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DOWN-BUCKLING OF A CORNER OF A DESCENDING PLATE

BARBARA E. LOWREY

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Barbara E. Lowrey
Geodynamics Branch

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One of the mysteries of an island arc is the arcuate structure. Also Karig[1] has concluded that crustal extension in small ocean basins behind (that is, inside) island arcs requires modification of plate tectonic theory concerning simple plate boundaries. According to the assumptions of plate tectonic theory[2,3,4], the earth's crust is represented as a set of rigid crustal blocks where crust is being consumed, or compressed, or created, only at the boundaries of the blocks. This paper will suggest that the trench boundary moves with respect to the colliding plates due to a down-buckling of a corner of the descending plate. This mechanism requires plate consumption of the descending plate at a rate faster than the relative plate motion; and infilling of the basin behind the arc to compensate for the increased destruction. The evidence relating to this model--earthquake, heat flow, paleomagnetic, gravity anomaly and geologic data--is referred particularly to the region of Japan and the Sea of Japan.

The model assumes a descending lithosphere behind a trench, but considers the particular case where a <u>corner</u> of the descending plate is advancing. If the structural properties are somewhat like a heavy sheet of paper and if the stresses on the upper part of the corner exceed those on the lower part, then the upper part of the corner will buckle (Fig. 1). The sense of the buckle will be downwards and backwards, that is, opposite to the direction of motion of the plate. The result will be a concave face in the upper part of the plate where the stress has caused a cave-in, the remnants of the previous corner at lower depth and two new corners generated at the edge of the buckle.

The primary evidence, and indeed the inspiration, for the model is the isobaths of the mean epicenters of the earthquakes[5,6]. The earthquake lines of equal depth look like the top view of the model (Fig. 2). Proceeding eastward from Japan, the slope of the earthquake isobath radically changes, in accord with the changed shape of the plate in the proposed model. The point of flexure of the buckling plate is ~200 km. The result on the surface is that the Japanese trench was formed by the collapse of the corner where the Izu-Bonin and Kurile trenches formerly met.

There must be two surface effects when a plate buckles. First, the trench will appear to move backwards into the Pacific plate, i.e., "migrate seawards" as Karig[7] suggests (Fig. 3). Any point on the descending plate will move laterally at the same rate as the plate but downwards at a faster rate than if the trench were not moving. Therefore the rate of plate consumption will be higher during down-buckling than predicted by plate tectonics from the speed of the plate.

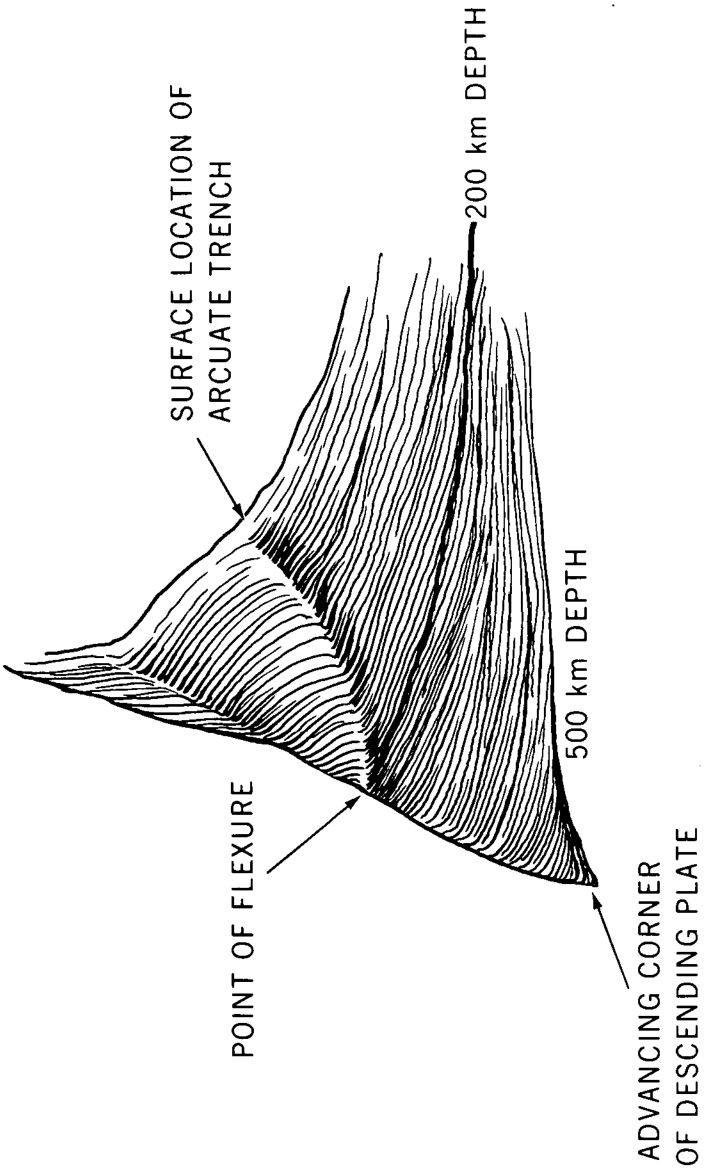

FIG. 1 STRUCTURE OF A BUCKLING CORNER

Figure 1. Top View of the Proposed Buckling of a Corner of a Descending Lithospheric Plate. Contour lines show the edge of the plate at the indicated depth.

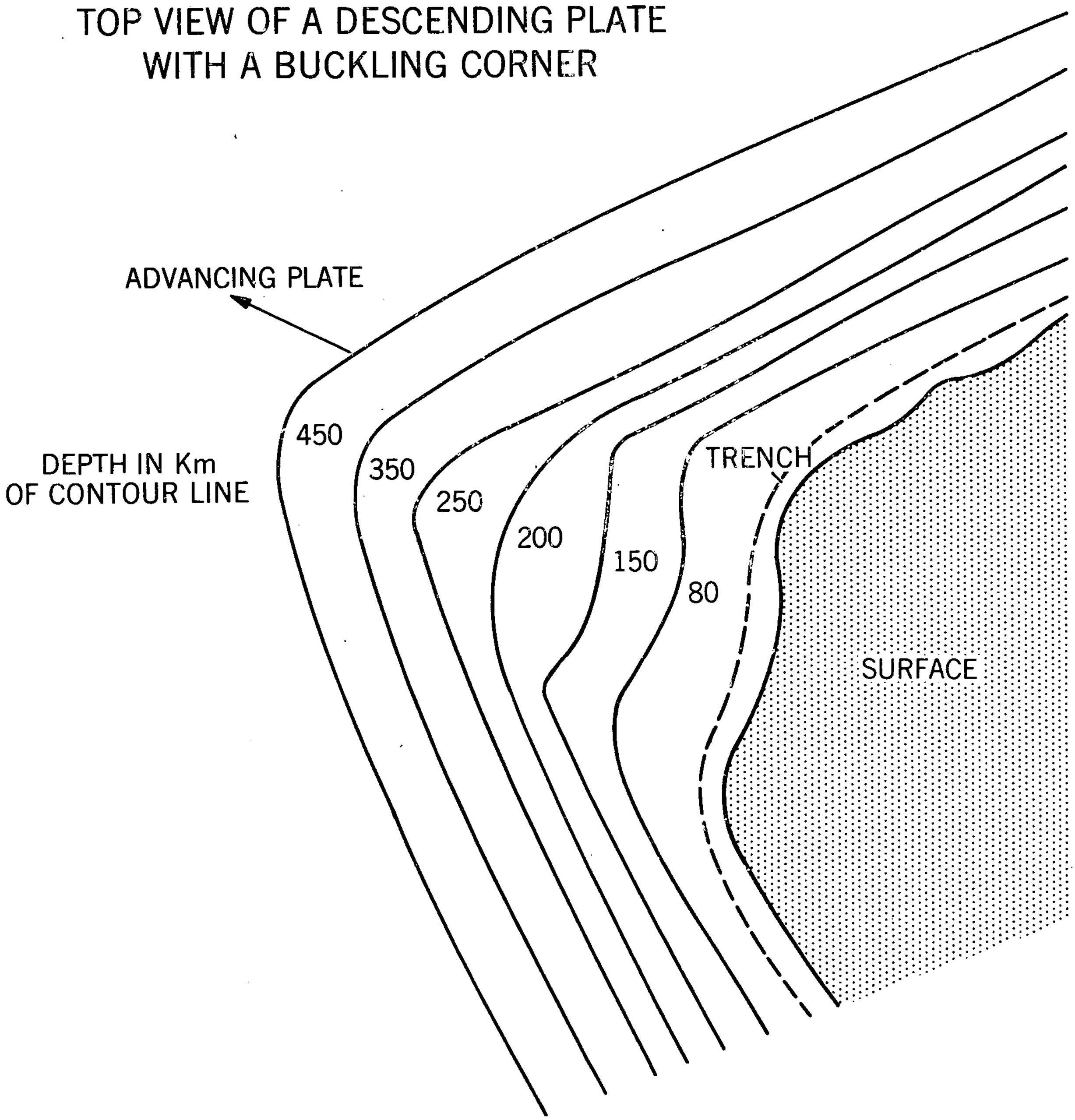

Figure 2. Seismicity below Japan and the Sea of Japan. The curves marked with depths are isobaths of the mean epicentral positions of deep-focus earthquakes. Also included are the heavy line representing the volcanic front and hatched areas indicating positive gravity anomalies. (After Sugimura, 1968.)

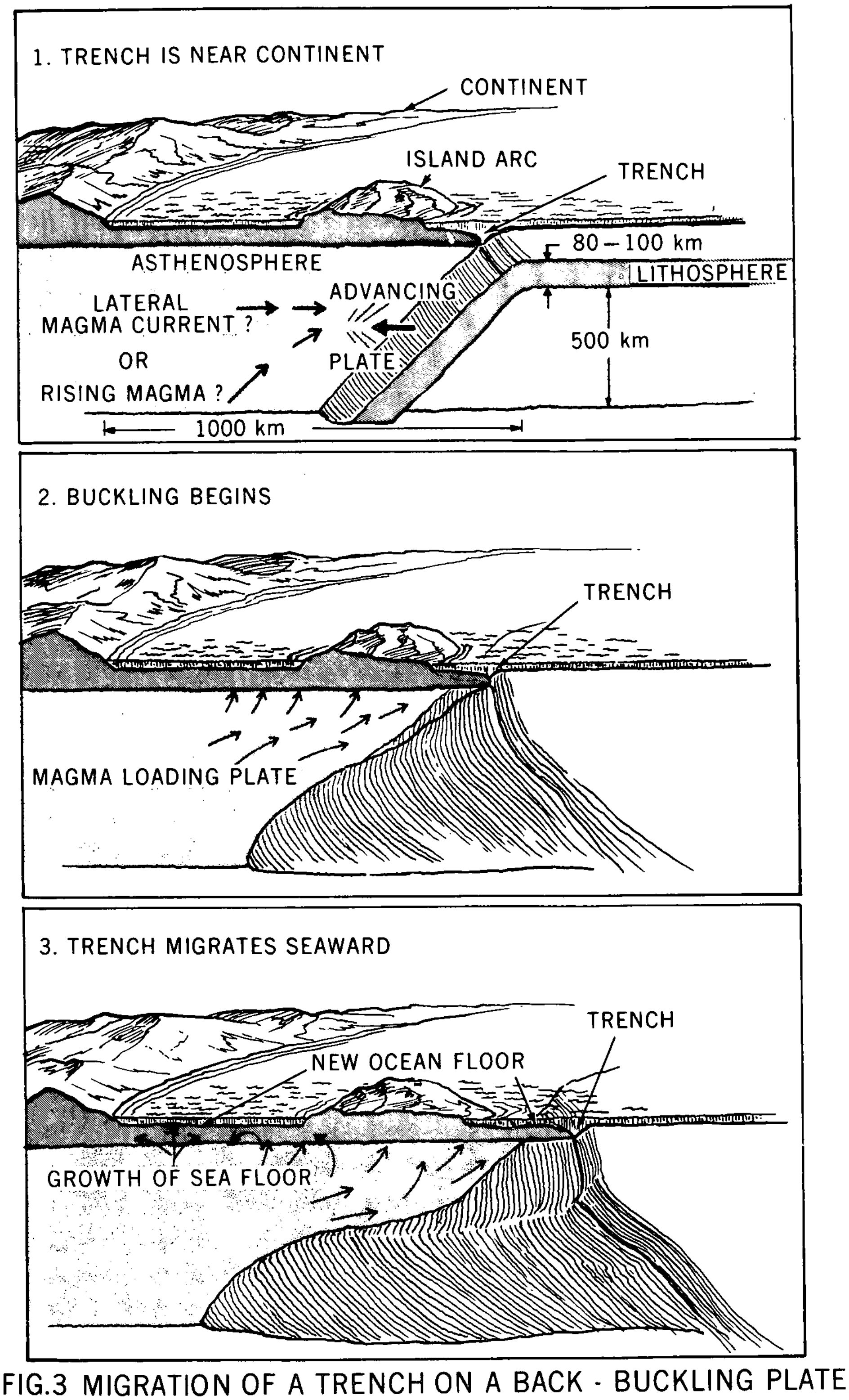

Figure 3. Trench Migration

Second, the basin inside the arc must increase in size to fill the gap left by the moving trench, requiring high heat flow as the crust increases.

Vening Meinesz[8] suggested that convective currents descend beneath trench axes and carry the lithospheric plate down into the mantle. This hypothesis requires low heat flow, in the trench region, corresponding to a cold descending limb of a convection cell. But the observed heat flow in the Sea of Japan is anomalously high[9]. The average heat flow measured in the Sea of Japan is above $2\mu cal/cm^2/sec$, while the world average is about $1.5\mu cal/cm^2/sec$. McKenzie and Sclater, in reviewing the possible sources of high heat flow, considered convective heat transport as a possibility. In order to produce high heat flow by this mechanism, hot material must be transported in a direction opposite to the temperature gradient. Then, if the excess heat is produced by the cooling of intrusions, they found that the observed crustal thickness in the Sea of Japan must have been produced in ~10 m.y. They concluded that it is unlikely that the trench and the island of Japan are sufficiently recent; however, this model proposed here requires only that the sea floor be recent. The pre-existing trench and crustal block forming Japan moved outwards from the continent. The rate of movement is consistent with Karig's[1] estimate of an average rate of an average rate of trench movement of 4 cm/yr for the Marianas and Kermadec-Tonga trenches. Further, Karig[12] has suggested that extension in the Sea of Japan began in the early Miocene and ceased before the end of the Tertiary. Also, this time scale is compatible with Morgan's[2] deduction from fracture zones that the Pacific plate changed direction toward the Japanese and Aleutian trenches about 10 m.y. ago. This convective material may be coming either up from the mantle or laterally from the continental area. The latter seems to fit this model better; there may be an asthenospheric current coming from below the continental platform at a depth of 100-150 km. This current might be return flow which has spread radially out from a convective plume from the lower mantle, according to the suggest of Morgan[13].

The positive gravity anomaly near an island arc[14] may be due to some of the convective material loading on the plate. In this model the loading is not static but may increase due to the incoming material until relieved by back-buckling of the plate. Karig's evidence for "pulses" is crustal extension suggest episodic buckling; if so, episodic buckling may occur when the movement of material on the top of the descending plate has increased the loading beyond the limit. The rate of down-buckle depends on the competency of the asthenosphere behind the plate to support it under lateral compression and on the strength of the plate. These conditions are not analogous to those in previous studies of rebound from subsidence or uplift[15].

The recent movement of Japan is supported by the paleomagnetic evidence[16], which indicates a bend in Japan since the early Tertiary time. The pre-Tertiary rock samples indicate a systematic difference of declination in the mean directions of magnetizations of rocks from northeast and southwest Japan. This difference is about 40°, corresponding to the angle between the physical axes of the northeastern and southwestern parts of Japan.

The bend has a surface expression known as the Fossa Magna ("big ditch"). There is volcanism and high seismicity in the area of the Fossa Magna. The geologic evidence of recent evolution in the South Fossa Magna includes regional subsidence of the crust with eruption of tholeiite and basalt magmas in the early Miocene and crustal deformation with emplacement of calc-alkaline magma in the late Miocene[17].

It is interesting to consider the possible evolution of the system. The buckling of a corner of a descending lithospheric plate has created two new corners, one at the northern Fossa Magna and one at the north of Japan. At some point in time the buckling may cease and the trench move toward the continent; later the load may increase and the buckling recommence. Or the two corners may buckle instead, depending on the relative motions of the Pacific plate and the convective material.

In the meantime, the sediments accumulating in the Sea of Japan may be undergoing regional metamorphism[18], as in a classical geosyncline. If at some future time, the down-buckling of the plates should cease, the motion of the Pacific plate will carry the trench into the continent, initiating an orogenic phase of the Sea of Japan. This mechanism may thus produce the second kind of mountain building discussed by Wilson and Burke[19]; that is, the orogeny associated with island arcs.

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