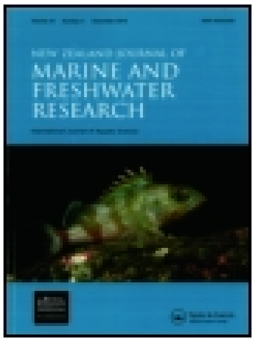

New Zealand Journal of Marine and Freshwater Research

ISSN: 0028-8330 (Print) 1175-8805 (Online) Journal homepage: http://www.tandfonline.com/loi/tnzm20

Shallow-water sand bars on the Ruamahanga River delta Lake Wairarapa

R. A. Pickrill & J. Irwin

To cite this article: R. A. Pickrill & J. Irwin (1978) Shallow-water sand bars on the Ruamahanga River delta Lake Wairarapa, New Zealand Journal of Marine and Freshwater Research, 12:2, 109-119, DOI: 10.1080/00288330.1978.9515732

To link to this article: https://doi.org/10.1080/00288330.1978.9515732

N.Z. Journal of Marine and Freshwater Research 12 (2): 109–19. June 1978

Shallow-water sand bars on the Ruamahanga River delta Lake Wairarapa

R. A. PICKRILL AND J. IRWIN

New Zealand Oceanographic Institute, DSIR, P.O. Box 12-346, Wellington,
New Zealand

ABSTRACT

In the shallow waters of Lake Wairarapa, a multiple series of sublimnic sand bars has developed around the outer edge of the Ruamahanga River delta. Shore-normal movements in bar positions occur in response to changing lake level and wave conditions. Unlike many bar systems, most of these movements are lakeward of the breaker zone. Sediments on the bar crests are well-sorted fine sands; the troughs are a mixture of fine sand and mud settling out of the turbid lake waters during calm conditions.

INTRODUCTION

On gently sloping sand beaches, the nearshore relief is commonly marked by a series of low embankments of sand, or nearshore bars. Two or three bars usually form parallel to the shoreline, and may run for tens of kilometres without interruption. They are most fully developed on low energy, sandy, open coast shores with low tidal ranges, such as in the Baltic and the Mediterranean, or on the shores of large lakes with small fluctuations in water level such as the Great Lakes of North America.

Despite much research into the development of bar systems, their conditions of formation, stability, and decay, Zenkovich (1967, p. 219) has suggested that the origin and modification of submarine sand bars is the most complicated and confused problem of the coastal zone. He considers that bar formation may be related to the onshore movements of sand, and other Russian workers reported by him think that both unidirectional and opposing littoral currents are responsible for the erosion of the troughs. In contrast, Bascom (1953) suggests bars form in a zone of interference, where shoreward flowing currents generated by wave action beyond the breaker zone meet seaward-flowing return currents generated shoreward of the breakers. All these processes probably play a part in bar formation, some being more important in certain places than in others. However, breaking waves are generally accepted as the dominant controlling factor in most bar systems (Evans 1940; King & Williams 1949; Shepard 1950; Greenwood & Davidson-Arnott 1975), scouring material out of the troughs and depositing it on the crests on either side.

Under breaking waves, multiple bars may form in three ways. First, as a response to a range of wave energy conditions with outer bars forming under storm waves and inner bars forming during calmer periods. Secondly, under a range of water levels with the most seaward bars formed in response to breaking waves at low tide and subsequent landward bars in response to higher stages of the tide. Thirdly, multiple bars may be a product of reformed waves, the outer bar being a product of the initial wave break and all shoreward bars being formed under reformed waves (Komar 1976).

In the shallow waters of Lake Wairarapa a particularly well-developed series of sublimnic bars has formed on the topset beds of the Ruamahanga River delta (Fig. 1). In this paper the general deltaic environment is described and the morphology, sediments, and stability of the bar system outlined. Limnic processes likely to control bar development are discussed and suggestions made as to probable modes of formation.

STUDY AREA

Lake Wairarapa has formed in the graben between the fault-bounded Rimutaka Range to the west and the Aorangi Mountains to the east. Alluvial deposits from the Ruamahanga River have cut off a former, long, shallow extension of Palliser Bay to impound the lake (Cotton 1958). The main freshwater inflows to the lake come from the Tauherenikau River in the north and the Ruamahanga River in the south. However, flood control works in 1968 diverted the Ruamahanga River southward into the outlet channel connecting Lakes Wairarapa and Onoke; no appreciable water flows or sediment inputs have come into Lake Wairarapa across the Ruamahanga delta since that date.

The lake trends NE–SW, with a maximum length of 18.2 km (Fig. 1) and maximum width of 9.6 km (Irwin 1975). It is an extremely shallow basin with a maximum depth of 2.5 m and low slope gradients, typically less than 0.001. The Ruamahanga River delta provides the only break in relief around the shoreline. The outer edge of the topset slope of the

---

Received 17 June 1977; revision received 5 December 1977.

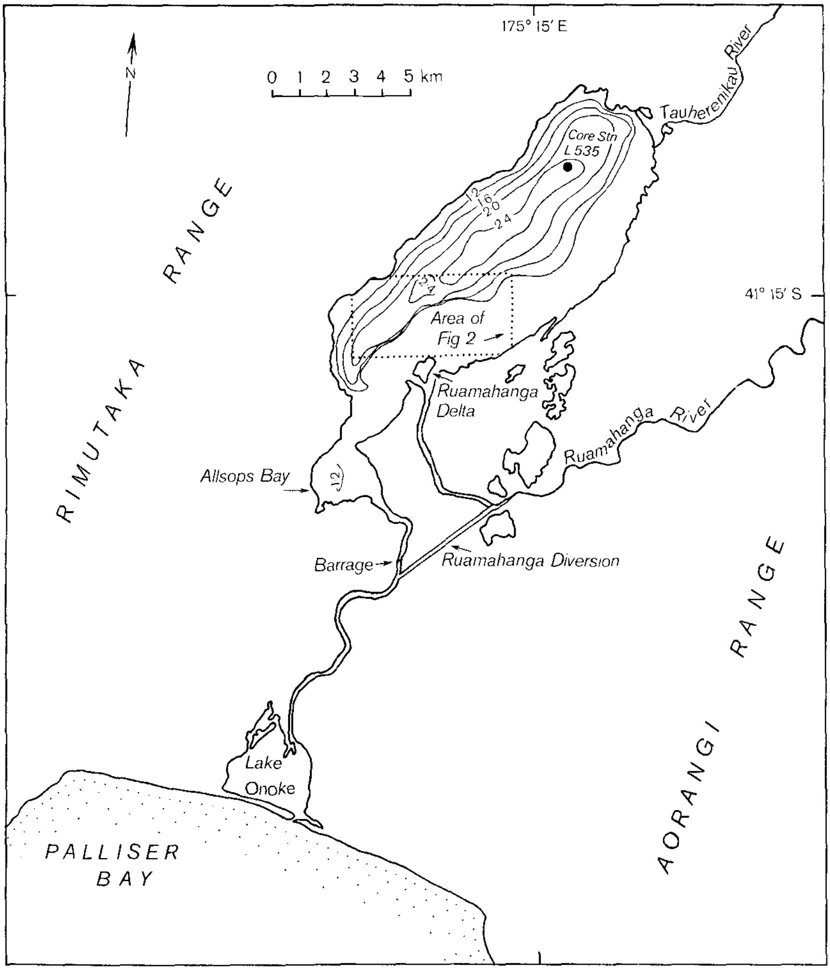

FIG. 1—Location of Lake Wairarapa, showing the Ruamahanga delta, and bathymetry from Irwin (1978). The area of detailed study is marked.

delta is marked by a relatively abrupt change in slope, the gradient of the foreset beds being the steepest in the lake (0.01) before flattening out on the floor of the central basin. From the narrow neck at the entrance to Allsops Bay the delta extends 8 km along the eastern shore of the lake. None of the other streams or rivers flowing into the lake has such a well-developed deltaic form.

METHODS

Delta morphology was mapped using a Raytheon 200 kHz echo sounder. Shore-normal transects approximately 200 m apart were run across the delta, positions being fixed with a compass, rangefinder, and sextant. One of these transects was surveyed in detail using a Watts quick-set level. Permanent reference markers were placed at the ends of this line to enable it to be resurveyed to assess short term changes in submarine bar morphology.

In shallow water surface sediments were collected by hand, and in deeper water a 12-cm-diameter pipe dredge was used. All sand-sized samples were sieved at 0.5 ϕ intervals, the finer fraction (less than 4.0 ϕ) being sized by pipette analysis. Mean size, sorting, and skewness were calculated according to Folk (1968). A 1.5-m-long 75-mm-diameter gravity corer with 27 kg of lead weight was used to recover short cores. The shallow water limited the height from which the corer could free fall, and consequently penetration was not usually very great; longer cores were obtained by driving the corer into the bed with a sledge hammer. Sub-samples from the cores were sieved and statistical parameters calculated. In addition, X-ray radiography was used to reveal any internal bedding structures within the cores.

DELTA AND SUBLIMNIC BAR MORPHOLOGY

The bathymetric chart (Fig. 1) shows the Ruamahanga River to have a convex deltaic form. The southern end of the delta ends in the shallow constriction of Allsops Bay; the northern limit is more difficult to depict and is marked by a gradual

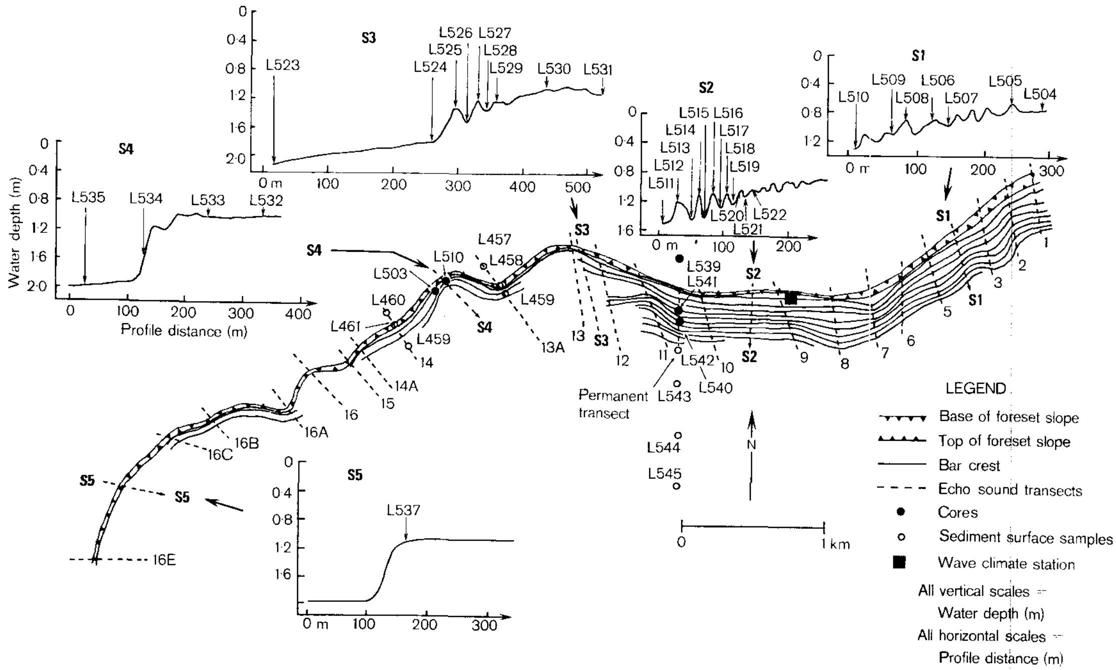

FIG. 2—Morphological map of the outer Ruamahanga delta (the area marked in Fig. 1), showing sounding tracks, station positions, morphological boundaries, and bar crest locations. Five sounding and sediment sampling transects across the delta are shown in detail (vertical exaggeration 120×).

decrease in the slope of the foreset beds. The more detailed mapping carried out in the present survey (Fig. 2) shows the outer edge of the deltaic topset beds does not have a regular convex form but instead is marked by a series of irregular wavey indentations.

Transects across the delta highlight the depositional shelf form (Fig. 2). The outer edge of the low angle topset slope is marked by a relatively sharp break in slope: similarly, the steep foreset slope ends abruptly in the almost flat basin of the central lake. On the southernmost transect (S5) the profile is smooth; further north (S4), on the outer edge of the topset slope, low rudimentary nearshore bars become discernible. Northwards there is an increase in the number and amplitude of the bar crests, with a maximum of 11 off the former river outlet. North of the outlet the number of crests decreases .

Attempts to map the bars from aerial photographs were unsuccessful because of extreme turbidity and the plan of the ridge crests (Fig. 2) was drawn from the echo-sounding transects instead. Where possible, ground checks were used to confirm both the orientation and spacing of the crests, but it is uncertain whether some of the crests are continuous between transects or whether some are crescentic in plan. However, the map show two important features. First, bar morphology is confined to the outer edge of the topset slope; the inshore end of the transects are very flat. Secondly, the most lakeward bar crest forms close to, or actually on, the outer edge of the topset slope.

The more detailed survey with the level across the most fully developed bars in the centre of the delta (Fig. 3) shows successive crest and trough forms to be regular, although the bars are largest in the deeper water on the lakeward end of the transect where typical crest to crest wave lengths are 30 m and crest to trough amplitudes are 0.15 m. In the shallower waters close inshore the wave length and amplitude decrease to 20 m and 0.10 m respectively, before the bars merge with the flat lake margin.

BAR STABILITY

Over a 4-month period, the permanent transect was surveyed four times at intervals ranging from 8 to 40 d. The bar system was found to be constantly changing its form (Fig. 3).

Most of the morphological changes are the result of shore-normal shifts in the ridge crest and trough positions. The largest of these displacements (25 m) was recorded in the 8 d between surveys 2 and 3. Changes in crest to trough amplitudes are small, mostly only 1–2 cm. Although relatively large volumes of sediment are moved in these shore-normal shifts in crest positions, the fundamental sinusoidal shape of the transect is maintained. Net changes in volumes of material within the transect (expressed as volume changes over a 1-m-wide strip of beach, i.e., $m^3.m^{-1}$) are small, averaging 2.23 $m^3.m^{-1}$; distributed over the 340 m long profile, this represents an average

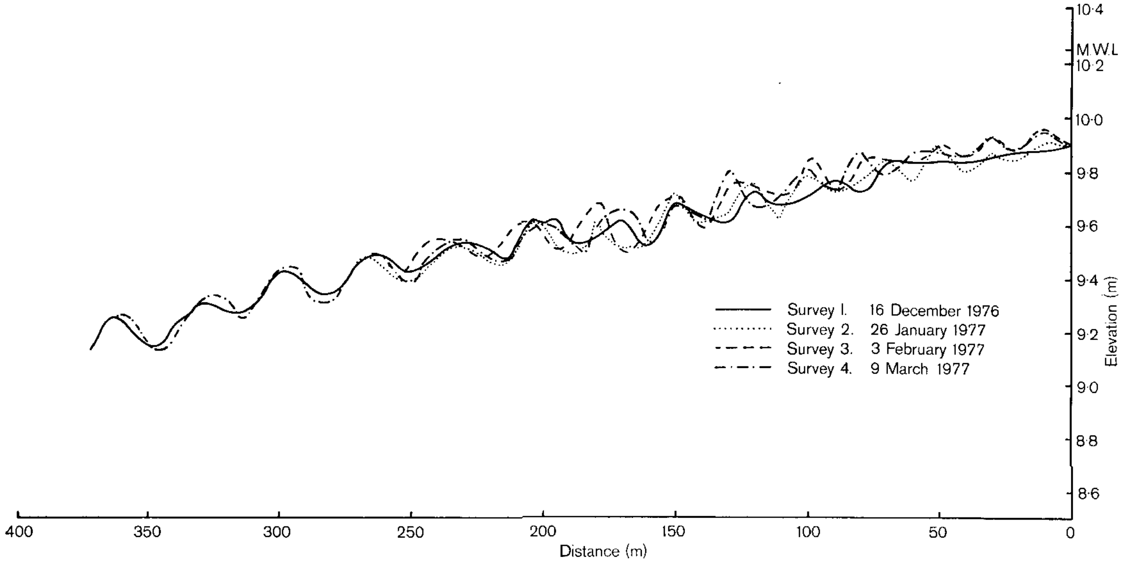

FIG. 3—Four surveys of the permanent transect across the multiple bars of the Ruamahanga delta, as marked in Fig. 2. Horizontal distances are from an arbitrary reference marker, vertical elevations above Wairarapa Catchment Board datum.

elevational change of 0.65 mm. Therefore, although changes in profile involve the redistribution of large quantities of sediment they produce only shore-normal shifts in the form of the profile and do not involve any substantial net addition or subtraction of material within the transect.

The magnitude of both the horizontal shifts in crest position and elevational changes in crest to trough amplitudes decreases in the deeper water over the outer bars. Furthermore, the repeated surveys show the inshore boundary to the bar system, and hence the number of bar crests, to be variable. In the initial survey the first 70 m of the profile were flat with no bars; subsequent surveys show three crests.

DELTA SEDIMENTS

SURFACE SEDIMENTS

Samples were collected at the stations marked in Fig. 2 (Sediment characteristics are summarised in Appendix 1). The topset slope of the Ruamahanga delta is covered with well-sorted medium to fine sands with very little variation in grain size around the 8 km perimeter. Sediments are coarsest on the central delta off the former river outlet, and fine to the north and south. The coarser material on the central delta is well sorted while the finer material to the north and south is extremely well sorted (Folk 1968).

On the transects without bars the topset slope shows no shore-normal trends in grain size or sorting; sediments are uniformly well-sorted sands out to the base of the foreset slope. However, at the toe of the foreset slope there is a change to 'poorly sorted' muds typical of those found throughout the central lake basin.

Transects across areas with well-developed bars (e.g., Transect S2 in Fig. 4) have well-sorted sand, similar to the sands mantling the crests on the non-barred lake bed. In contrast, bar troughs contain a poorly sorted mixture of very fine sand and mud, which becomes progressively muddier towards the lake until the most lakeward troughs are predominantly silt and clay. The sediment modes show the sands to be similar to those on the bar crests whereas the mud appears to be derived from the central lake basin.

Not all the barred profiles conform rigidly to this pattern; most of the crests and troughs on Profile S1 are composed of well-sorted sands, similar to the crests, but on Profile S3 only the most lakeward troughs contain any silt and clay.

Despite these differences between troughs on different profiles a scattergram of mean grain size against sorting makes it possible to identify three sedimentary environments on the delta (Fig. 5):

(a) Well-sorted, medium-fine sands of the foreset and topset delta slopes (except in the troughs of the submarine bars);
(b) Poorly sorted muds in the central basin of the lake, beyond the toe of the sandy foreset slope; and
(c) Very poorly sorted bimodal sediments in the bar troughs, made up of two sub-populations, the well-sorted sands of the topset beds and the poorly sorted muds of the central basin.

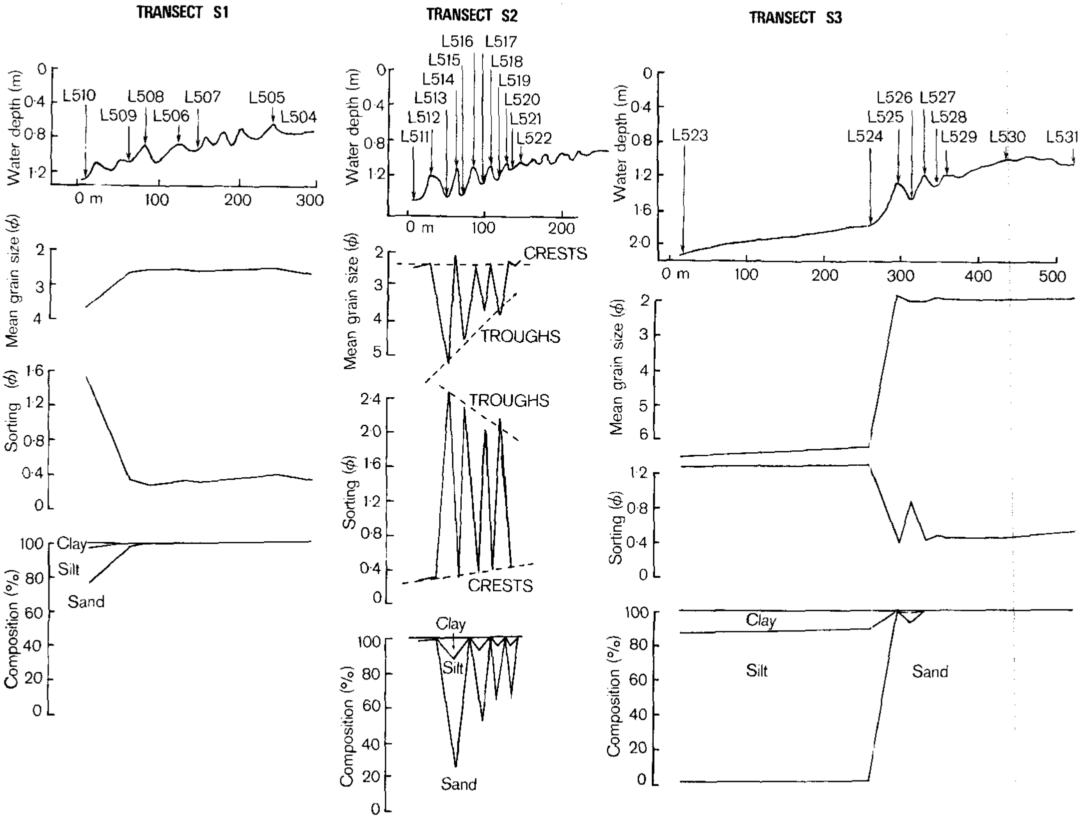

FIG. 4—Shore-normal trends in mean grain size, sorting, and clay : silt : sand ratios across those transects of the Ruamahanga delta with multiple offshore bars.

SUBSURFACE SEDIMENTS

Six short cores were taken from the three depositional environments outlined above; the central lake basin, the bar crests, and the bar troughs.

Central Lake Basin: Cores from the northern lake, 6 km from the delta (L 538; 60 cm long) and just off the base of the foreset slope (L 539; 70 cm long), have similar textural characteristics and bedding structures, suggesting that processes of sedimentation are comparable throughout the central basin (Fig. 6 a & b). Both cores consisted of finely bedded muds similar in size distribution to the surface sediments, with no obvious size difference down the cores. However, X-ray radiography reveals alternate laminations of coarse and fine sediment (Fig. 7). Between 40 and 60 different laminae can be identified within any 10 cm section of core length. The spacing of the laminae is less regular and individual laminations are thicker in L 539 close to the delta than in L 538 from the northern lake. Each alternate layer of banding, i.e., coarse and fine material, probably reflects pulsational sediment inputs from inflowing streams during storms. As such, the thicker laminae in L 539 may be a product of higher and less regular sediment inputs close to the former river outlet than those in L 538, which is further from the sediment sources.

Bar Crests: Cores L 540 and L 541 penetrated 40 cm and 70 cm through the surficial sandy topset beds (Fig. 6 c & d), into massive, well-sorted fine sands extending 15 cm and 37 cm beneath the bar crest. The sands are underlain by mud similar in size composition to that in the central basin. The boundary between the two deposits is well defined. In the lower core the muds are interbedded with muddy sands up to 5 cm thick.

Bar Troughs: L 540, like the cores from the bar crests, comprises sand overlying interbedded muds and muddy sands (Fig. 6c). However, unlike the cores from the bar crests, the sand in the top of L 540 is interbedded with occasional thin mud laminae (see below). In Core L 503 the overlying, well-sorted sand was not present, the total length of the core being interbedded muds and muddy sand similar to those underlying all other cores through the topset beds of the delta. Scour in the bar trough has probably eroded the surficial sands down to the underlying muds.

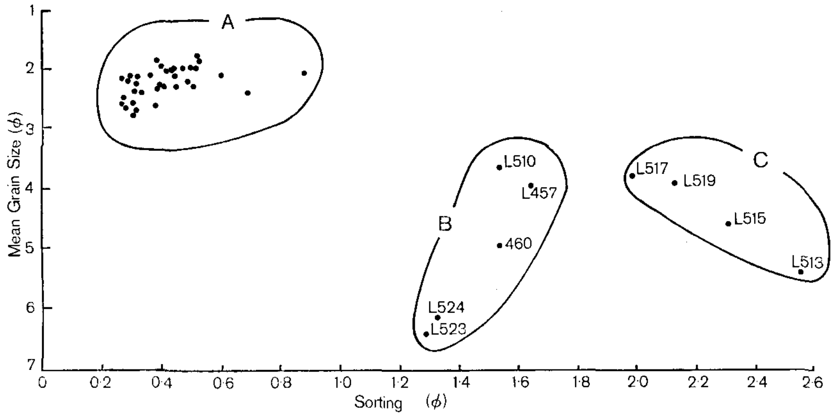

FIG. 5—Bivariate plot of mean grain size against sorting for the surface sediment samples from the Ruamahanga delta shown in Fig. 2. Three environments of deposition are identified: A. Sands of the foreset and topset slopes, excluding the bar troughs (includes all stations except those shown in B and C); B. Muds of the central lake basin; and C. Muddy sands of the bar troughs.

Despite the delta being inactive since 1968, the gross sedimentary structure can best be interpreted to fit the classic model of shallow water deltaic sedimentation outlined by Gould (1970). Silts and clays entering the delta are swept lakewards beyond the sandy delta edge into the pro-delta zone to build up a platform for delta advance. Sands are deposited in the shallow water over this platform to form a continuous sheet of sand overyling mud.

HYDRAULIC REGIME

There are two important prerequisites for bar development. First, bars normally form only on beaches composed of medium to fine sands, and secondly they form only on low slope profiles. Although the Ruamahanga delta meets both these conditions, the presence of fine sands and low, nearshore slopes does not necessarily mean that bars will always form; the hydraulic regime across the nearshore zone is very often the important controlling factor.

Lake Levels: Submarine bars are best developed in nontidal seas and lakes with low water-level fluctuations. The level of Lake Wairarapa is controlled by a barrage at the outlet (Fig. 1) to avoid flooding of the surrounding low-lying farm land. As a result the lake has a controlled range of almost 2 m and a mean level of 10.25 m (Wairarapa Catchment Board datum). The range at ±1 standard deviation (i.e., for 68% of the time) is only 0.5 m, so that although the overall range is large, the lake is mostly subjected to small water level fluctuations conducive to bar formation.

Wind Waves: All waves in small lakes are generated by local winds. Once the wind regime is known, using empirical wave forecast curves, it is possible to approximate the wave climate at any point around the shoreline. Winds blowing across the lake are strongly bimodal, as at most sites close to Cook Strait, reflecting the orographic funnelling effect of the straits on wind directions (Garnier 1958). Records from the Barrage meteorological station at the southern end of the lake show the prevailing winds are from the north-west and south-south-west (Fig. 8). The southerly component blows along the long axis of the lake, but the north-westerlies blow obliquely across it. The Ruamahanga delta, being on the south-eastern shore of the lake, is exposed to the prevailing north-westerlies.

Forecast wave heights have been calculated for a single station on the outer bar of the central delta (Fig. 2). Wave height has been summed at 10° intervals for wind directions from 300° around to 40° using the methods outlined by the U.S. Army Corps of Engineers (1962). Heights have been plotted as a percentage exceedence curve (Fig. 9).

For about 40% of the time the lake is calm; for less than 1% of the time wave heights exceed 45 cm. Maximum wave heights of 90 cm are very rare, being generated by occasional strong winds blowing down the long axis of the lake. The depth of water over the outer bar ranges from 0.6 m during low lake levels to 1.0 m at high levels; it is 0.8 m at mean level.

If breaking waves are responsible for bar formation they might be expected to break on the outer bar before reforming and breaking on subsequent bars in shallower water. Waves entering shallow water break in depths equivalent to 4/3 their height (King 1972, p. 95). Therefore, waves of at least 60 cm would need to be generated for them to break on the outer bar during mean lake levels; similarly waves of 45 cm and 75 cm would be required during periods of high and low lake levels. Such large waves are rarely generated, but frequent shore-normal shifts in bar position have been recorded. Bar movement must, therefore, be taking place in the relatively deep water before breaker collapse.

Lakeward of the zone of breaking waves, sediment movement is a function of the near-bed orbital velocities; sediment movement is initiated when this velocity exceeds the threshold of sediment movement.

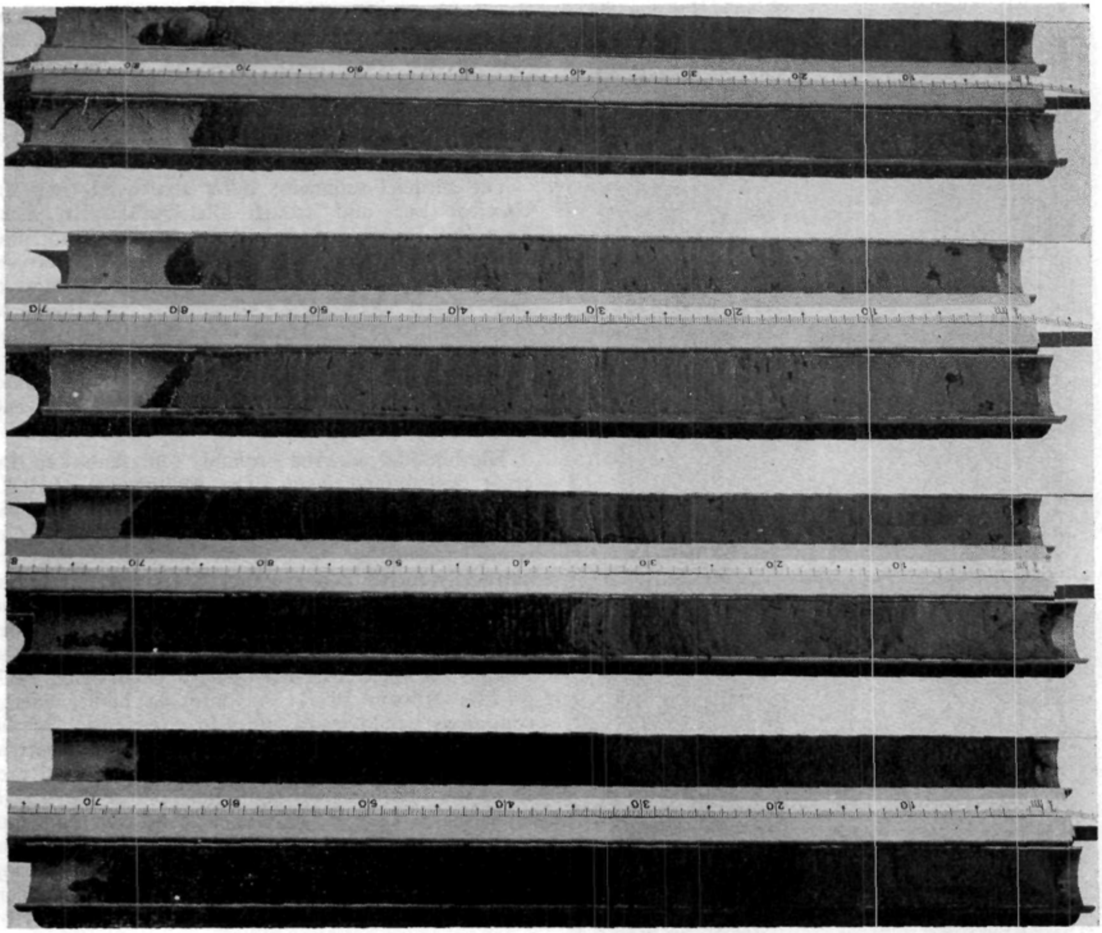

FIG. 6—Cores (*top to bottom*) from the central lake basin (L 538, L 539), from a bar crest (L 541), and from a bar trough (L 540); the base of each core is at the right. Note the massive sand overlying mud in L 541. In L 540, from the trough, thin mud laminae are interspersed in the sand.

Under short-period lake waves Johnson (1961) demonstrated near-bed peak particle velocities (U_p) to be a function of the wave velocity (C), wave height (H), and water depth (d).

$$U_p = 0.42\,C\,\{\,(H/d) - 0.062\,\}\,0.72$$

Near-bed velocities under mean water depths on the outer bar were plotted for various wave conditions (Fig. 9).

For short-period lake waves the threshold orbital velocity required to set medium-fine sand in motion is less than 10 cm.s^{-1} (Komar & Miller 1975). On the outer bar such near-bed velocities are equalled or exceeded 32% of the time (Fig. 9). This frequent disturbance of the outer topset bed sediments by wind waves is probably the major process responsible for bar formation and crest mobility.

DISCUSSION

The morphology and sediments of the Ruamahanga delta conform to classical concepts of deltaic sedimentation. The outlet of the Ruamahanga River has a typical progradational convex deltaic form, with low angle topset slopes and steeper foreset slopes. Both surface and subsurface sediments conform to the shallow water deltaic model outlined by Gould (1970) whereby a thin sheet of sands overlies prodelta muds. Despite the restricted fetch in Lake Wairarapa the sublimnic bars on the outer topset slope of the delta are similar to other limnic and oceanic bar systems. For instance, they have formed in fine sands on a gently sloping shelf, they assume a sinusoidal wave form with larger amplitudes and longer wave lengths in deeper water, and short term movements in crest position are produced by changes

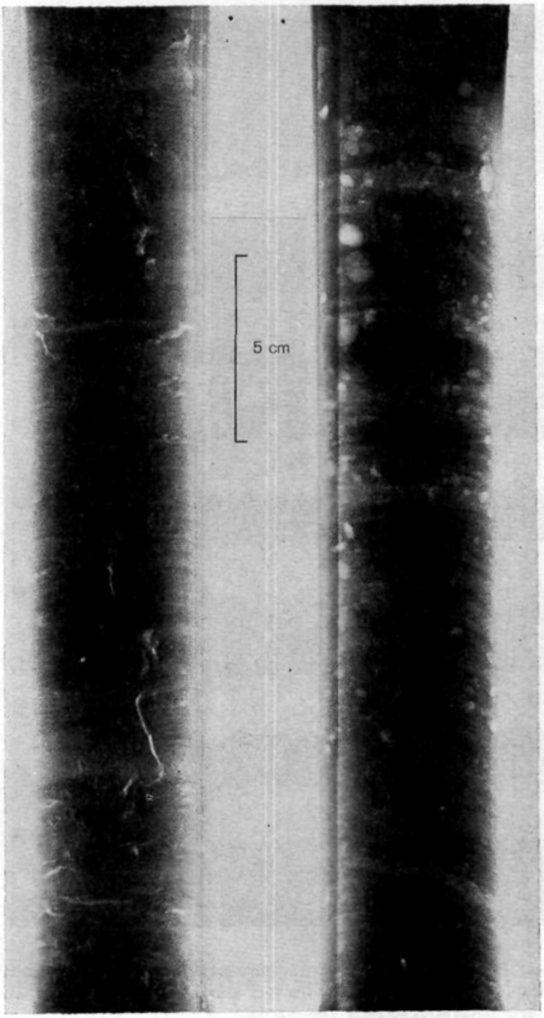

FIG. 7—X-ray radiograph of cores L 538 (*left*) and L 539 (*right*) from the central basin of Lake Wairarapa; upper parts of both cores are at top. Both show fine banding within the mud. The laminations are thicker and less regular in L 539, which was closer to the sediment supply. Lengths shown are 31–62 cm from top of core L 538, 10–41 cm from top of core L 539. The blotchy appearance in L 539 was caused by a defect in the X-ray process; other apparent structures in both cores are shrinkage cracks.

in the hydraulic regime affecting the delta. However, there are several important differences between the situation in the Ruamahanga delta and most other bar systems.

Most submarine bars on oceanic and limnic shores are made up of 2 or 3 crests running parallel to the beach; in places on the Ruamahanga delta there are more than 10. The large number of bars is probably a function of the extremely gentle gradient of the topset delta slope. Waves shoaling across this slope dissipate energy across a broad zone in which they may reform many times before finally breaking in shallow water close to shore. Nilsson (1972) found that a similar combination of a low-energy wave climate and very gently sloping beach produced a series of up to 30 multiple bars in Cape Cod Bay.

The surficial sediments differ somewhat from the classical bar and trough distribution. In Lake Superior, for example, breaking waves scour fine material out of the troughs to be deposited on the crests, so that trough sediments are coarse lag deposits and crests well-sorted, winnowed, fine material (Mothersill 1970). The opposite was found on the Ruamahanga delta where the troughs are finer than the crests. The troughs were made up of bimodal deposits, sands similar to those on the bar crests, and muds similar to those in the central basin.

The bimodal material probably represents two discrete depositional facies. The shallowness of Lake Wairarapa and the muds blanketing much of the bed leads to the resuspension of fine sediments during windy conditions. As a result the lake waters are extremely turbid and visibility rarely exceeds 15 cm. During calmer periods these muds are redeposited and concentrated in the troughs in a similar manner to that in which algal detritus accumulates in the troughs on open coast bar systems (Zenkovich 1967, p. 227; Nilsson 1972). A return to higher energy conditions would result either in resuspension of the muds in the troughs or burial under shore-normal shifting sands from the bar crests. Burial could preserve the mud horizon as a thin lens in the trough sands, as in Core L 540. Bimodal surficial sediments from the troughs probably reflect poor sampling technique, whereby the veneer of mud deposited during calm conditions has been sampled with the underlying sand deposited during periods of wave activity.

The recorded trend of higher mud concentrations in the more lakeward troughs during the calm periods may be a product of several processes. First, more mud would tend to settle out of the deeper water column over the more lakeward troughs; secondly, higher concentrations of mud might be expected in the water over the delta edge closest to the mud sources in the central basin, and, finally, the mud settling out in the deeper troughs may not be resuspended as readily as that in the shallower water closer inshore. This rather unusual pattern of sedimentation is unlikely to be found on higher energy open coasts or larger lake bar systems where zero wave energy conditions and high suspended mud concentrations are rare.

Most multiple bar systems are produced by waves breaking at different depths on the nearshore slope. On the Ruamahanga delta the bars have formed in response to prevailing onshore winds and waves from the northwest. The crests are extremely mobile with shore-normal shifts occurring in response to changing wave and lake level conditions. Although the inshore bars have formed in depths equivalent to those expected under breaking waves, the more lakeward crests are in depths well beyond the breakers;

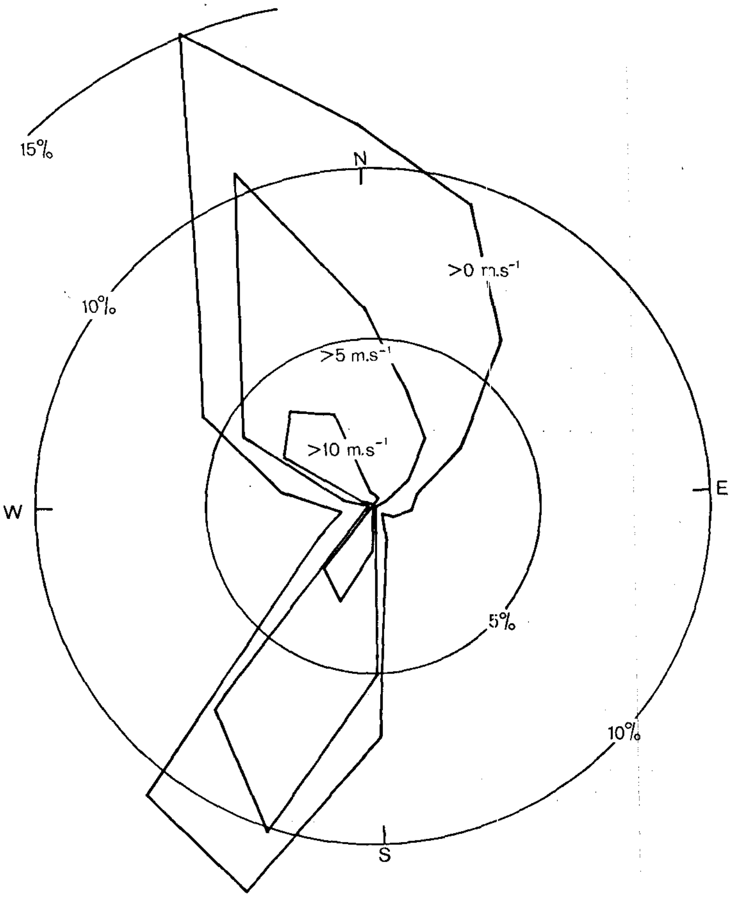

FIG. 8—Windrose of the frequency and speed of winds from different directions at the Barrage meteorological station, Ruamahanga River, 1973–75.

sediment movement and crest mobility on the outer bars is taking place under orbital wave motion before breaker collapse.

The sublimnic bars on the Ruamahanga delta, although similar to other oceanic and limnic bars, have unique morphological and sedimentological characteristics as a result of the peculiar characteristics of the lake. The shallowness of the lake, the muddiness of the bed, the very low gradients of the delta topset slope, and the intermittent periods of zero wave activity all modify the normal processes of bar formation. In the long term, the future stability of the delta and bar system is probably in doubt as sediment is no longer being supplied to the delta by the Ruamahanga River.

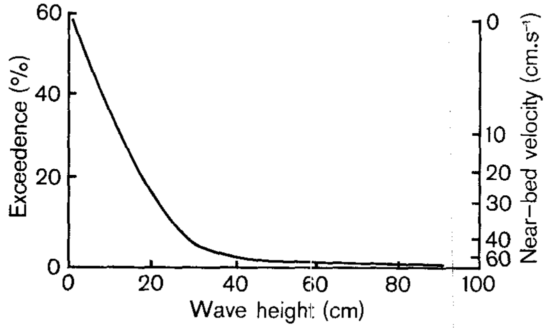

FIG. 9—Forecast wave heights on the Ruamahanga Delta for the station marked with a solid square in Fig. 2. Heights are plotted as percentage exceedence levels, along with calculated near bed orbital velocities for mean lake level.

ACKNOWLEDGMENTS

G. Hancock, M. K. Kwapisz, W. DeL. Main, R. C. Trevor and P. D. Wilson (NZOI) are thanked for their assistance in the field. J. S. Mitchell and R. C. Trevor (NZOI) analysed the sediment samples and B. J. Hunt made the shallow-water coring equipment. The assistance of the Wairarapa Catchment Board and N.Z. Meterological Service in making water level and anemometer records available is gratefully acknowledged. Drs L. Carter and K. B. Lewis (NZOI) made helpful comments on the manuscript.

LITERATURE CITED

BASCOM, W. N. 1953: Characteristics of natural beaches. Pp 163–80 *in* J. W. Johnson (ed.) Proceedings of the 4th Conference Coastal Engineering, Chicago, October 1953. 398 pp.

COTTON, C. A. 1958: "Geomorphology". Whitcombe and Tombes, 7th edition, Christchurch. 503 pp.

EVANS, O. F. 1940: The low and ball of the east shore of Lake Michigan. *Journal of Geology 48:* 476–511.

FOLK, R. L. 1968: "Petrology of Sedimentary Rocks". Hemphills, Austin, Texas. 170 pp.

GARNIER, R. J. "The Climate of New Zealand". Edward Arnold, London. 191 pp.

GOULD, H. R. 1970: The Mississippi delta complex. Pp. 3–30 *in* Morgan, J. P. (ed.) "Deltaic Sedimentation Modern and Ancient." Special Publication of the Society of Economic Paleontologists and Mineralogists 15.

GREENWOOD, B. & DAVIDSON-ARNOTT, R. G. D. 1975: Marine bars and nearshore sedimentary processes, Kouchibouguae Bay, New Brunswick. Pp. 125–50. *in* Hails, J. & Carr, A. (eds.) "Nearshore Sediment Dynamics and Sedimentation" Wiley, London. 316 pp.

IRWIN, J. 1975: Checklist of New Zealand lakes. *N.Z. Oceanographic Institute Memoir 74:* 161 pp.

IRWIN, J. 1978: Lake Wairarapa bathymetry 1:25 000 *N.Z. Oceanographic Institute, Lake Chart Series.*

JOHNSEN, R. 1961: Wechselbezienungen zwischen der Welle und dem strandrahen Unterwasserhang. *Veröffenthlichungen der Forschungsanstalt für Schiffahrt, Wasser- und Grundbau 9.* Not seen, in Norrman, J. O. 1964: *Geografiska Annaler 46 (1–2)*: 1–238.

KING, C. A. M. 1972. "Beaches and Coasts". Arnold, London. 570 pp.

KING, C. A. M. & WILLIAMS, W. W. 1949: The formation and movement of sand bars under wave action. *Geographical Journal 113:* 70–85.

KOMAR, P. D. 1976: "Beach Processes and Sedimentation". Prentice Hall, New Jersey. 426 pp.

KOMAR, P. D. & MILLER, M. C. 1975: Sediment threshold under oscillatory waves. Pp 756–75 *in* Proceedings of the 14th Conference Coastal Engineering, Copenhagen, June 1974. American Society of Civil Engineers, New York. 2647 pp.

MOTHERSILL, J. S. 1970: Relationship of grain size modes to nearshore sedimentary environments, Lake Superior, Ontario. *Canadian Journal of Earth Science 7:* 522–7.

NILSSON, H. D. 1972: Sand bars along low energy beaches Part 1. Multiple parallel sand bars of southeastern Cape Cod Bay. Pp. 99–113 *in* Coates, D. R. (ed.) "Coastal Geomorphology". Proceedings of the 3rd Annual Geomorphology Symposia Series, New York, 1972.

SHEPARD, F. P. 1950: Longshore bars and longshore troughs. *U.S. Army Corps of Engineers Beach Erosion Board Technical Memorandum 15.* 31 pp.

U.S. ARMY CORPS OF ENGINEERS 1962: Waves in inland reservoirs (Summary report on civil works investigation projects C.W. 164 and C.W. 165). *U.S. Army Corps of Engineers Beach Erosion Board Technical Memorandum 132.* 60 pp.

ZENKOVICH, V. P. 1967: "Processes of Coastal Development". Oliver & Boyd, London. 738 pp.

APPENDIX 1—Summary of textural properties of sediments from the Ruamahanga River delta. (– = no data.)

NZOI Stn	Graphic Mean (ϕ)	Inclusive Sorting (ϕ)	Inclusive Skewness	Sand %	Silt %	Clay %
SURFACE SAMPLES						
L 502	2.41	0.24	−0.24	100.00	0	0
L 503	–	–	–	–	–	–
L 504	2.74	0.31	0.05	99.90	0.09	0
L 505	2.61	0.38	0.07	100.00	0	0
L 506	2.60	0.28	0.26	99.95	0.05	0
L 507	2.67	0.31	0.19	99.87	0.13	0
L 508	2.59	0.27	0.26	99.91	0.01	0
L 509	2.67	0.31	0.22	98.54	1.03	0.43
L 510	3.66	1.54	0.72	76.14	20.15	3.71
L 511	2.46	0.27	−0.03	98.53	1.10	0.37
L 512	2.33	0.30	−0.24	99.94	0.06	0
L 513	5.37	2.51	−0.24	26.04	61.70	12.26
L 514	2.11	0.28	0.23	99.92	0.08	0
L 515	5.54	2.30	0.25	49.70	42.66	7.64
L 516	2.37	0.33	−0.14	99.97	0.03	0
L 517	3.77	1.98	0.75	62.31	32.64	5.05
L 518	2.29	0.34	−0.15	99.92	0.08	0
L 519	3.83	2.12	0.77	63.15	30.30	6.55
L 520	2.29	0.40	−0.98	99.94	0.06	0
L 521	2.35	0.40	−0.24	99.91	0.09	0
L 522	2.25	0.45	−0.21	99.93	0.07	0
L 523	6.42	1.30	0.40	1.20	85.92	12.88
L 524	6.15	1.33	0.35	1.04	87.95	11.01
L 525	1.87	0.39	−0.75	99.93	0.07	0.00
L 526	2.03	0.88	0.30	93.29	5.79	0.91
L 527	2.00	0.42	−0.01	99.97	0.03	0
L 528	1.94	0.46	−0.07	99.94	0.06	0
L 529	1.98	0.44	−0.00	99.99	0.01	0
L 530	2.03	0.45	−0.06	99.98	0.02	0
L 531	1.96	0.52	−0.14	99.97	0.03	0
L 532	1.97	0.51	−0.05	99.96	0.04	0
L 533	1.96	0.46	0.02	99.95	0.05	0
L 534	2.20	0.31	0.06	99.98	0.02	0
L 535	–	–	–	–	–	–
L 536	2.13	0.32	0.13	99.86	0.14	0
L 537	2.08	0.37	0.03	100.00	0	0
L 542	2.11	0.60	−0.19	99.94	0.06	0
L 543	2.36	0.69	0.12	97.38	2.62	0
L 544	2.18	0.49	−0.06	99.69	0.31	0
L 545	2.27	0.50	−0.12	99.54	0.46	0
L 456	1.81	0.52	0.04	99.22	0.78	0
L 457	3.93	1.64	2.92	78.64	8.82	12.53
L 458	2.10	0.31	−0.18	98.68	1.37	0
L 459	1.86	0.53	0.02	98.32	1.68	0
L 460	4.95	1.53	1.97	68.30	19.40	12.31
L 461	2.16	0.29	−0.14	98.57	1.43	0
CORES						
L 541 (1)	2.12	0.48	−0.320	100.00	0	0
(2)	3.27	0.80	0.61	64.90	29.34	5.75
(3)	2.39	0.31	−0.12	99.02	0.98	0.00
(4)	3.87	0.81	0.46	78.65	20.23	1.11
(5)	4.67	1.12	0.50	6.32	83.35	10.33
L 539 (1)	4.99	0.67	0.04	4.18	95.82	0.00
L 540 (1)	2.48	0.02	0.02	99.29	0.71	0
L 540 (2)	3.20	0.54	0.24	91.83	8.17	0