran, C.P. 2009, Evidence of episodic brittle faulting in the cratonic part of the Peninsular India and its implications for seismic hazard in the slow deforming regions, Tectonophysics, 471, pp. 240-252

John, B.& Rajendran, C. P., 2008. Geomorphic indicators of Neotectonism from the Precambrian terrain of Peninsular India: a study from the Bharathapuzha Basin, Kerala, J. Geol. Soc. India, 71, pp. 827–840.

Kjerulf, T. (1880), 'Die Geologie des südlichen und mittleren Norwegan', Authorized German edition by Gurlt, Bonn, pp. 350.

Keller, E.A.& Pinter, N., 2002. Active Tectonics: Earthquakes, Uplift, and Landscape. Prentice Hall, New Jersey.

Krishnamurthy, J., Venkatesa kumar, N., Jayaraman, V. (1996), 'An approach to demarcate ground water potential zones through Remote Sensing and GIS', International Journal of Remote Sensing 17(10),1867-1884.

Kumar, N., Singh, A.P., Rao, M.R.K.P., Chandrasekhar, D.V. and Singh, B. (2009), 'Gravity signatures derived crustal structure and tectonics of Achankovil Shear Zone, southern India', Gondwana Research 16, 45–55.

Latterman, L. H. (1958), 'Technique of mapping geological fracture traces and lineaments on aerial photos', Photogrammetric Engineering 24, 568-576.

Lin, A. (1997), 'Fluidization and rapid injection of crushed fine-grained material in fault zones during episodes of seismic faulting', 'Proceedings 30th international geological congress', vol 14, pp. 27- 40.

Leopold, L.B., Wolman, M.G., Miller, J.P. (1964), 'Fluvial Processes in Geomorphology', Freeman, San Francisco, 511.

Markose, V., Jayappa, K. (2012), 'Hypsometric analysis of Kali River basin,Karnataka, India, using Geographic Information System', Geocarto international 26, 553-568.

Marshak, S., Mitra, G. (1988), Basic method of structural geology, Prentice Hall, Englewood cliffs, New Jursey, pp 446.

Mawer, C.K., Williams, P.F. (1985), 'Crystalline rocks as possible paleoseismicity indicators', Geology-3, 100-102.

Miller, V. C. (1953), 'A quantitative geomorphic study of draiuage basin characteristics in the Clinch Mountain area Virginia and Tennessee'. Tech. Rept. 3, Dept. of Geol., Columbia Univ., New York.

Mishra, N., Satyanarayana, T. and Mukherjee, R. K. (1984), 'Effect of topo element on the sediment production rate from sub watersheds in upper Damodar valley', J Agric. Engg, ISAE, 21(3), 65-70.

Nichols, D.R. and Buchanan-Banks, J.M. (1974), Seismic hazard and land use planning, U.S Geological Survey Circ. 690, 33.

Otsuki, K., Monzawa, N. and Nagase, T. (2003), 'Fluidization and melting of fault gouge during seismic slip: Identification in the Nojima fault zone and implications for focal earthquake mechanisms', J. Geophys. Res, 108.

Praseeda, E., John, B., Srinivasan. C., Singh. Y., Divyalakshmi. K. S.& Samui. P., 2015. Thenmala Fault System, Southern India: Implication to Neotectonics, J. Geol. Soc. Inia, 86, pp.391-398.

Peters, G., Van Balen, R.T. (2007), 'Tectonic geomorphology of the northern Upper Rhine Graben, Germany', Glob. Planet. Chang. 58, 310–334.

Reddy, GPO., Maji, A, K., Gajbhiye, K, S. (2004a), 'Drainage morphometry and its influence on landform characteristics in basaltic terrain-A remote sensing and GIS approach', Int J Appl Earth Obs Geo inform 6,1-16.

Schumm, S. A., 1956. Evolution of Drainage systems and slopes in bad lands at Perth, Amboy, New Jersey. Bull. Geol. Soc. America, 67, pp.597-646.

Shreve R. L. (1966), 'Statistical law of stream numbers', Journal of Geology, 74, 17–37.

Singh Y., John,B., Ganapathy, G.P, Abhilash George, Harisanth, S., Divyalakshmi, K. S., and Sreekumari Kesavan, (2016), 'Geomorphic observations from southwestern terminus of Palghat Gap, South India and their tectonic implications'. J. of Earth System Science, 821-839.

Suzen, M.L. and Toprak, V. (1998), 'Filtering of Satellite Images in Geological Lineament Analyses: An Application to a Fault Zone in Central Turkey', International Journal of Remote Sensing 19 (19), 1101-1114.

Strahler, A. N., 1957. Quantitative analysis of watershed geomorphology; Trans. Am. Geophys. Union, 38, pp.91–920

Strahler, A. (1952), 'Dynamic Basis of Geomorphology'. Geological Society of America Bulletin 63, 923-938.

U. S. Atomic Energy Commission, (1971), 'Nuclear power plants; seismic and geologic siting criteria': Federal Register 36 (228), pp. 22.

Wentworth, C. M., Ziony, J. I., and Buchanan, J. M. (1970), 'Preliminary geologic environmental map of the Greater Los Angeles area, Calif', U. S. Geol. Survey Rept. Tl0-25363, p. 43.

Willis B. (1923), A fault map of California, BSSA 13, 1-12.

Wood H.O. (1916), 'The earthquake problem in the western United States', BSSA 6, 181-217
