Split sea and walls of water

Moses' phenomenon at the Izmit earthquake, Turkey

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(Communicated by Seiya Uyeda, M. J. A., Feb. 12, 2002)

Abstract: A statement of split sea in the Izmit Gulf, where the North Anatolian Fault is extending, was obtained from a witness fisherman when we collected retrospective statements about unusual phenomena before the Izmit earthquake in 1999. The split sea and walls of seawater on both sides of his boat, which we name the Moses' phenomenon after the Exodus, were ascribed to larger outflow of seawater out of the fault zone before and at the time of faulting than the inflow from outside sea. The water removal by preseismic dilatancy at large areas and by fissures and breccia at the fault zone in addition to the horizontal outflow due to subsidence of the land and sea floors overwhelmed the horizontal inflow from both sides of the zone; the inflow would be blocked in a narrow and shallow channel at the Cape Gölcük. The split water has hydrodynamically been calculated assuming "an open channel hydraulic water flow" and reproduced experimentally in an aquarium model. The tidal withdrawal and appearance of the sea floor as reported for the great Kanto earthquake in 1923 may also be explained for a bay cut by a fault line and limited inflow of seawater blocked by submarine sand dunes.

Key words: Moses; split sea; earthquake; precursor; tidal withdrawal; Izmit.

Introduction. There are many legends as well as statements by citizens concerning macroscopic anomalous phenomena before or at the time of a big earthquake. One of the authors (Ü.U.) asked Turkish citizens to report anything unusual before the Izmit earthquake on August 17, 1999. More than 770 statements were collected through letters, fax and e-mails, but there lacked reports from the epicenter. Hence, we visited the refuges at Adapazari, Izmit and Istanbul in September to collect statements directly from the witnesses. Most statements such as earthquake lightning, unusual animal behavior and malfunctioning of electrical appliances were exactly the same as those told in legends,[1),2)] collected after the Kobe earthquake,[3)] and explained as electromagnetic phenomena.[4),5)] Among them, a report of split sea by a fisherman in Izmit-Gölcük was like the story of Moses in the Exodus, the Old Testament.

While Tributsch referred observations of "sea splitting" at the Caribbean earthquake in 1783 and Chilean earthquake in 1835,[6)] Japanese literatures indicated tidal withdrawals before earthquakes.[1),7)] In physics, water splitting under an intense magnetic field, almost million time more intense than the Earth's magnetic field, was named "Moses' effect" after Moses' crossing of the Red Sea in the Exodus.[8)] The sea splitting cannot be ascribed to this Moses' effect since the magnetic field changes before earthquakes were a few thousandth of the Earth's magnetic field at most. Hence, the sea splitting is named "Moses' phenomenon" in this work. Although the credibility of stories by lay citizens is always controversial and "afterthoughts" must inevitably be involved, old legends and reports by citizens on earthquake precursors should not be dismissed out of hand.

In this paper, we ascribe the split sea to drastic geodynamical flow of seawater on the fault zone into microfractures, fissures as well as subsidence of the large areas of sea floor and land before or at the time of faulting. If horizontal inflow of seawater to the

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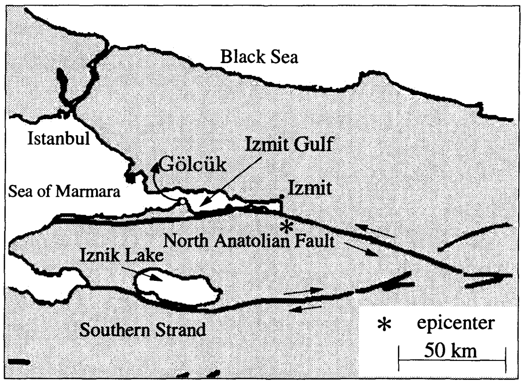

Fig. 1. A map of the North Anatolian Fault and some cities around the epicenter of the Izmit earthquake at 03:01:37(LT), Aug. 17, 1999. A fisherman on a boat near the Cape Gölcük witnessed the split sea.

fault zone is blocked by capes and submarine dunes, split sea and tidal withdrawal may occur. The wall shape of seawater has theoretically been calculated assuming "an open channel hydraulic water flow" and demonstrated in an educational experiment on a model channel with open slits.

Statement of split sea at the Izmit Gulf. (i) *North Anatolian Fault.* Fig. 1 shows a map of the North Anatolian Fault, one of the longest strike-slip faults, cities and Cape Gölcük where we collected unusual story of split sea from a fisherman. The Izmit earthquake (M_w7.4) at 03:01(LT), August 17, 1999 destroyed Izmit and Adapazari along the fault. Extensive flooding of coast lines of Izmit Gulf due to tectonic subsidence was reported in press accounts.

(ii) *Witness of sea splitting.* The fisherman told us that he was on a boat in the Izmit Gulf.

I had seen fireball lightning for two months or so and also deep-sea fish floating near the surface a day before the Izmit earthquake. When I was capturing fish in the Izmit Gulf close to Gölcük, at 02:57(LT), I heard strange sounds from the bottom and felt some vibration (Authors' note: this is four minutes before the earthquake). *I thought something wrong with the screw, but it had no problem. Then I saw a pink-red color light from the surface of the sea to the sky. At about 3:04, the sea split into two and I saw the walls of seawater on both sides, about 15 m in height. I felt that my boat was standing on the sea floor. Big waves run to the building of the Turkish naval school and I was on the waves and brought to the land.*

The sea splitting as schematically shown in Fig. 2 (a-1) and (a-2) seemed to have started ear-

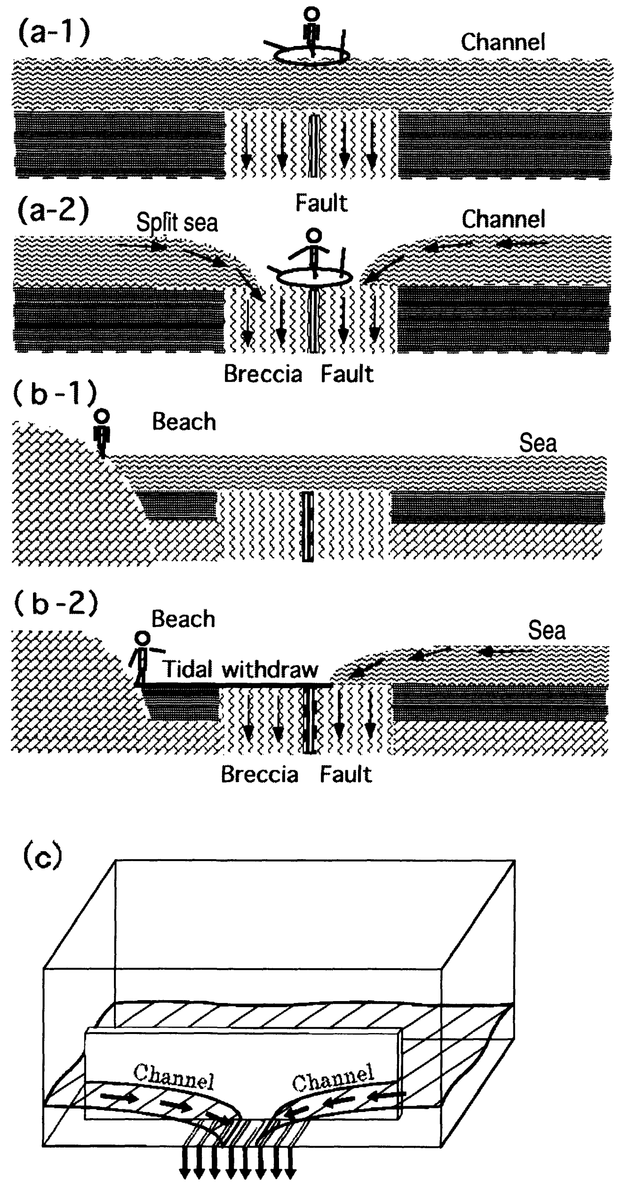

Fig. 2. (a) The split sea named "Moses' phenomenon" at Gölcük before the Izmit earthquake. Draining of channel water to fissure, breccias and subsidence of sea floor during faulting is considered to overwhelm the fluid inflow restricted by the shallow and narrow channel. (b) The same balance of seawater in a bay before (b-1) and after (b-2) the Great Kanto earthquake in 1923 lead to the tidal withdrawal. (c) A model aquarium with a channel and bottom slits for draining water to demonstrate the Moses' phenomenon.

lier than the main shock. The story of split sea is like Moses' story in the Old Testament.

Moses stretched out his hand over the sea; and the Lord pushed the sea back by a strong east wind all that night, and made a dry path through the sea *where the waters were divided. The children of Israel went into the midst of the sea on dry ground, and waters formed walls on their right hand and on their left* (Exodus 14: 21–22).

Similar statements of sea splitting and sea withdrawal as well as the report of 30–40 m high waves by a ferryboat captain were also collected by New Zealand group at the coastal area of the Izmit Gulf in a field investigation of tsunami.[9)]

(iii) *Coseismic and preseismic tidal withdrawal.* Old literatures in Japan tell stories of tidal withdrawal and reversed flow of river water before earthquakes[2)] but not the split sea. The sea front was also reported to have receded and the sea floor appeared as schematically shown in Fig. 2 (b-1) and (b-2) just after the Great Kanto (Tokyo, Japan) earthquake in 1923.[7)] If these stories were true, what were the mechanisms which caused the tidal withdrawal and split sea and where did the seawater go?

Hypothesis. (i) *Open channel with water drained by fissures, microcracks and tectonic subsidence.* The map of the Izmit Gulf and the Cape Gölcük in Fig. 1 indicates that the fault is extending to the Izmit Gulf. Newly formed fissures, breccias and dilatant area at the fault zone would soak seawater. A rapid flow vertically down toward the focus would occur as well as a horizontal flow out of the channel (bay) to the fault zone on the land. Subsidence of the large areas of sea floor and land would also cause the rapid flow out of the fault zone.

(ii) *Topography that blocks inflow of water: Narrow channel and submarine dunes.* Topographic conditions such as the presence of a cape (the Cape Gölcük), submarine dunes and narrow channel block the supply of seawater from the upstream to the fault zone. The seawater may be drained rapidly at the time of dilatancy formation a few minutes before the shear fracture and fault movement. The walls of seawater may be formed on both sides of the fault zone depending on the balance between flow-out and flow-in of seawater.

Model experiment. We only consider narrowness of channel for topographic barrier and use slits on the bottom for draining of water in a model experiment as shown in Fig. 2 (c). The channel with the width of about 1 cm was made using a plastic plate in a rectangular acrylic water tray of 200 mm × 200 mm × 30 mm. Note that the bottom slit with the open ratio of 0.5 represents not only the vertical flow down to the ground into newly formed dilatant volume with microcracks but also horizontal flow to fissures and subsided areas on the coast. No materials to simulate the permeability is placed under the slit. Neither a model cape nor submarine dune, which would make the channel locally narrow and shallow and blocks the inflow, was formed in this simplified preliminary experiment.

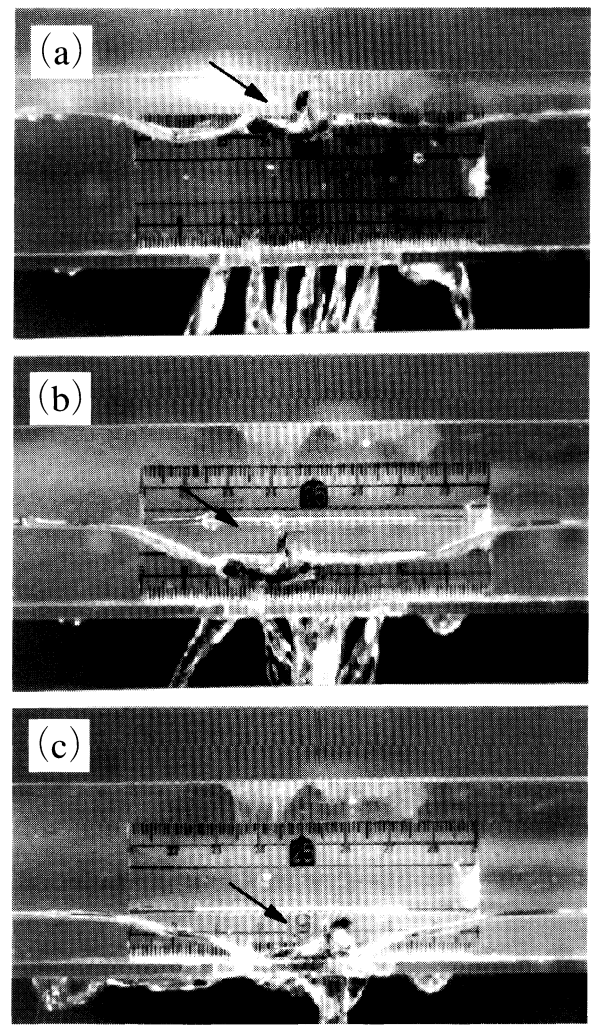

Fig. 3. A series of photographs on the spatial profile of water flow in a model experiment of an open channel using a scale to demonstrate the split sea. A fisherman on a boat made of a piece of paper float is shown by an arrow.

As the water was drained from the bottom with slits, the water level goes down and walls of water were made on both sides of the paper boat as in the photographs in Fig. 3. Thus, the walls of water can be formed by the balance of water flown-in and flown-out of the fault slit zone.

Theoretical calculation. (i) *Surface flow-profile in a channel with bottom slits.* A textbook "Open Channel Hydraulics" by Chow[10] gives analytical equation for the surface flow profile. The specific energy, E, which is the energy divided by gravity acceleration, g, consists of the potential and the kinetic energies at the height of the water, y, from the bottom with the velocity, V, at the distance x from the entrance of the bottom slit region as shown in Fig. 4.

$$E = y + \frac{V^2}{2}g = y + \frac{Q^2}{2}gb^2y^2, \qquad [1]$$

where Q is water discharges through the bottom slits, in our case through fissures and breccias at a fault zone, and b, the channel width. The specific energy is considered constant for a spatially varied flow. Hence, the condition of $\mathrm{d}E/\mathrm{d}x = 0$ gives

$$\frac{\mathrm{d}y}{\mathrm{d}x} = Qy\left(-\frac{\mathrm{d}Q}{\mathrm{d}x}\right) \Big/ (gb^2y^3 - Q^2). \qquad [2]$$

The discharges through the length $\mathrm{d}x$ of the slit zone $(x > 0)$ may be expressed by

$$-\frac{\mathrm{d}Q}{\mathrm{d}x} = \alpha Cb(2gy)^{1/2}, \qquad [3]$$

where α and C are the ratio of the opening area to the total area and the coefficient of discharges from the slits, respectively. The latter actually varies considerably across the slits and was empirically determined from 0.4 to 1 for different types of slits with different hydraulic permeability such as percolated screens and of parallel and perpendicular bars. The final analytical equation is

$$\frac{\mathrm{d}y}{\mathrm{d}x} = \frac{2\alpha Cy^{1/2}(E-y)^{1/2}}{3y - 2E}. \qquad [4]$$

The integration of the equation gives the flow profile,

$$x = \frac{1}{\alpha C}\left[E\sin^{-1}\left(1 - \frac{2y}{E}\right) - \frac{3}{2}y^{1/2}(E-y)^{1/2}\right] + C'. \qquad [5]$$

Fig. 4 shows the profiles calculated under the condition of $y = h_0 = 10$ m at $x = 0$ for an empirical $C = 0.45$ and the experimental ratios of opening α. Note that the curve of the water slope given by the theory is concave, while the water slope in the laboratory experiment in Fig. 3 is convex. This discrepancy stems from the assumption given in eq. [1] where the vertical velocity on the slits at $y = 0$, w, is given by the Bernoulli's theorem implicitly, i.e.,

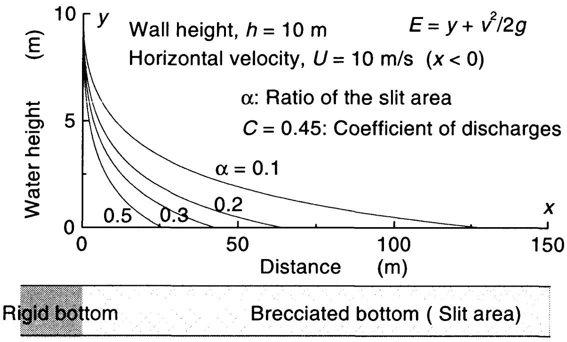

Fig. 4. The height of the sea surface, y as a function of the distance x from the start of the slit zone has been calculated using a model of a hydraulic open channel with the coefficient of water discharges and the ratio of opening, 0.1, 0.2, 0.3 and 0.5, following the theory by Chow (1959).

$$\frac{V^2}{2} + gy = \frac{w^2}{2}. \qquad [6]$$

This is valid only when the streamline of the water at the slits is connected with the water surface. A constant horizontal velocity assumed at $x = 0$ as a boundary condition is not consistent with eq. [1]. Dynamical aspects must be calculated.

(ii) *Time dependent water slope after formation of fissures and cracks.* Let us consider a still water with the depth y, initially h_0 at time $t < 0$. At $t = 0$, the rigid bottom in all parts at $x > 0$ is replaced by fissures where the water falls rapidly. The supply of seawater is limited by the narrow channel and the depth of the water is gradually lowered. Time evolution of the fluid depth is calculated by considering only a vertical motion of a water column in which the horizontal flow-out to the subsided land is included implicitly. Assume for simplicity that this water column behaves like a rigid vertical stick even after the escape of water from the fissure. Then, the vertical velocity, w, of the water column is governed by the equation of motion as

$$m\frac{\mathrm{d}w}{\mathrm{d}t} = -mg - kw, \qquad [7]$$

where m is the mass of the water column, k is the drag coefficient at the hole depending on the hydraulic permeability for fissures and breccias. This equation can be integrated to yield the solution that

$$w = -\frac{mg}{k}\left(1 - \exp\left(-\frac{k}{m}t\right)\right). \qquad [8]$$

Note that the column experiences a free fall (motion of a constant acceleration) in the initial stage, but the

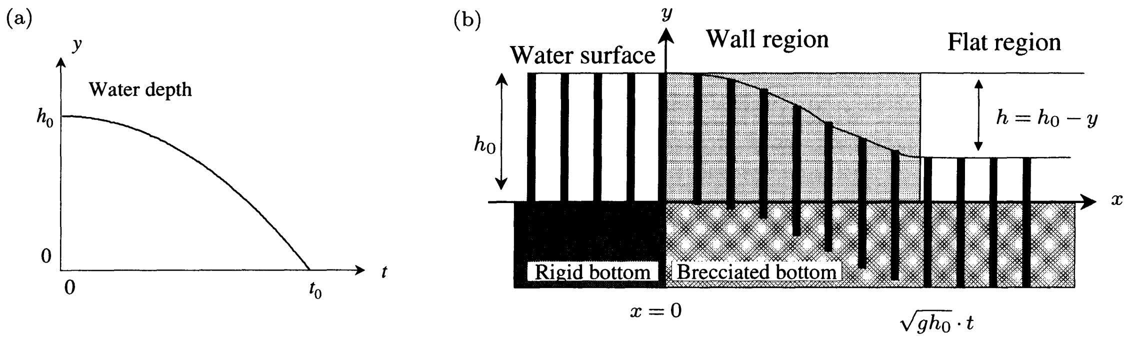

Fig. 5. (a) The time evolution of the water depth by soaking from the bottom. (b) The form of the sea surface theoretically calculated using a dynamical model of water soaking. Only vertical flow indicated by bars in the fault zone is considered for theoretical simplicity without considering the horizontal flow out of the fault zone to the fissures and large areas of subsidence on land.

velocity turns into constant in the later stage (due to the drag at the hole). By integrating eq. [8], we get the time evolution of the water height as

$$y = h_0 - \frac{mg}{k}t + \frac{m^2 g}{k^2}\left(1 - \exp\left(-\frac{k}{m}t\right)\right). \quad [9]$$

This is schematically drawn in Fig. 5(a). The time required for all water is drained is given by:

$$0 = h_0 - \frac{mg}{k}t + \frac{m^2 g}{k^2}, \quad [10]$$

which yields

$$t_0 \approx \frac{k}{mg}h_0 + \frac{m}{k}. \quad [11]$$

Since the width of the fault zone ($x > 0$: half infinite) is much longer than the water depth, the shallow water equation may be applied in this problem, where the horizontal surface velocity can be regarded constant at the bottom. Therefore, the water column will behave like vertical sticks with the drop of $h = h_0 - y$ from the surface.

The horizontal motion is produced by the horizontal pressure gradient. The gradient initiated at the edge of the zone ($x = 0$) propagates with the phase velocity of shallow water waves ($= \sqrt{gy}$). Thus, one-dimensional model can be applied in the region defined by $x > \sqrt{gh_0} \cdot t$. In other words, the water "wall" is created in the region roughly defined by $0 < x < \sqrt{gh_0} \cdot t$. This configuration is shown in Fig. 5(b). After $t > t_0$, all water is drained in the inner region, where the bottom is outcropped and the water "wall" is maintained in the steady state.

We can assume that the horizontal velocity, U, does not depend on x in the "wall" region because the pressure inside of the falling water is almost constant. Then the width or the "wall", D, is given by

$$D = Ut_0. \quad [12]$$

The vertical velocity at the bottom is given by

$$w(x) = w(t) \quad \text{at} \quad t = \frac{x}{U}. \quad [13]$$

Substituting this relation into eq. [8], we get

$$w(x) = -\frac{mg}{k}\left(1 - \exp\left(-\frac{k}{m}\frac{x}{U}\right)\right). \quad [14]$$

Since the flow is steady, the water mass drained in the unit time from the fault zone is balanced with the volume flux supplied from the upstream region as given by

$$\int_0^D w(x)\mathrm{d}x = -Uh_0. \quad [15]$$

Substituting eq. [14] into this equation, we get

$$Uh_0 = \frac{mg}{k}D - \frac{m^2 U}{k^2}\left(1 - \exp\left(-\frac{k}{m}\frac{D}{U}\right)\right). \quad [16]$$

If $\exp\{-(k/m)(D/U)\} \ll 1$, this equation gives the width of the water "wall".

$$D \approx \frac{kU}{mg}\left(h_0 + \frac{m^2}{k^2}\right). \quad [17]$$

The shape of the wall is obtained as shown in Fig. 5(b) by replacing the abscissa from t to x/U although U is given by an external condition.

Discussion. (i) *Hydraulic permeability to fault planes and fissures.* Three cracks with the width of about 1 m across parallel to the North Anatolian Fault line were formed in the ground at the time of the Izmit earthquake. If these cracks were also in the sea floor and continued to the focus at 10 km depth, the draining is 30,000 tons for 1 m length of the fault line. This model experiment of the split sea was presented at the Seismological Society of Japan in 1999 and in a book in Japanese.[11] There were critical arguments that the permeability of the crust is not so large as to soak the water down to the focus in a short time. Skeptical scientists consider that fissures and cracks are tapered and extend merely 30 m or so at most and that the opened volume is too small to explain the soaking of seawater.

The presence of an over-pressurized, fluid-filled, fractured rock matrix was revealed from seismic tomography resulting from low velocities of seismic S- and P-waves generated by the Kobe aftershocks.[12] Although underground water flown into the fractured focus is considered to have nucleated the Kobe earthquake, the surface water might also be soaked into the ground by the lowering of water level. In fact, the drill core of the Nojima Fault from the depth of several hundred meters showed brown oxidized clay minerals. This suggest the surface water with dissolved oxygen had flown down to several hundred meters at least (Dr. S. Uda, private communication), not to mention down to the focus.

(ii) Water *flow into dilatant areas and area of tectonic subsidence.* Recently, Yoshida *et al.*[13] measured electric potential changes in dry and saturated rock and found very rapid flow of water into the dilatant region when the stress dropped prior to the shear fracture. The volume fluid of inflow was 0.2 % of the sandstone specimen. If the whole volume at the fault zone down to 10 km became dilatant before the movement of the fault, seawater, 200 m in height, may be absorbed in a short time.

Land subsidence occurred at the Izmit earthquake. Seawater also flowed out of the zone in both horizontal directions toward the subsided areas of land and sea floor. The total outflow would be tremendous in amount considering the horizontal flow in addition to the fall into fissures, breccias and dilatant areas.

(iii) *Topographic barrier to water inflow.* The Izmit Gulf is a narrow channel which restricts the inflow of seawater to the fault zone crossing the channel. The Cape Gölcük will also block the inflow of seawater. If submarine dunes block the inflow of seawater to the zone, water balance may cause split sea.

The tidal withdrawal, which were often reported before earthquakes in Japanese literatures, may be formed in a bay with undersea dunes when a fault line cut the bay. Since beaches with submarine sand dunes are abundant at Japanese coastal areas, a rapid tidal withdrawal may occur by dilatancy formation before earthquakes.

Conclusion. The sea splitting named Moses' phenomenon and the tidal withdrawal may occur as rare natural phenomena at specific topographic places like a shallow and narrow channel and a bay. The horizontal water inflow to the fault zone from the upstream would be blocked by capes and submarine dunes. Hence the draining into fissures and subsidence area of the land and seafloor overwhelm the horizontal infow to the fault zone. Walls of seawater may be formed on both sides and the sea floor may be exposed by a rapid tidal withdrawal. The Moses' phenomenon has been calculated theoretically and reproduced experimentally.

Acknowledgements. We thank Prof. S. Uyeda, M. J. A., for his encouragement, Prof. T. Sunamura for useful discussion, Dr. N. Whitehead at New Zealand ISDR, Drs. S. Uda and S. Yoshida at Earthquake Research Institute, University of Tokyo for valuable information and finally Prof. S. Park for his critical comments.

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