Sedimentation in Loch Earn and Loch Lubnaig, Scotland

IN their paper about sedimentary features associated with slumping in Loch Earn and Loch Lubnaig, McManus and Duck[1] indicate that there is no prior record of the use of sonar devices in lakes for the investigation of "subaqueous landforms". This is a curious statement given our[2] earlier reported work in their own field area and the extensive surveys of the Canadian Centre for Inland Waters in for example, the Great Lakes (see ref. 3), where acoustic techniques have become standard for mapping both lakebed and sub-bottom landforms, whose recognition is regarded as a normal prerequisite for any engineering undertaking.

While McManus and Duck[1] recognize that their observed slumps occur at depths below the influence of surface water waves, they do not consider the possibility that longer period waves, such as seiches or internal waves, may influence bed forms. It is instructive to investigate the theoretical seiche[4] for any lake under sedimentological investigation to see if water velocities expected at the lakebed may be great enough to cause sediment movement. I have done this for a water body of rectangular cross-section (length 2,500 m, depth 30 m) as a crude model of the Stank Basin[5] of Loch Lubnaig and conclude that a water particle velocity of 5 cm s^{-1} is possible for a seiche of only 0.1-m amplitude, the period of oscillation being ~5 min. Seiche observations by Gill[6] on Llyn Gwellyn, a lake of comparable size to the Stank Basin, suggest that a real seiche would be of longer period than the approximate theory predicts, but that particle velocities at the base of the water column would still be sufficient to transport silts and finer grains (Graf and Acaroglu[7]) even if the seiche amplitude were only a few centimetres. We[2] have observed three sediment waves or mounds in the bed of the Stank Basin. They rise, with gradients of 1:5, to a height of 5 m above the general level of the fine lakebed sediment, which is itself no more than 5 m thick. The sediment waves are symmetrical and show layering which parallels the sediment–water interface. Such layering and symmetry would not arise from slumping, but could be produced by a seiche-driven oscillatory water current. McManus and Duck[1] have drawn attention to the effect that sediment disturbance from slumping will have on the interpretation of lakebed sediment cores retrieved for palaeomagnetic or palaeoecological purposes. Disturbance in the manner I propose will be a more subtle effect because of the presence of seemingly undisturbed layers.

In Scottish lochs, the use of modern acoustic equipment (with the exception of its largely ludicrous use in Loch Ness) has been neglected. This is not the tribute that Murray and Pullar[7] would have wished. As well as conventional sidescan and profiling records, sediment acoustic velocity determinations are required[8,9] to help assign proper depth scales and to assess sediment gas content, cited by Monroe[10] as an important factor in causing slumping. I hope that McManus and Duck[1] and others will receive support to extend their work to other lochs and perhaps to map more completely the mounds in the Stank Basin and to verify if they are indeed associated with seiche activity induced by the winds howling down the glen at Ardchullarie Mor.

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1. McManus, J. & Duck, R. W. *Nature* **303**, 161–162 (1983).
2. McKay, A. G. & McEwen, I. J. *Mar. Sedim. Atlantic Geol.* **18**, 58 (1982).
3. Thomas, R. L., Demp, A. L. & Lewis, C. F. M. *Can. J. Earth Sci.* **10**, 226–271 (1973).
4. Neumann, G. & Pierson, W. J. *Principles of Physical Oceanography*, 291 (Prentice-Hall, Englewood Cliffs, 1966).
5. Gill, W. W. S. thesis, Univ. Coll. North Wales (1967).
6. Graf, W. H. & Acaroglu, E. R. *Bull. Int. Ass. Sci. Hydrol.* **11**, 27–43 (1966).
7. Murray, J. & Pullar, L. *Bathymetric Survey of the Scottish Freshwater Lochs* (Challenger Office, Edinburgh, 1910).
8. Bell, D. L. & Porter, W. J. in *Physics of Sound in Marine Sediments* (ed. Hampton, L.) (Plenum, New York, 1974).
9. McKay, A. G. & McKay, P. M. *J. acoust. Soc. Am.* **71**, 871–878 (1982).
10. Monroe, J. N. *Science* **161**, 1394–1395 (1969).

DUCK AND MCMANUS REPLY—We welcome the comments of McKay concerning our recent contribution[1]. He is correct to draw attention to sonar work in the North American Great Lakes. In view of their enormity these water bodies behave as inland seas and are not directly comparable with even the largest of the Scottish lochs.

Our contribution[1] specifically referred to sidescan sonar surveys and not to the use of sonar devices in general. The principal work reported was undertaken on Loch Earn and mention was made of Loch Lubnaig to illustrate that the subaqueous landforms recognized are not mere curiosities confined to one water body. We have since detected them in other lochs.

We were unaware of the boomer seismic work of McKay and McEwen[2] in Loch Lubnaig as their brief abstract was published in a Canadian journal not known for its contributions to Scottish environmental studies. The report of sediment waves or mounds in the Stank Basin[2] is interesting but, despite re-examination of sonographs and echograms[3], we have been unable to confirm their presence due to lack of information regarding their position or orientation. However, marginal spurs are recognized extending into the basin floor from the bounding slopes.

Seiches or internal waves may indeed influence loch bedforms. However, as yet, we have insufficient hydrodynamic data to corroborate this. Furthermore we have reservations about the seiche-associated current velocities calculated by McKay for Loch Lubnaig. Although we have not undertaken seiche observations in the loch there is good reason to believe that the 0.1-m surface seiche amplitude used in McKay's model, and to which the horizontal current velocity is proportional[4], is excessively large. Chrystal[5] demonstrated that seiche activity is poorly developed in Loch Lubnaig due to its shallow nature (mean depth, 13 m), its very irregular bottom and its orientation across the path of atmospheric disturbances. During a 6-week period only four instances of definite, but short-lived, seiche activity, with a period of about 24 min, were recognized[5]. For most of the period "... nothing was found but wind embroidery and sub-permanent wind denivellation, such as would be naturally expected in a shallow lake"[5]. Moreover, the maximum seiche amplitude observed by Chrystal[5] (Fig. 22) was only about 0.5 cm. On the basis of McKay's model for the Stank Basin the maximum current velocity, at a seiche node, associated with such activity would be less than 0.3 cm s^{-1}. Average current velocities would be about half this value and tend to die away rapidly with time[6]. Thus currents resulting from surface seiches are unlikely to be responsible for the bedforms described.

To our knowledge the thermal behaviour of Loch Lubnaig has not been investigated. However, it is likely that internal wave (internal seiche[7]) activity will occur in association with summer stratification. Horizontal current velocity components generated by such water movements are known to be up to five times greater than those associated with corresponding surface seiches[8,9]. Moreover, these currents can persist for several days[8]. Hence it is possible that internal waves may have a role in the formation of the structures recognized by McKay and McEwen[2], perhaps in the manner advocated by Mortimer[10].

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1. McManus, J. & Duck, R. W. *Nature* **303**, 161–162 (1983).
2. McKay, A. G. & McEwen, I. J. *Mar. Sedim. Atlantic Geol.* **18**, 58 (1982).
3. Asaad, N. M. thesis, Univ. Dundee (1982).
4. Proudman, J. *Dynamical Oceanography* (Wiley, London, 1953).

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