DEPARTMENT OF THE INTERIOR

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VERTICAL CRUSTAL MOVEMENTS IN THE CONTERMINOUS UNITED STATES OVER THE LAST 10 MILLION YEARS

By

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DISCUSSION

Knowledge of vertical movements, both uplift and subsidence, is a useful tool in its application to siting, planning, and design of major engineering structures, and in seismotectonic analyses. Location, direction, and rate of movement, geometry of the regions of vertical movements, and a grasp of mechanisms are all important in understanding basic crustal structures and their evolution within the Earth's crust. Tectonic history can be a guide to where to expect future movements, and their direction, rate, and magnitude. The emphasis of this report is on vertical tectonics over the last 10 million years. Horizontal movements, though equally important, have not been documented here.

Vertical movements are detected and measured by amounts of vertical displacement on faults, uplift of positive areas and downwarp or subsidence of negative areas, based on data derived from geology, geomorphology, geophysics, paleobotany, radiocarbon dating, geodetic leveling, and sea-level measurements (tide-gage data). Geodetic and tide-gage records, unlike the other forms of information, seldom go back more than 100 years, and, therefore, must be treated differently as will be discussed later. Because of the diversity of data and the scale of the features to be shown, several maps (one- to five-million scale) are needed to show the important details. Vertical movements in the western half of the United States are better documented due to higher rates of activity (thus, better exposures) during the last 10 million years. The amount of vertical movement shown, based on all types of data except geodetic and tide-gage data, is a minimum figure, because erosion has generally removed part of the record. There are many areas, however, where it is not possible to document the 10 m.y. time span because of erosion, the lack of datable units, or complexity of the tectonic history. Where the geologic time span used must be extended, usually 12 to 13 m.y. is sufficient. This report is intended to be a first edition with the maps subject to revision as new data becomes available and the magnitude and rate of vertical movements become better defined.

The four maps that depict vertical movements over the last 10 m.y. (late Miocene to present) are described below.

PLATE 1. SOURCE MAP OF DATA FOR VERTICAL MOVEMENTS--Shows localities of data compiled on vertical movements pertaining to the 10 m.y. time interval. In compiling the data, late Miocene is defined as the 10-5 m.y. b.p. time span; Pliocene, 5-1.8 m.y. b.p.; Pleistocene, 1.8 to 0.01 m.y. b.p.; and Holocene, 10,000 yrs. b.p. to present time (Berggren, 1972). Physiographic boundaries have been modified from Fenneman (1931).

PLATE 2. MAP OF NEOTECTONICS, RATES AND MAGNITUDE OF VERTICAL MOVEMENTS--In addition to identifying the larger features depicting vertical movements, the map shows magnitude and rate of movement. Measurements of vertical movements are based mostly on geologic data for the last 10 m.y. but include

data derived from paleobotany, radiocarbon dating, geophysics, and geomorphology. Neotectonic movements, both positive and negative, whether initial or recurrent, are shown. Faults are generally shown at their greatest known extent, in as much as some dormant segments may be potentially dangerous sometime in the future. They may be even more dangerous than parts of the fault that have been active, since in some cases stresses are known to build up along dormant parts of faults.

Plate 2 also shows a separate but related map (fig. 1): On this figure, contours depicting magnitude of uplift or subsidence have been drawn combining all neotectonic data for a location based on written descriptions of an area as well as actual figures on vertical movements. In places only a single figure represents magnitude of uplift or subsidence for an entire mountain range or basin. One drawback of compilation at this scale is the resultant generalization since it masks most problems which would be discovered by a closer scrutiny of the area. This is not as much of a problem in the central and eastern part of the country where data is so sparce that every fragment of data is used. The magnitude of movement recorded in the 10 million years for any single structure on the map is, in many cases, less than the total uplift or subsidence recognized for the region. In the western Part of the country there are at least two areas where this occurs. One area is the uplift of the western craton (an area including the Great Plains westward into Utah, north to the Canadian border and south to Mexico); this uplift is very gentle in the central part of the country but steadily rises to about 2,100 meters on the western edge of the Colorado Plateau (Trimble, 1978). The second area is in Oregon and southern Washington where uplift is about 900 meters (Mackin and Cary, 1965). These broad uplifts must be considered in any compilation of the magnitude of vertical movement on smaller structures within the region.

PLATE 3. MAP OF POST-GLACIAL (11,000± YEARS) AND HISTORIC (100± YEARS) TECTONICS SHOWING RATES AND MAGNITUDE OF VERTICAL MOVEMENTS--Based primarily on geodetic leveling data and, to a lesser extent, on data derived from tide-gage, geomorphology, geology, and radiocarbon dating. Other forms of data on the map indicating uplift or subsidence include marine terraces, relict shorelines, and subsidence due to dissolution of salt and fluid withdrawal. Marine terraces and relict shorelines indicate fluctuations of sea level due to isostatic changes that may be due to 1) unloading of the land either as glacial rebound as the ice melted or unloading due to drainage or evaporation of a large body of water, 2) loading such as by an intrusion of a body of salt or magma, or 3) deformation due to movements accompanying earthquakes, or 4) the loading and unloading of an area due to mass transport of sediments. Isostatic changes due to draining and evaporation of Lake Bonneville in Utah have been recognized by shoreline topography and also by geodetic leveling surveys (Crittenden, 1963; Anderson and Bucknam, 1979; Brown and others, written commun.). The problem is determining to what extent marine terraces and

relict shorelines are the result of crustal movements either on land or areas of the ocean floor and are not due to eustatic changes caused by the ice ages. The National Geodetic Survey has a complete network of level lines for the United States, much of which has been releveled, but the task of interpreting the data and relating it to neotectonic activity is often difficult and the results, inconsistent. Leveling gives only relative changes in height between two points and is based on an arbitrary datum or sea level. However, it is believed precise leveling surveys can be an important source of information on recent crustal movements' especially where movements are large enough and rapid enough over a short period of time. Leveling reliability and crustal movements have been studied and discussed at length by Brown and Reilinger (written commun., Brown and Oliver, 1976), and Bulanzhe and Magnitskiy (1974). A few of the factors that may cause inconsistencies in leveling data include systematic leveling errors, benchmark instability, and steep terrain along traverse. A tide gage measures the height of a body of water relative to the land adjacent to the tide-gage station. Errors in tide-gage data, read over a short period of time, may be as large as the total reading for a particular gage, and unless observed over a long period of time results are highly interpretative. Tide-gage readings are shown on plate 3 in both the New England and Great Lakes areas, off the Gulf Coast in the vicinity of Alchafalaya Bay, Louisiana, and in the Seattle, Washington, area. Tide gages are providing practical data on glacial rebound or post-glacial uplift in the Great Lakes region where uplift is particularly noticeable in the 100-year record. Tide-gage information, even with all its inherent problems, is also a prime datum used in leveling surveys. Only published data relating leveling and tide-gage data to geology are included in this report. No attempt was made to interpret any of the new raw data, and leveling and tide-gage data have not been combined in order to resolve magnitude or rates of movement for any one location since the data from each often tend to disagree.

PLATE 4. PRELIMINARY CONTOUR MAP SHOWING RATES OF VERTICAL MOVEMENTS--A highly interpretative map strongly indicating our lack of knowledge on rates of movement, especially in the central and eastern parts of the country. Rates for the eastern part of the country are primarily based on geodetic leveling surveys and those for the western states, on geologic data. Vertical movements indicated on plates 2 and 3, and used to compile this plate may be highly episodic, and to represent them with one rate of movement was difficult because the various investigators used many different rates of movement to explain vertical tectonics. While most vertical movements in the east have been reported as annual average rates, the rate most reasonable for the western part of the country is in terms of 10,000 years. This rate was a common denominator of all rates shown on the map and could be reasonably adjusted to contouring purposes and be geologically acceptable. For a few western areas, geodetic leveling

surveys have been interpreted by geologists and the results appear superimposed (see map explanation) and are credited accordingly. This is for comparison purposes only. Leveling data is at least an order of magnitude greater than the geologic record indicates but this is typical for leveling data in general. In the central and eastern parts of the country, because the record of uplift is dominated by geodetic data, it seemed wise not to try and contour the area at this time because of the inherent problems related to the data. Some data appears to relate to geologic structures exceedingly well but much of the data is highly interpretative, and the serious ambiguities in the geodetic data preclude its usefulness in a compilation of vertical movements.

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