THE CONTINENTAL MARGIN OF NORTHERN ISRAEL

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The continental margin of northern Israel is narrow and steep; the continental shelf is 12-14 km wide, and slightly more off Haifa Bay. The continental slope is about 5 km wide, with an average gradient of more than 8°, and is dissected by many submarine canyons. The continental margin of Lebanon has similar features, whereas off central and southern Israel, the continental shelf and slope are wider, less steep, and submarine canyons are absent. At the base of the slope, at a 900 to 1,100 m water depth, the gradient decreases abruptly in transition to a hilly area which slopes gently toward the deeper part of the Levantine Basin.

An important characteristic of the investigated area is the presence of Neogene-Quaternary faults that extend from the land into the sea. Most conspicuous are the NW trending Carmel fault and the Rosh Haniqra fault which trends roughly E-W. The extension of the faulted western Galilee graben is located between them.

Pre-Eocene sediments exposed on land extend under the continental margin, forming a flexure about 20 km wide, descending to about 3 km below sea level under the base of the continental slope. Under the deep sea, the pre-Eocene strata are probably flat. Similar to the area further south, the flexure in the investigated area was probably formed or accentuated during the Neogene (Garfunkel *et al*, 1979). The Saqiye Group accumulated along this flexure. Its pre-Pliocene part is thin or absent at depths of less than 1-1.5 km, but in the western Galilee graben, beds of this part of the Saqiye Group extend to the coastal plain where they are a few tens of meters thick.

During the Messinian event, the area beneath the continental shelf and slope was differentiated from the area under the deeper sea floor. In the former domain, a steep and dissected relief existed, but there were no large valleys which extended landward. In this marginal domain, the evaporite-bearing Mavqi'im Formation is probably absent at depths of less than 1-1.5 km, so that reflector M at shallow depths often signifies an unconformity. In the basinal domain, the evaporite-bearing sequence thickens seaward, attaining a thickness of about 1 km at a distance of 80 km offshore. Reflector N, designating the base of the Messinian evaporite-bearing sequence, appears at a depth of 2.6-2.8 sec and is quite flat. Reflectors and bedded portions within this sequence show that in addition to evaporites, other components are present, most likely clays.

In the Pliocene-Pleistocene, the Yafo Formation accumulated, building the present continental slope and shelf. In the investigated area, its thickness reaches 1-1.5 km under the base of the continental slope, but decreases seaward, mainly because of the thinning of the upper part of the formation.

In much of the investigated area, the Yafo Formation and the underlying evaporite-bearing sequence are deformed by rootless structures which do not extend below the base of the latter. On the continental slopes north and south of the western Galilee graben, slump structures are developed in the Yafo Formation: it is crossed by curved faults which flatten downward and become rooted in the Mavqi'im Formation. These faults extend to the sea floor and are still active. The southern slump structures are the extension of the Dor disturbance (Garfunkel *et al*, 1979). Slumping occurred where the Pliocene-Quaternary sedimentary column accumulated over a slope on which the Mavqi'im Formation is present, and its thickness exceeds a critical load value. Movement became possible because of the flowage under loading of the Mavqi'im Formation. Over the submarine extension of the Carmel high, the Yafo Formation is especially thin, and slumps are absent. The Mavqi'im Formation also flowed under the deep sea. It is especially disturbed close to the base of the continental slope, where the evaporite-bearing sequence broke away from the marginal domain and flowed seaward. The overlying Yafo Formation was deformed by the motions in its substratum. Similar features also occur off central Israel and northern Sinai (Garfunkel *et al*, 1979; Almagor and Garfunkel, 1979; Almagor, 1980). These structures and the slumps generally appear to be rootless, and do not extend below reflector N. In most parts of the investigated area, the various structures (mainly folds) in the Yafo Formation developed more or less continuously after deposition of the lower half of the formation. Under the deep sea off the Dor disturbance and the Carmel promontory, disturbances in the Yafo Formation were formed mainly in the Late(?) Pliocene, but later became largely inactive.

The fault structures apparent on land extend seaward under the continental margin. The Carmel and Rosh Haniqra faults practically meet some 25 km offshore, so that the western Galilee graben disappears. Beyond the continental slope only the Carmel fault extends to the NW, into a particularly disturbed area. There, elongated diapiric uplifts originating in the Mavqi'im Formation, whose trend shifts from about N-S to NW, are developed. Such structures are not found in nearby areas. Some of these are active and deform the sea floor, so that a special morphological domain is formed. Most conspicuous is a row of NW

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trending diapiric ridges, on which collapse structures are developed. These ridges occur on a line connecting to the Qishon graben, with an active fault north of the area. Though it is difficult to identify reflector N under these structures, it is likely that they mark the submarine extension of the Carmel fault. Its activity induced especially strong flowage in the evaporitic series above the fault and in nearby areas.

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STABILITY OF CONTINENTAL SHELF SLOPES UNDER EARTHQUAKE LOADING CONDITIONS

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The purpose of this summary is to outline the approach in applying geotechnical methodology, the evaluation of the cyclic load, properties of the continental shelf sediments, and how the results of the geotechnical tests may be applied in order to determine the effects of earthquakes on the stability of the slopes involved. This research was initiated several months ago and is scheduled to be completed in two years.

Mass creep and small rotational slumping are widespread along the entire shelf edge at 80 to 150 m water depth (about 4 km wide strip, 0.5-1° inclination), and the uppermost continental slope, at water depths of 200-325 m (4-5 km wide shore-parallel strip, 1-2.5° inclination) (Neev *et al*, 1976; Almagor, 1976). These strips are characterized by undulating topography, made up of a system of low amplitude, elongated hillocks that are separated by elongated depressions, and by numerous shallow horizontal clefts. This topography is in outstanding contrast to the very smooth, rounded topography of the shelf and upper slope of Israel. The height of these hillocks range between 5 and 15 m, and their width, between 100 and 300 m (rarely 400 m). The clefts are 150-200 m wide and reach 20-25 m depth. The horizontal dimensions of both the hillocks and clefts are less than 1 km long.

Analysis of the static force equilibrium that exists within the shelfedge and upper slope sediments indicates that the sediments are sufficiently strong to sustain the slopes at the shelf edges and upper slope, even if subjected to the effects of earthquake accelerations greater than those detrimental to the steepest slopes (α= 5-7°) of the middle continental slope. However, this analysis indicated that only a minor addition of an earthquake-induced horizontal acceleration of gravity is needed to initiate undrained mass movement of the shelf edge and upper slope sediments , if a static analysis is applied. This means that even a small amount of weakening of the sediments by the low magnitude earthquakes that generally occur in the region, is sufficient to cause mass creep (the term creep, is herein defined as continuous yielding of the soil particles under applied undrained stress).

It is suggested that these creep phenomena reflect long-term deterioration in shear strength of the sediments due to repeated loading effects. Frequent loading reversals can occur rapidly during earthquakes, or more slowly when caused by wave loading. The effects of repeated loading depend mainly on the cyclic stress level, their number, frequency and duration, and on the sediment types. Application of cyclic loading on normally consolidated and slightly over-consolidated clays, where drainage is poor (and on metastable and confined loose sands) will lead to a build-up of pore-water pressure, increased strain and subsequent decrease of shear strength of the sediment with time (Fig. 1). In addition to this long-term deterioration in shear strength which may develop over a period of hundreds and thousands of years, each individual earthquake may cause a further, momentary decrease in shear strength due to a bulid-up of fluid pressure in the sediment pores during action of the quake. If the excess pore-water pressure reduces the effective normal stress to a suf-

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