

The Basin and Range Province

The Basin and Range Province displays the characteristic landscape of what is known as Basin and Range topography. Governed by sub-parallel ranges intervened by adjacent basins, the topography's appearance on a map was suggested to resemble "an army of caterpillars crawling northward out of Mexico" by Clarence Dutton (King). Geologists have long debated the origin of the formation of the Basin and Range topography and have spent much time examining the structural products for any clues. Many believed that the topography was simply a result of erosional processes acting upon folded and faulted rocks in an arid climate (King, 1977). However, G.K. Gilbert suggested that faults bordered the ranges causing them to have been raised and tilted (King, 1977). At first many of his fellow geologists were skeptical of his suggestion, pointing out that faults could be present even if they did not relate to the formation of the topography. Also it was noted that if faults really did border the ranges, they would be hidden beneath the erosional deposits in the piedmont areas (King, 1977). It is now universally agreed that the Basin and Range topography is a result of partially buried fault blocks that have been produced by the extension of the region initiated during the late Cenozoic time. The cause of this extension is still controversial; however there has been much agreement that asthenospheric upwelling has been an important part. In recent years, geophysical technologies have greatly improved our understanding of the

importance of tectonic processes involved with the formation of the Basin and Range province.

The Basin and Range Province is located in the western United States, and includes approximately 800,000 km² of area extending from southern Oregon and Idaho through most of Nevada, and parts of California, Arizona, Utah, and New Mexico to northern Mexico (Eaton, 1982). Characterized by north-south trending alternating mountain ranges and sediment-filled valleys, the province is situated in the western part of the North American Cordillera which is comprised of the Mexican lowlands, and all the mountain ranges and plateaux west of the Great Plains (see figure 1)(Allaby et al., 1999). The term Cordillera is derived from “cord” or “rope” in Spanish, and is used to describe a “chain” of mountains (King, 1977). In the east the province is next to the Colorado Plateau and the Rockies, while in the west it borders the Sierra Nevada mountain chain. Many of the internal ranges are long and slender, parallel in relation to one another, and display tilted rock strata in a block-like structure. The average elevation of the Basin and Range Province is approximately 1400m; however the eastern and western boundaries are characterized by lower elevations (Ellis et al., 1999). In comparison to its bordering counterparts, i.e. the Sierras, the Rockies and the Colorado Plateau, the province overall is relatively similar in elevation.

The Basin and Range Province has been divided into five physiographic sections, the largest and most infamous being the Great Basin (Eaton, 1982). This landmass is characterized by an isolated interior drainage system, meaning that its surface water does not drain to the sea, but rather into interior lower-than-sea-level basins. The Great Basin, as one may assume, is not actually a single basin but rather a combination of 200 or more

separate hydrographically closed areas (Eaton, 1982). The landforms present in the Great Basin are most notably alternating mountain ranges intervened by basins, however a number of secondary landforms exist among them.

Running along the long axis of the majority of the ranges is a central drainage divide from which pertaining catchment features originate (Ellis et al., 1999). The place where corresponding basins and ranges meet is not distinctly defined because erosional processes have deposited material along the range flanks. The present climate in the basin and range is arid; annual precipitation is less than the amount of water that would evaporate and be transpired by plants if the water supply were infinite (Allaby et al., 1999). Although rainfall is scarce in these dry regions, when it does occur it can have a catastrophic effect upon the landscape. The surface and groundwater systems derive their water from a recharge area high in the mountains. From here surface water travels down towards the adjacent valley, while groundwater percolates down through porous rock towards underlying aquifers. As surface water makes its way to the valley, it mechanically breaks down rock and transports it further down the mountain. These deposits form the piedmont area, an area characterized by landforms created sedimentary deposits (Allaby et al., 1999). These include bajadas; extensive plains of unconsolidated rock debris resting again the foot of the mountain. Typically a bajada is created by the combination of a number of alluvial or debris-flow sedimentary deposits congregating at the margin of the basin and the range (Allaby et al., 1999). These landforms are easily recognizable by their poorly sorted gravel composition and concave-upward shape that slopes smoothly towards the level basin (Eaton, 1982). Low fault scarps that run parallel to the range front and alluvial fans at the outlets of canyons interrupt these landforms

sporadically. Fault scarps originate when the movement of a fault offsets the overlying strata. This results in one side standing higher than the other similarly to a step or a cliff. Due to the overlying strata being composed of unconsolidated material, the scarp tends to be easily eroded away.

Discharge areas associated with Basin and Range topography are generally occupied by playas. Playas occur in the lowest part of the adjacent valleys, and exhibit shallow lakes characterized by high chemical concentrations of crust-forming minerals (Allaby et al., 1999). The dry and arid climate associated with the Great Basin causes a major flux of water out of the lakes in the form of evapotranspiration (Güler, 2004). The water that enters these shallow lakes contains salt-forming minerals such as halite, natron, borax, thenardite, mirabilite and trona (Allaby et al., 1999). When the water evaporates these minerals remain and form a large layer of salt on the basin surface, resulting in salt flats such as those present in Death Valley.

The dominant physiographic structure of the Basin and Range Province is the result of a series of normal fault-blocks, most of which are tilted either to the east or west. The results of such are horsts (high ends of tilted fault blocks) that form the characteristic north-south trending ranges and grabens or half-grabens (lowered ends of tilted fault blocks) that form the intervening down-dropped valleys. These faulted blocks of crust are composed of rocks that date back before the Cenozoic time, some of which are extremely deformed. During the early Cenozoic, and most likely also before, the crust underlying the Basin and Range area began to uplift and crack brittlely due to upwelling. The cracking formed numerous faults, some of which protruded deeply into the crust. This point in the formation of the basin and range is controversial; however one tends to

believe that the extension would have caused informal deformation in the form of listric faulting. This form of faulting consists of numerous smaller faults deriving from a larger extensional fault that curves at depth into a flattened horizontal zone of displacement (Allaby et al., 1999).

Generally faults within the basin and range are located at the borders of the main ranges, however other less important faults are present throughout the region. Fault's contribution to the basin and range is primarily as initiators to the creation of fault-block mountains. However most likely these faults were in place prior to the Cenozoic extension and thus were reactivated by asthenospheric activity. Similarly to faulting, volcanism is widespread throughout the Basin and Range. The most recent activity has occurred along the bordering edges of the range and it appears to have migrated north-westerly.

One may be able to infer from the physical topography of an area the mechanism by which it was formed. It was by this method that G. K. Gilbert proposed the presence of faults along the edges of ranges and how they produced the infamous topography. However, the study of relating geophysical properties such as seismology, gravity, magnetism, heat flow and geochronology enables one to support their inference with concrete evidence in the form of quantitative data. To understand what mechanisms are at work under and around the Basin and Range one needs to know more about the larger tectonic processes affecting the area. To do this geophysical studies have and must continue to be performed to increase understanding of the subsurface. Such questions might include: what evidence is there to prove that the Basin and Range is continuing to extend? Geologists have been keeping track of the magnitude of extension through the

use of GPS equipment and have coupled this data with other geophysical evidence. Estimations of the total amount of displacement in the province range from 60 km to approximately 300 km since its initiation, while possible extension rates for the Great Basin are about 1-5 cm per year (Moores et al., 1995).

There is a distinct relationship between heat transfer and tectonics that is based upon the process of thermal conduction within the earth. Heat is constantly being lost from the earth's interior due to the existence of a temperature gradient. The presence of solid state tectonic plates on the outside of the spherical earth affects the rate and way in which thermal conductivity occurs (see figure 2). Continental crust is usually thicker and less dense than oceanic crust, and thus would tend to display a lower seismic velocity and lower heat flow. However, high heat flow ($\sim 90 \text{ mW/min}^2$) in the Basin and Range province indicates that the crust below it is thinner than usual ($\sim 65 \text{ km}$) (Liu, 1998). One measures the heat flow, also known as heat flux, by first measuring the temperature difference between two points a known distance apart. Secondly, one must measure the thermal conductivity of the rock material within which the two points were located (Moores et al., 1995). The general heat flow of continental crust is lower than that of oceanic crust, implying that it varies depending upon the tectonic environment. Areas characteristic of volcanic activity or extending terranes, such as the Basin and Range province, tend to have high heat flows (Moores et al., 1995). Generally, when an area of the crust is thick a low heat flow will be exhibited; heat flow is proportional to crustal thickness. High heat flow in the Basin and Range province indicates the presence of hotter, less dense material close to the surface and thus implies that mantle upwelling is occurring.

Additionally to heat flow, one can measure the seismic velocity so as to learn about the density and elasticity of the rocks forming the crustal structure. Velocities are assumed to increase with depth within subsurface structures, due to the pressure of overlying material. Thus one would presume the velocity to steadily increase as it works its way down through the rock to the presumed boundary of that layer. However in the case of the Basin and Range, there is a low velocity zone located right below the crust. One would infer from its presence that lower density asthenosphere is welling up and eating away at the base of the continental lithosphere. This upwelling of mantle material is directly related to the stretching and thinning of the basin and range region, causing a 'soft-spot' in the North American plate.

The thinness of the lithosphere below the Basin and Range and the overall elevation of the region are inconsistent with the general pattern of isostasy. Isostasy relates differences in topographical elevation to the depth and density of the supporting lithospheric material. In the case of the Basin and Range the reasonably high elevations would imply that the supporting crust would be proportionally thick and dense. However, geophysical studies have shown that this is not the case. One way of explaining this phenomenon would involve the thin Basin and Range crust floating on top of extremely low density mantle material.

The role of upwelling mantle material in the extension of the Basin and Range is universally accepted; however the cause for this is still undecided. Studies of major tectonic plates propose the upwelling to be a result of the subduction of parts of the Farallon and Pacific plates. Separated by the East Pacific Rise, the Pacific and Farallon plates were present west of North America during the middle Cenozoic era. About 29

million years ago the East Pacific Rise (a spreading oceanic ridge) began to subduct underneath the western border of the North American plate. Spreading ridges are a direct source of new oceanic material and thus are areas of mantle upwelling. The presence of this spreading ridge somewhere below the Basin and Range province is most likely as is its contribution to the regions topography.

Vast improvements have been made in understanding the formation of the Basin and Range; however there are still many things still to be studied. Large-scale studies involving tectonic plates and processes should continue to take place. However, it has been noted that studies of the Basin and Range have paid less attention to the topography of individual mountain ranges, than that of the overall structure (Ellis et al., 1999). If studied, the superficial morphology of the individual mountain ranges could lead one to learn more about the tectonic and climatic conditions that have shaped them.

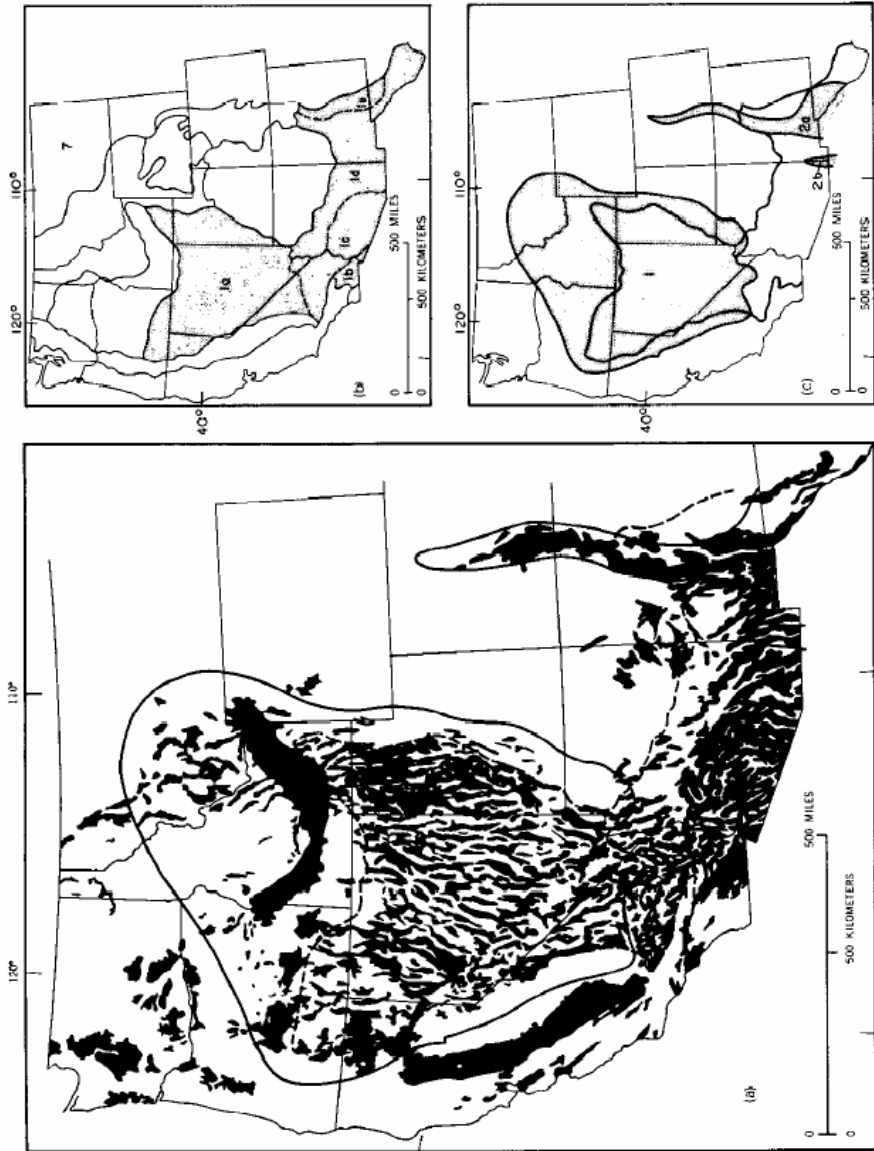
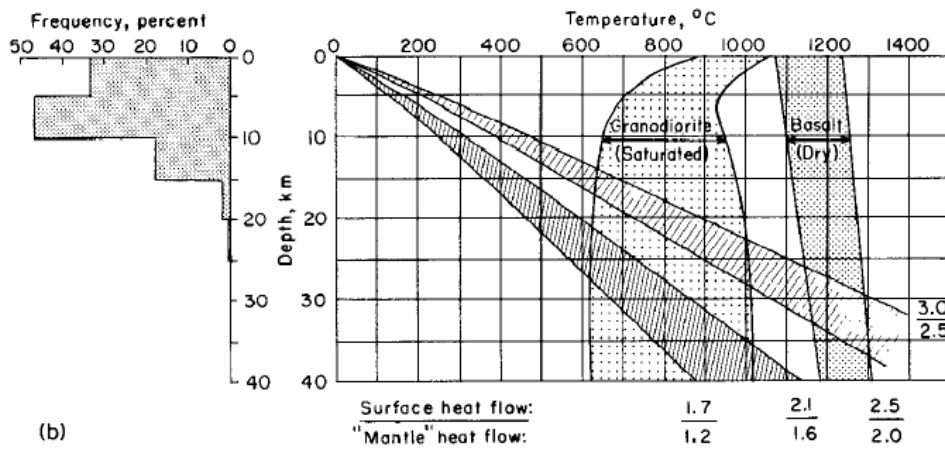
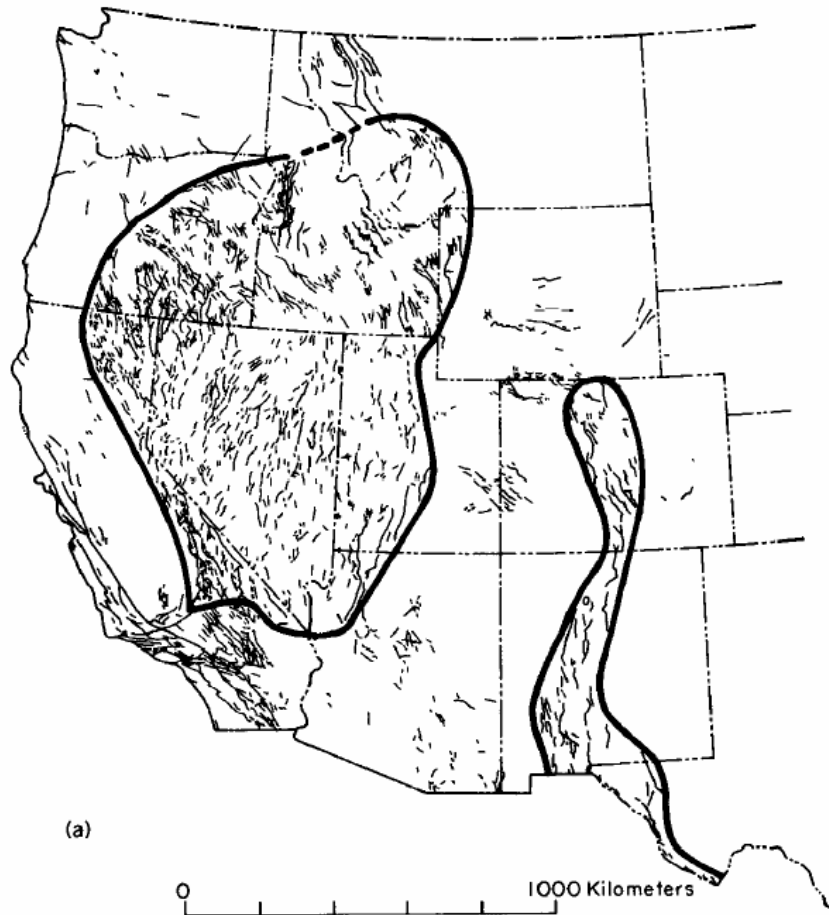


Figure 1: Map of Basin and Range Province (Eaton, 1982)

Figure 1 Maps of the Basin and Range province: (a) Distribution of grabens and other structural basins in the western United States containing Miocene, Pliocene, and Quaternary sedimentary rocks, as well as Quaternary volcanic rocks; (b) Map of physiographic subdivisions of the western United States, with sections of the Basin and Range province as follows—1a, Great Basin; 1b, Salton Trough; 1c, Sonoran Desert; 1d, Mexican Highland; 1e, Sacramento; (c) Map of regions tectonophysically active in Quaternary time, exclusive of coastal California. Sources: Fenneman 1928, 1931, King & Beikman 1974, Eaton 1979b.

Figure 2: 1) Active faults in past 10 to 15 Ma
 2) Conductive temperature profiles for the Basin and Range crust
 (Eaton, 1982)



- Dott, R.H., Prothero, D.R., 1994. Basin and Range Province. *Evolution of the Earth*. 460-480
- Eaton, G.P. 1982. The Basin and Range Province: Origin and Tectonic Significance *Ann.Rev. Earth Planet. Sci.* 10:409-40
- Ellis, M.A., Densmore, A.L., Anderson, R.S., 1999. Development of mountainous topography in the Basin Ranges, USA. *Basin Research*. 11:21-41
- Gawthorpe, R.L., Leeder, M.R., 2000. Tectono-sedimentary evolution of active extensional basins. *Basin Research*. 12:195-218
- Güler, C., Thyne, G.D., 2004. Hydrologic and geologic factors controlling surface and groundwater chemistry in Indian Wells-Owens Valley area, southeastern California, USA. *Journal of Hydrology*. 285:177-198
- Kent, G.M., Babcock, J.M., Driscoll, N.W., Harding, A.J., Dingle, J.A., Seitz, G.G., Gardner, J.V., Mayer, L.A., Goldman, C.R., Heyvaert, A.C., Richards, R.C., Karlin, R., Morgan, C.W., Gayes, P.T., Owen, L.A., 2005. 60 k.y. record of extension across the western boundary of the Basin and Range province: Estimate of slip rates from offset shoreline terraces and a catastrophic slide beneath Lake Tahoe. *Geology*. 33:365-368
- King, P.B., The Evolution of North America. USA: Princeton University Press, 1977
- Liu, M., Shen, Y., 1998. Sierra Nevada uplift: A ductile link to mantle upwelling under the Basin and Range province. *Geology*.26:299-302
- Moores, E.M., Twiss, R.J.,Tectonic. USA: W.H. Freeman and Co.,1995.
- Sonder, L.J., Jones, C.H., 1999. Western United States Extension: How the West was Widened. *Annu. Rev. Earth Planet. Sci.* 27:417-62
- Stewart, J.H., Coney, P.J., Smith, R.B., Blackwell, D.D., Cenozoic tectonics and regional geophysics of the western cordillera. USA: The Geological Society of America, Inc., 1984