CHAPTER IX

SEA LEVEL REPORT

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INTRODUCTION

Sea level changes are an important factor in the study of a site under consideration as a radioactive waste repository. If sea level rises relative to the repository there are potential problems in erosion, sedimentation, submergence, and saturation. If sea level falls relative to the repository there are potential problems in erosion, leaching, lowering of the water table, and lowering of base level.

Furthermore, sea level changes relate directly to plate tectonic, glacial, and climatic events, which, in turn, are important considerations in siting of a waste repository.

For all of these reasons, the investigation of past and possible future sea level changes becomes a vital component of any systematic approach to the radioactive waste isolation problem.

CENOZOIC SEA LEVEL

The following discussion deals with sea level changes during the Cenozoic Era. The discussion is divided into several sections, dealing with the following intervals of time: the last 20 million years of the Tertiary Period; the 2 million years of the Quaternary Period (the Pleistocene Epoch); and the last 17,000, 100, and 10 years.

Tertiary Sea Level

During Miocene-Pliocene times sea level was descending, either at a steady rate or oscillating downward (Tanner, 1968), through a period of

20 million years. Such a prolonged and uniform change could be explained either by an expanding earth hypothesis or by global tectonics theory. The general concensus appears to favor the latter. According to proponents of the global tectonic approach (Wyllie, 1976; Valentine and Moores, 1972), active plate break-up is followed by a time of transgression caused by general mid-ocean ridge uplift and spreading, as well as by thermal expansion of ridge areas. After the initial transgression, there is an interval of regression as the ridge area both contracts and subsides. Thus, the mid-Mesozoic break-up of Pangaea was followed by high sea levels during the Cretaceous Period and by continually lowering sea levels during the period of quiescence that has ensued since then. The changing of sea level by basin enlargement or reduction is referred to as tectono-eustatic.

Pleistocene Sea Level

Pleistocene Epoch sea levels fell and rose with the advance or retreat of the ice caps (Bird, 1969). Water was subtracted from or added to the oceans as ice was alternately accumulating on or melting off of the land. The changing of sea level caused by growth or ablation of glaciers is referred to as glacio-eustatic.

Of the many mechanisms which have been proposed to initiate glacial advance and retreat, one appears to have gained a slight preponderance of acceptance over the others. This is the Milankovitch Theory, which is based on the additive or subtractive influence of three climate-producing variations of the earth's position and path in space (Table IX.1).

TABLE IX.1. Variable Components of the Milankovitch Theory

Axial Precession	21,000 years cycle
Axial Tilt	40,000 years cycle
Orbit Ellipticity	92,000 years cycle

The advent of glacials and interglacials is correlated with the result of these cycles being in or out of phase with one another.

The interglacial high sea levels and glacial low sea levels appear to have been imposed upon an overall continual fall in sea level. Thus, there was a shorter-term, glacio-eustatic oscillation of sea level superimposed upon the later part of a longer-term, tectono-eustatic lowering of sea level.

Flandrian Transgression

The rise of sea level that followed the ebb of the last glacial age, the Wisconsin, is obvious. Yet experts do not agree upon the pattern of that rise. The many variations that are proposed fall into three categories: stillstand, higher-than-present, and asymptotic. According to the stillstand proponents, who are considerably in the minority, sea level reached its present level 3,000 to 5,000 years ago and has remained essentially stable since then. The higher-than-present curve, as recently refined by Fairbridge (1976), follows a fluctuating rise which exceeded present sea level some 4,000 years b.p. and has been oscillating above and below, in diminishing increments, since that time. Asymptotic refers to a rapid initial rise, gradually tapering off to the present level. The latter two curves are, jointly, the most widely accepted. The asymptotic curve finds favor in North America, but the Fairbridge curve predominates around the rest of the world.

Mid-1800 To Mid-1900, and Present

Tide data, mainly from the Netherlands, indicate that from the mid-1800's to the mid-1900's there has been a world-wide rise in sea level of about 1.2 mm yr. Somewhat shorter-term tide records from the east coast of the United States indicate that there was a slight dip in sea level in the mid-1960's (Hicks, 1973). This temporary reversal of the longer trend, however, was followed by a continuation of the rise into the 1970's.

SEA LEVEL FLUCTUATIONS: RATES AND PARAMETERS

Rates and parameters of sea level fluctuations were discussed at a sea level prediction symposium that was convened on October 31, 1977, at Western Washington University. Coastal specialist participants included:
Dr. E. C. F. Bird, University of Melbourne; Dr. F. Danes, University of Puget Sound; Dr. R. W. Fairbridge, Columbia University; Dr. M. L. Schwartz, Western

Washington University; and Dr. H. J. Walker, Lousiana State University. Some of the information on sea level changes that was provided by the symposium participants is included in the following discussion.

Some of the factors affecting sea level changes are: the galactic cycle, paleogeography, the variables in the Milankovitch Theory, albedo, solar cycles, sun tides, steric effects, glacio- and tectono-eustacy, and tectonic movements. For the one million year time period being considered for the Waste Isolation Safety Assessment Program, glacio-eustacy and tectono-eustacy are of primary importance. Table IX.2 contains information about parameters of sea level change.

TABLE IX.2. Expected Parameters of Sea Level Change

		Heights (m)			
Type	Time (yrs)	Pos.	Neg.	Amplitude or Range	Locale
Tectono-eustatic	10^6	250	250	500	global
Glacio-eustatic	10^5	100	100	200	global
Glacial surges	10^{2-3}	20			global
Tsunami	Less than 1	200	20		local
Storm surge (seiche)	Less than 1	10	1-2		local
Concurrent glacio- and tectono-eustatic		350	350	700	global

At present, mean sea level rise is recorded at 3-4 mm/yr. Of that 3-4 mm, 1-2 mm/yr is attributed to eustacy and 2 mm/yr is attributed to subsidence. However, maximum sea level rise can be as much as 4 cm/yr. During the Quaternary Period, maximum changes on the order of 2 cm/yr have been associated with both eustatic changes and tectonic movements. During this period of time these extreme fluctuations of both eustatic and tectonic movements have occurred in various directions. Hence, eustatic rise combined with tectonic subsidence could produce a maximum increase in sea level of 4 cm/yr. Sea level lowering could also reach 4 cm/yr, provided that a eustatic fall were accompanied by a tectonic rise.

FUTURE SEA LEVEL CHANGES

Of all of the factors affecting a glacio-eustatic change in sea level over the next million years, the variables dealt with in the Milankovitch Theory are the most important. Therefore, this theory has been used as a basis for projecting climatic-induced changes in the level of the sea. According to the Milankovitch Theory, another glacial sea level low should be expected. Vernekar (1972) has calculated variations in incoming solar radiation for 119,000 years into the future. His data show secondary lows at 15,000 and 118,000 years and primary lows at 53,000 and 98,000 years. Berger (1976a, 1976b) also projects the variable considered by Milankovitch, in this case to 1 million years into the future. The Berger graphics are somewhat more difficult to interpret, in terms of glacial advance and retreat, than those of Vernekar. Yet, for the next 1 million years into the future, there is reasonable justification for expecting glacio-eustatic sea level oscillations akin to those of the last 2 million years of the past.

Predictions of future tectono-eustatic sea level changes are somewhat tenuous and difficult to make. Data from the later part of the Tertiary Period show a decline of 80 m in 20 million years. Sea level fell at a more rapid rate during the Pleistocene Epoch; the overall lowering during the Pleistocene, which lasted for less than 2 million years, was on the order of 100 m. To predict whether this trend will continue, it would be necessary to know more about present and future tectonism. Predictions about sea level changes necessarily involve predictions about tectonic activity. A future, perhaps imminent, phase of ridge activity could cause a rise of sea level. The Red Sea and Gulf of California are now centers of spreading, and eastern Africa may or may not be. On the other hand, the major ocean floors will move laterally about 20 to 50 km in the next million years, and that would not appear to put the continents in a transgression-causing position. At this point, perhaps, we must turn to the geophysicists for some answers.

An important factor in predicting sea level changes at a particular continental coastal site is the stability of that locale. Elevation changes from local tectonic uplift or subsidence could far outweigh world-wide tectono- or glacio-eustatic sea level changes. At a particular segment of the shore, sea level changes may be as much a matter of vertical displacement of the land as it is a rise or fall of the water surface level.

COASTAL EROSION AND SEDIMENTATION

Processes

An understanding of the processes of coastal erosion and sedimentation is important in any discussion about sea level changes. If sea level rises 50 m against a coast, the land will not be eroded 50 m down as a result. At any new stand of sea level, normal surf- or surge-base erosion will extend to 10 m below mean lower low water (MLLW). In regions of exceptionally high wave energy, such as the Capetown area of South Africa, erosion may extend to 20 m below MLLW. Therefore, a transgression does not in itself imply deep erosion. In the case of salt domes, they would suffer less from deep submergence than from engulfment (i.e., partial submergence). The latter, leaving them standing as offshore islands, would expose them to wave erosion along their seaward side. This situation could, in fact, result in erosion of the domes down to the level of the surrounding general topography.

As for sedimentation, very little pelagic sediment would come out of the shallow coastal water itself. Most sediment deposition would result from: a) sand being transported in with the transgressing sea, b) erosion of coastal topographic highs, c) shore drift along the coast, and d) runoff from the land. Of these, the latter, as deltas, would probably account for the largest magnitude of sedimentation at a given site. This would, of course, depend on the local relief and climate, but it is valid enough as a first order approximation.

Rates

Sediment accumulation rates and erosion rates were among the topics of discussion at the sea level prediction symposium convened at Western Washington University on October 31, 1977. Erosion rates agreed upon by the symposium participants are listed in Table IX.3.

TABLE IX.3. Typical and Maximum Erosion Rates Associated with Coastal Provinces

	Typical	Maximum
Soft sediments (sandy to deltaic)	1 m/yr.	50 m/yr.
Permafrost (high latitudes)	1 m/yr.	50 m/yr.
New volcanic material[a]	1 m/day	
Mudlumps[a]	1 m/day	
Hard rock[b]	less than 1 cm/100yr.	

(a) Very loose material introduced into a high energy environment.
(b) Non-weathering, only wave erosion.

Sediment accumulation rates can be as high as 20 m/100yr during uplift of coastal areas. The Mississippi Delta surface rises, by accretion, up to 1 m/100yr during a rise in sea level.

CONCLUSIONS

A study of Cenozoic Era sea levels shows a continual lowering of sea level through the Tertiary Perod. Short term fluctuations were superposed upon this general trend of sea level lowering. This overall drop in sea level accompanied the Pleistocene Epoch glacio-eustatic fluctuations, causing each succeeding glacial low and interglacial high to fall at a lower level.

The considerable change, during relatively short spaces of time, of Pleistocene Epoch sea level is most directly attributable to the glacio-eustatic factor. The effect is worldwide with a time span of 10^5 years and an amplitude or range of approximately 200 m.

The continuing and overall lowering of sea level that has occurred worldwide since the end of the Cretaceous Period is attributed to a subsidence in the world ocean floor and mid-ocean ridges accompanying a decrease in plate-tectonic activity during that time.

The maximum rate for sea level change is 4 cm/yr. At present, mean sea level is rising at about 3-4 mm/yr.

Glacio-eustacy and tectono-eustacy are the parameters that are most important for making predictions about sea level changes in the next 1 my. Glacio-eustatic sea level changes may be projected on the basis of the Milankovitch Theory. Predictions about tectono-eustatic sea level changes, however, involve predictions about future tectonic activity and are therefore somewhat difficult to make.

Coastal erosion and sedimentation are affected by changes in sea level. Erosion rates for soft sediments may be as mush as 50 m/yr. The maximum sedimentation accumulation rate is 20 m/100yr.

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