LONG MAC GROYNE, OTAGO HARBOUR

The History of Development and its function Past, Present and Future

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Prepared for

Port Otago Limited

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1.0 Introduction

Port Otago Limited, as a condition of its development dredging consents, is required to investigate the background and functionality of the Long Mac groyne.

ORC 2010.193, condition 22A states,

> "Prior to any incremental or capital dredging within 200 metres of the Long Mac groyne commencing, the consent holder shall undertake research into the coastal processes and the function of Long Mac as it was immediately after its construction and as it is now. If the research indicates that Long Mac has been or is working to provide protection to either the spit tip, Aramoana Ecological Area or maintain alignment of the harbour channel, then the consent holder shall apply for any necessary approvals and, if granted, undertake work necessary for the Long Mac to continue in this function without compromise to its structural integrity with a deepened channel."

Little or no development dredging or incremental increases in depth will be required directly adjacent to the Long Mac groyne over much of its length, with depths reflecting the presence of a large, naturally occurring scour hole between the groyne and across the channel to Harington Point, refer Figure 1.1 for locations. Dredging will be required in the channel seaward of the northern tip of the groyne.

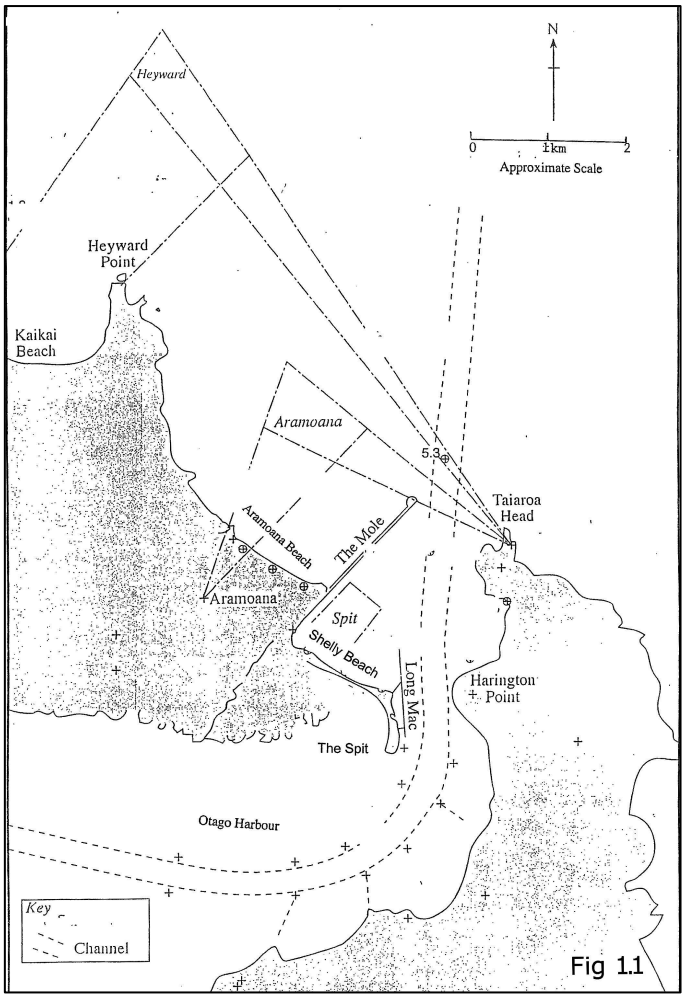

Figure 1.1 – Plan (annotated) showing sites referred to in text.

The location of the scour hole relative to the Long Mac is shown in Figure 1.2, POL drawing 11371 / 2, "Soundings: Howlett Point 20/11/12".

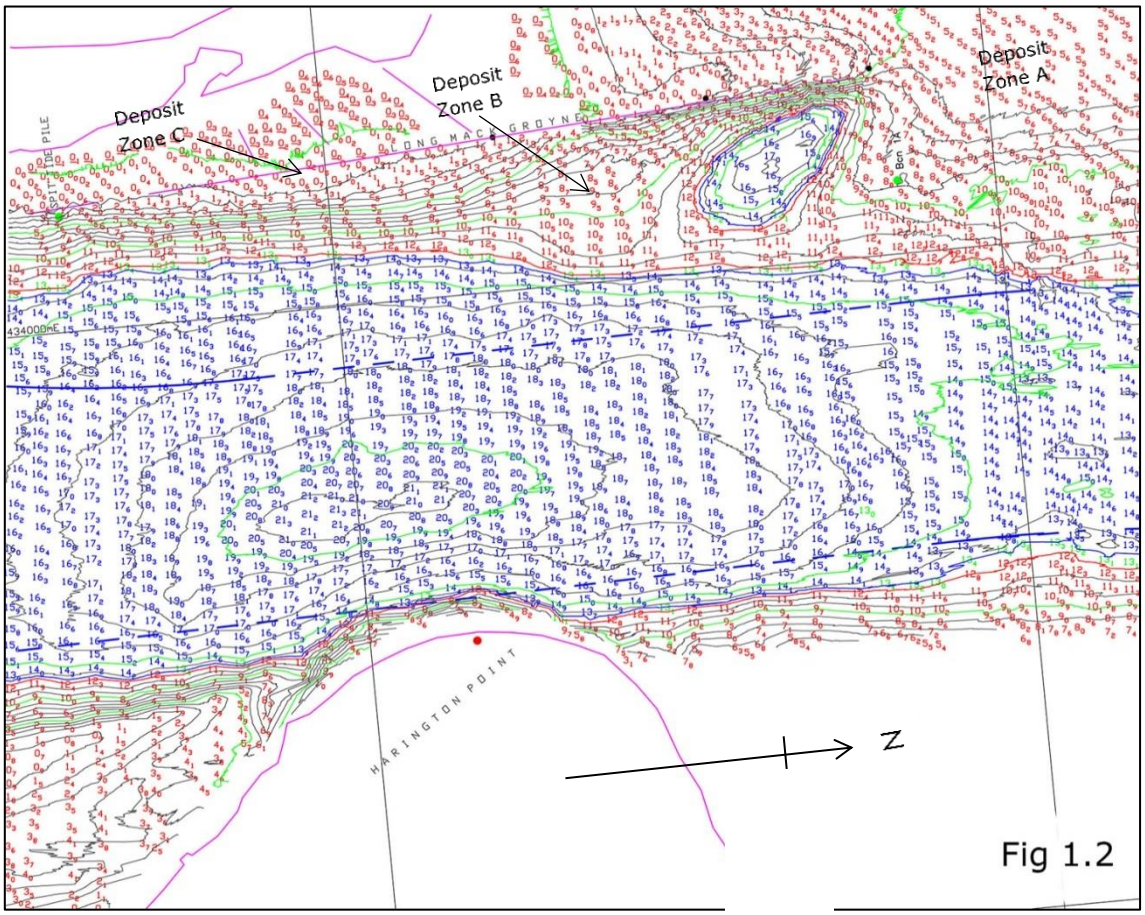

Figure 1.2 – POL Drawing 11371/2, "Soundings Howlett Point 20/11/12"

This scour hole is evident in repeated soundings and has been referred to in studies of sediment transport pathways undertaken by Kirk (1980), Single and Kirk (1994) and Bunting, Single and Kirk (2002). Kirk (1980) described this area as;

> "a turbulent throat section opposite Harington Point . . . and) . . indicate a deposit which is deficient in readily transportable grains and may be areas through which there is rapid sediment transport by waves and currents, or where current velocities are sufficiently high to prevent deposition of readily transportable grains."

2.0 History: Harbour Entrance Development

As far back as 1826, a chart showing the entrance to Otago harbour or "Port Oxley," prepared by Captain Herd, captain of the ship Rosanna, noted the presence of Spit Beach, fringed along its inner harbour edge by a ridge of sand hills which are in turn backed by what is referred to on the chart as a "cockle bank dry at low water", now more commonly identified as the Aramoana Ecological Area. It should be noted that the Spit Beach referred to at that time extended as a continuous beach from the northern headland to the entrance of the harbour inlet. Also evident on the chart is a discrete

mound located to the west of Harington Point on the Aramoana side of the entrance channel, which appears to coincide with the position of the south eastern end of Shelly Beach. Refer Figure 1.3, Herd's Chart of Otago 1826.

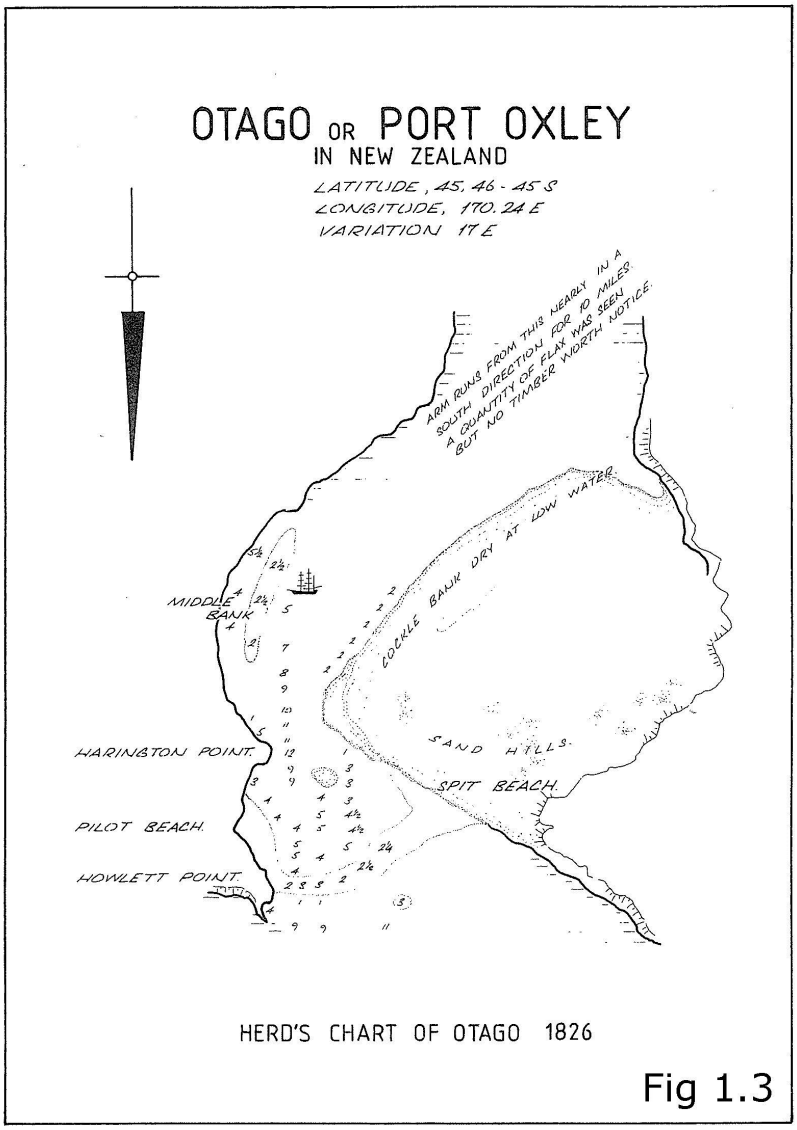

Figure 1.3 – Herd's Chart of Otago 1826

The then Spit beach and the intertidal sand flat are more clearly shown in subsequent soundings by Captain Stokes of the HMS Acheron, dated 1850. This chart, refer Figure 1.4, also clearly shows the extensive sand bank or bar extending in a north westerly direction from Taiaroa Head across the harbour entrance. This bar not only controlled the north westerly orientation of the deeper northern shipping channel, but also reportedly brought sailing vessels dangerously close in to the proximity of the lee shore. For that reason a "south channel" across the bar was alternatively used for navigation. Shoal formations were also present once inside the harbour entrance.

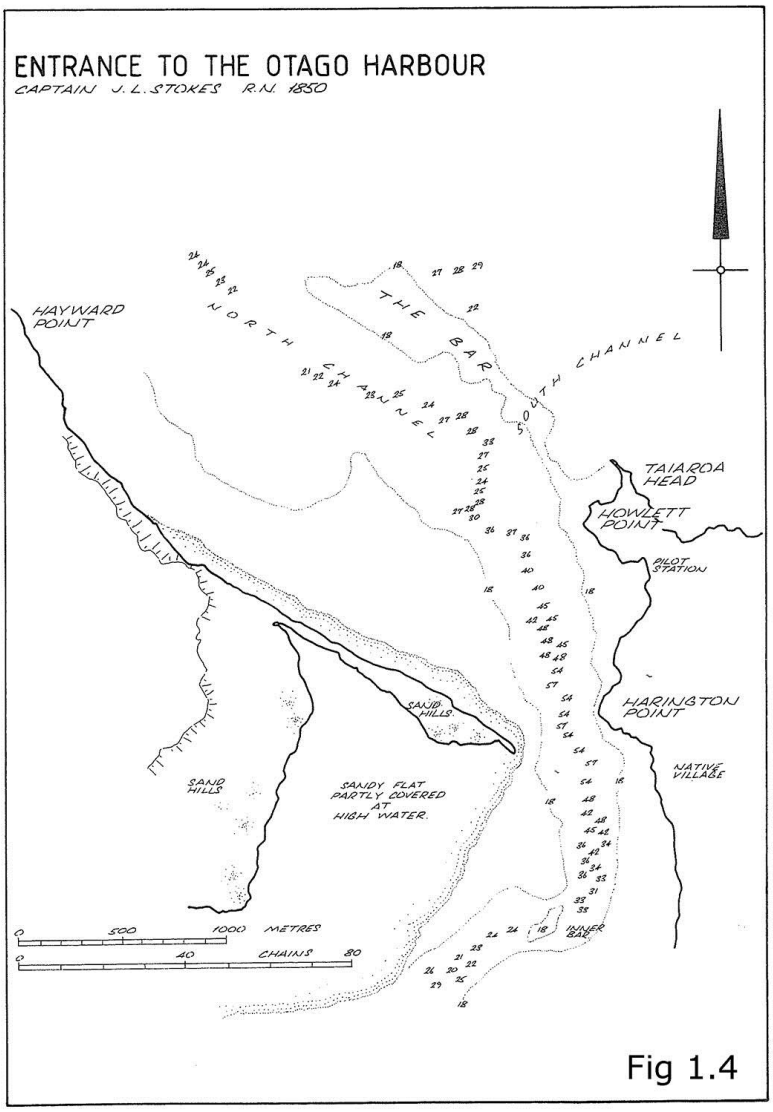

Figure 1.4 – Entrance to Otago Harbour, Captain J L Stokes RN 1850

Over the next three decades the harbour entrance, the area once inside the harbour and the coastal nearshore continued to change, formations migrating in response to seasonal weather patterns; tidal fluctuations; net sediment inflow; changes in the coastal northward drift of sediment through changing land use patterns; and the modification of the harbour tidal compartment with the development at Port Chalmers and Dunedin. The outer sand bank continued to grow, as did the Spit Beach directly across from Harington Point, toward the channel. Inflows and redistribution of sediment resulted in shoaling, limiting the size of vessels able to call, at times blocking or otherwise restricting the navigable waterways. Numerous reports exist of, "vessels striking the bar" (McLintock 1951).

3.0 Harbour Entrance Improvements

During this time the Otago Harbour Board endeavoured to deliver improvements to the entrance by means of dredging. Engineer to the Board G.M Barr reported that dredging alone was unlikely to deliver or maintain depths required to attract the larger merchant vessels being used at the time. For desirable depths to be secured, Barr noted, "something of a more permanent character than dredging was necessary." (McLintock 1951)

Toward the end of 1879 the Otago Harbour Board invited a marine engineer, Sir John Coode, to investigate alternatives for developing a more stable entrance as well as reporting on options for the development of both the upper and lower harbour channels. Figure 1.5 below shows Coode's proposal.

Coode formed a view that;

> "the only effectual and permanent method of treating the Bar lies in the construction of the two Breakwater moles so devised as to train and concentrate the tidal currents flowing into and ebbing out from the Estuary and thus to bring them to bear upon the Bar in the manner and direction best suited to create and maintain a sufficient navigable depth for vessels of the largest class to enter and leave in all weathers."

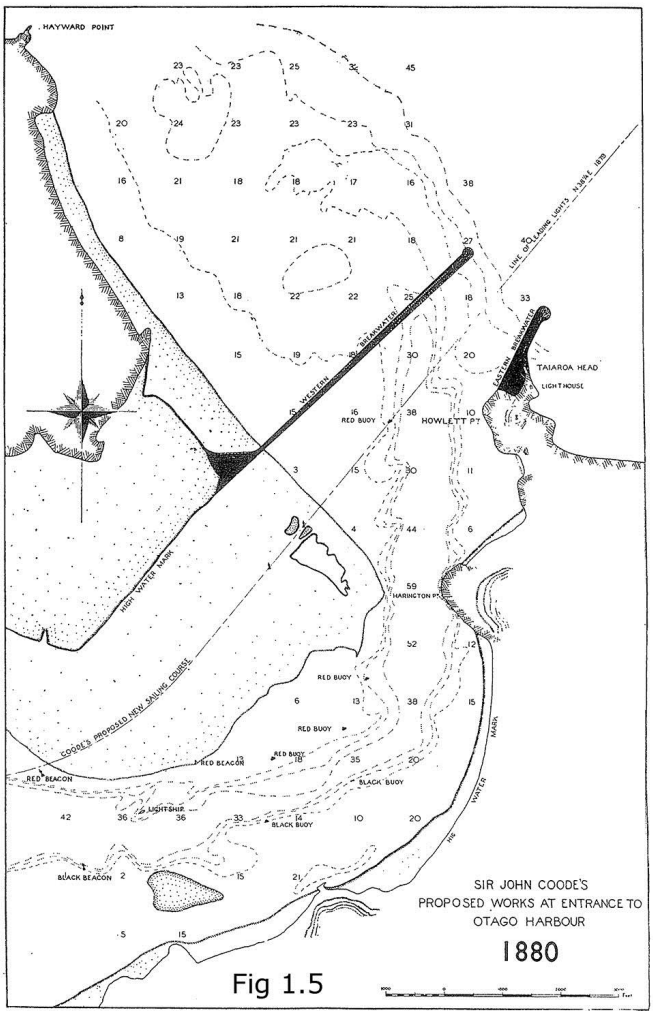

Figure 1.2 – Sir John Coode's proposal for works at the entrance to Otago Harbour 1880

The western most mole would be constructed across the Spit Beach commencing at the high water mark line around the northern headland, heading in a north easterly direction across to the outer sand bank, a distance of 6,200 feet (1890 metres). On the eastern side a shorter mole would extend 1700 feet (520 Metres) seaward of Taiaroa Head. As well as relying on the tidal currents to control the opening through the mobile outer bar, the configuration was intended to create a more direct north easterly alignment of the navigable channel, relocating the channel inside the entrance more to the west. The resultant scour effect was intended to remove the south eastern end of Spit Beach, (the area now referred to as Shelly Beach and "The Spit") and, the Tidal Flats (Aramoana Ecological Area) located directly behind the beach, in the process.

As well, the western mole was intended to prevent the recirculation of the coastal northward moving sediment from entering the harbour as a result of an anticlockwise gyre. This material, once deposited on the beach was transported in a south easterly direction along Spit Beach, the formation of which was migrating toward the channel and also causing a build-up of sediment into the channel along the inner edge of Harington Bend.

Work on a modified concept involving the construction of a single western mole was undertaken from 1884 through to 1888. This mole was only partially formed with a length of 5,000 feet, (engineer to the Otago Harbour Board, J. Blair Mason reported the mole as extending 4100ft from the sand-flat) the first 660 feet above high water, with the remaining section progressively stepping down to 4 feet below low water.

This partial formation had the effect of altering the previously intended alignment of the channel to true north, while maintaining the position of Harington Bend more toward the east and causing increased scour of the south eastern tip of what is now Shelly Beach. Deposition within the channel caused the ebb and flood tidal current streams to became separated and further shoaling of the navigable channel occurred along and toward the outer edge of Harington Bend. Importantly no scour channel formed across Shelly Beach. The split tidal stream was subsequently addressed with the construction of a rock training wall and a number of groynes along the eastern side of the channel between Harington Point and the Kaik, developed between 1903 and 1910.

The outer sand bank or newly forming entrance bar, extending from Taiaroa Head to the north along the eastern side of the new channel continued to grow forcing the navigable channel further to the west. Lack of maintenance caused the western mole to deteriorate until work commenced on reinstating and raising the structure above high water mark in 1925 out to a distance of 4080 feet.

This had the effect of directing a larger part of the tidal flood flow along the alignment of the mole normal to Shelly Beach, to result in a south easterly flow direction along the beach.

The increased height of the mole further improved the harbour entrance and by 1941 tidal scour had formed a channel straight out from the entrance through the offshore bar. Planning to raise the mole to its full height and, over its entire length was undertaken during 1941. (McLintock 1951). This work commenced in 1950.

Engineer to the Otago Harbour Board, Blair Mason, had reported in 1905 that prior to the construction of the mole during calmer weather, sand worked its way onto and along Spit Beach south eastward toward the channel, as a result of wave action and

> "became heaped up and accumulated at the narrows, remaining there until acted upon by an unusually high tide or high sea".

On those occasions, this material was rapidly reworked across the sand flats and into the harbour channel.

4.0 Long Mac development

Blair Mason noted that the alongshore sediment movement patterns remained the same. Prior to the construction of the mole this material was deposited from seaward onto Spit Beach as a result of an anticlockwise gyre that existed within the wider embayment (Blueskin Bay). Post mole construction the sediments being moved toward the harbour channel appeared to be derived more as the result of erosion of the Shelly Beach foreshore. Blair Mason reported;

> "sand hills that occupied the foreshore in 1882 have now largely disappeared and the position of high and low water marks of that date are now covered as much as 7 feet and 15 feet at high tide respectively"

As an addendum to his report of 1905, is an extract from a report by engineer C. Napier Bell dated April 1898, who noted;

> "From the base of the mole to near the jetty of the quarry railway the beach is wasting away; the waves, which often break heavily on this beach, stir up the sand which is then carried by the flood tide into the harbour and deposited on the north spit, thus furnishing a large part of the supply of sand which causes the troublesome growth of that spit.
>
> This disturbance is slow and may be left alone for a while; but the time will come when it must be attended to, and the plan herewith shows a training wall which would entirely stop the injurious circulation of sand, and at the same time help to direct the tidal currents in a proper course".

The training wall proposed, refer Figure 1.6, is the structure now referred to as the Long Mac, and the troublesome growth of the spit referred to was considered to be caused not only by the south eastward migration of sediment along Shelly Beach forcing the channel toward Harington Point, but also by the splitting of the ebb and flood tidal streams, separated by what was identified as the "Middle Bank", refer Figure 1.7.

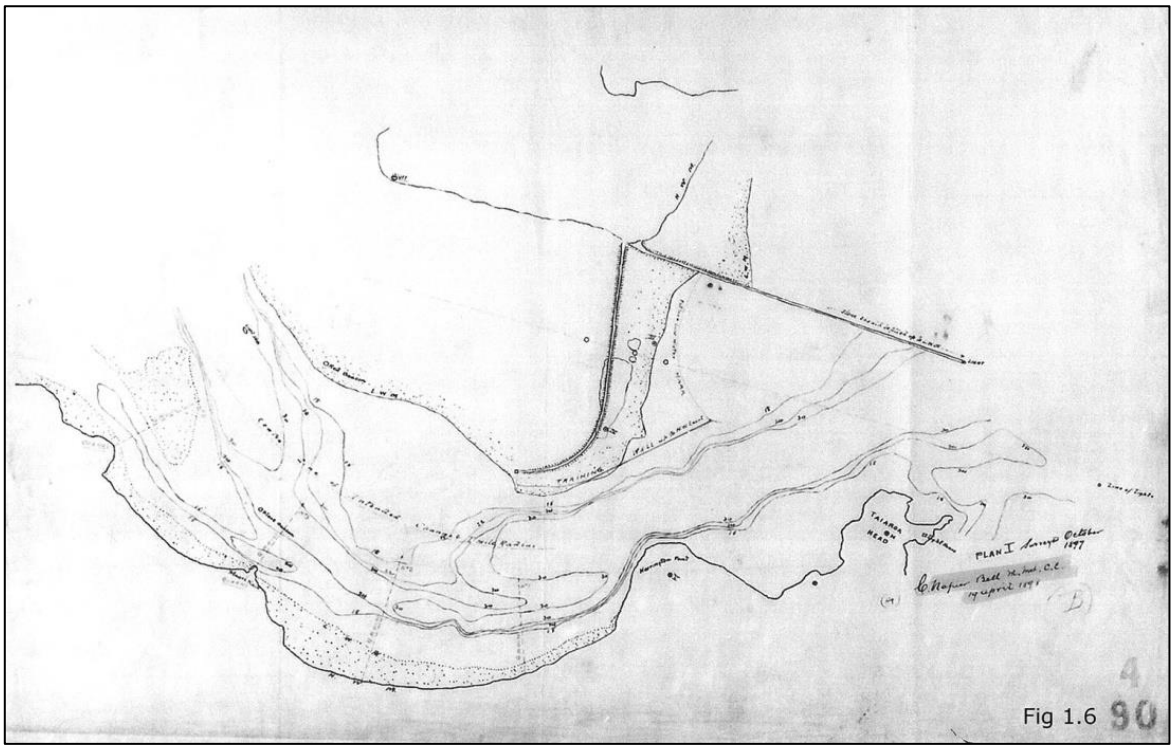

Figure 1.6 – Plan by C Napier Bell dated 19 April 1898, showing the proposed training wall

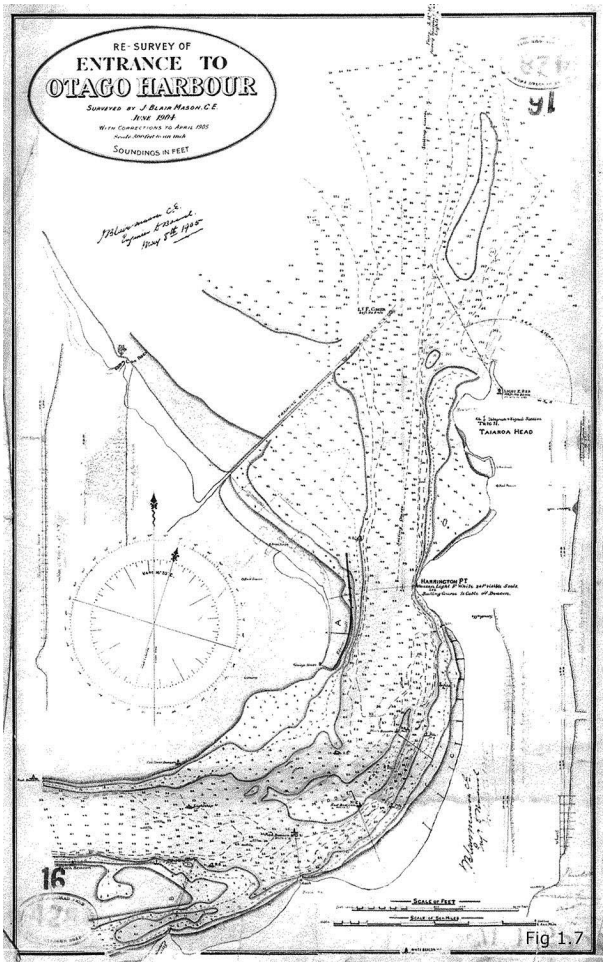

Figure 1.7 – Re-survey of the Entrance to Otago Harbour, surveyed by J Blair Mason CE, June 1904, with corrections to April 1905

Both appear to have been addressed between the period from 1905 to 1910 through the combined effect of the rock training wall and a number of groynes extending as far out as the line of the proposed channel between Harington Point and the Kaik referred to previously, and the construction of the Long Mac as largely proposed by Napier Bell.

It was later reported by McG. Wilkie, consulting engineer to the Otago Harbour Board in May 1947 that,

> "in order to protect the Eastern end of the Spit Beach (read Shelly Beach) from erosion, authority was obtained from the Marine Department in 1905 to build a rubble retaining wall from the Spit Jetty northward for a distance of 2000 feet (610 metres) and also to construct screens or groynes on Spit beach ("The Spit") itself."

The screens or groynes referred to, while not discussed by Napier Bell or shown on the drawing accompanying his report, are in part referred to in a sounding chart of the entrance to the harbour, surveyed by Blair Mason in 1904, with corrections to April 1905, refer Figures 1.7, and 1.8 . There the proposed cross section of "The Spit " at location A, shows the beach face extending out to the Long Mac with a " timber or wire " sand trapping fence back to the row of dunes. It is believed this fence was replaced at the time of construction with a series of rubble groynes. The largest of these extended from the toe of the dunes at the south eastern most end of Shelly Beach in a north easterly direction, to intersect with the Long Mac at an angle of some 45 degrees. Figure 1.9, shows the effect of the northern most rubble groyne, resulting in what appears to be a localised build-up of sediment against the upstream side, as well as the remnants of at least two other structures further along "The Spit" to the south.

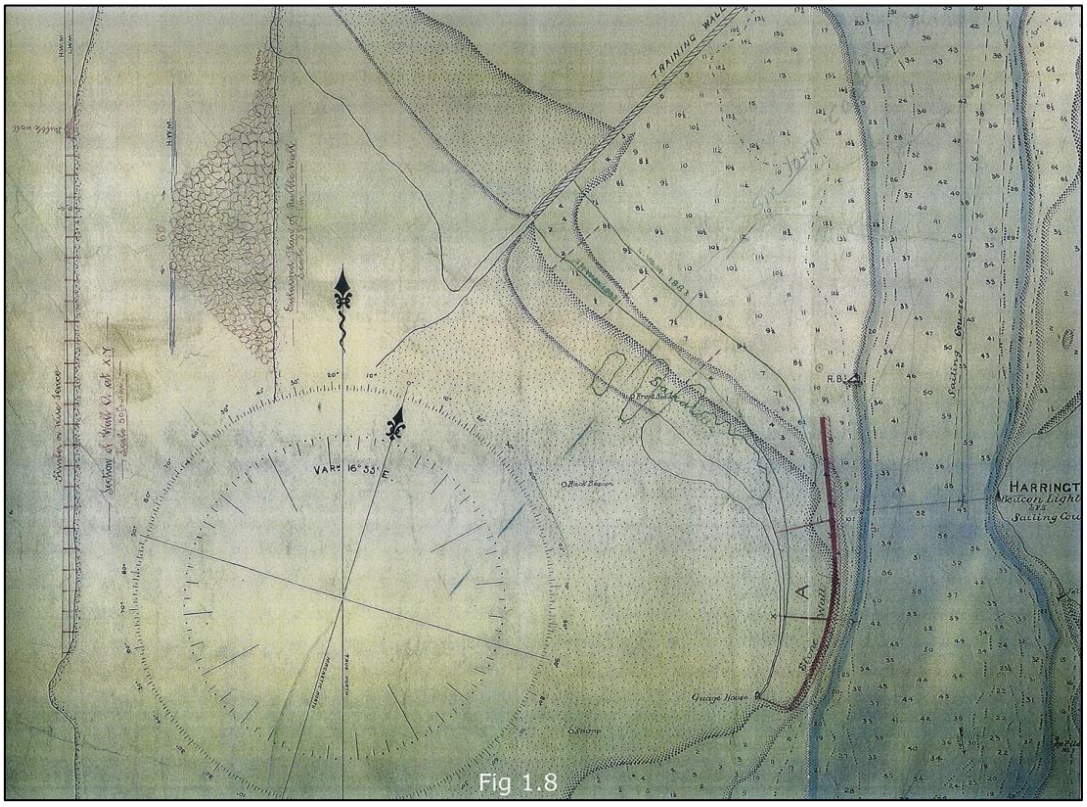

Figure 1.8 – Extract of J Blair Mason survey June 1904

Figure 1.9 – Aerial photograph showing the Long Mac, together with several of the remnant secondary groynes

In a paper presented to the Otago Institute, Technological Branch, (entitled "Sand Movements in Otago harbour") Blair Mason reported that;

> "a rubble wall was constructed along the spit . . . Groynes were run at intervals from the shore at high water mark out to this wall. The most northerly of these groynes effectively arrested and accumulated most of the wave – borne sand. When the accumulated sands rose above the level of high water, sand catching fences were constructed of a sufficient height to raise the level about 6ft above high water mark. Marram grass (Arundo arenaria) was then planted to fix the sand, followed by the Californian Lupin. These now grow luxuriantly where a few years ago the water ran 10ft deep. The foreshore is now continually being made up and extended, and in the process of time all that was lost in land by the effect of the mole will be regained. The quantity of wind-borne drift now entering the harbour is small. Sand brought in by the flood must do so at a depth between the rocky buttress of Harington Point on the one hand and the stone wall (which has 12ft of water alongside) on the other, where it is subject to the greater scouring effect of the ebb current. One may, therefore confidently expect that the sands about the channel near Harington Point will decrease in quantity to a minimum."

The most northerly structure remains evident today, refer Figure 1.9, and appears to have been constructed to a similar height as the Long Mac. The figure clearly shows the build-up of sediment that has occurred on the upstream, or Shelly Beach side of this secondary groyne. Several, largely sand covered rubble mounds are also evident further along "The Spit" toward the jetty.

It was noted by Wilkie that together with the mole and the beach, the formation of the Long Mac rubble wall had the effect of creating a partial enclosure during certain stages of both the flood and ebb tides, creating a pond of "dead "water. At other times the tidal flood flows resulted in strong currents across the rubble wall. A build-up of sand on the beach and a dune formation was attributed to the development of the western mole together with the rubble wall, (Long Mac) further reinforced by the installation of a railway embankment along the sand flat at the rear of the dune to the Spit Jetty, formed during the construction of the western mole. This railway line is shown on the drawing accompanying the report by Napier Bell in 1898, refer Figure 1.6.

Evidence also exists of a roadway formed to service several houses located toward the south eastern end of Shelly Beach. These houses were constructed in 1913 by the Otago Harbour Board and were used to accommodate Pilot staff until 1923 when staff were relocated to Port Chalmers, with the houses subsequently sold. The roadway buried as a result of sand migration, lies beneath the single row of dunes along Shelly Beach, but has in several locations been exposed more recently as a result of erosion.

Strong currents continue to be observed to this day, running from west to east and then across the Long Mac groyne particularly during the flood tide, with weaker currents also noted at times during tidal ebbing. Anecdotal reports suggest this is accompanied by a localised increase in water level against the western side of the groyne, compared to that on the eastern, channel side.

The construction of the Long Mac and the associated groynes was completed in 1906. In 1917 Otago Harbour Board resident engineer, Wilkie, in a report to the Board, acknowledged the beneficial effects of the Long Mac on the adjacent channel depth and its contribution to the formation of Shelly Beach, particularly toward the south eastern end. He also noted that an adequate supply of sand was no longer available to enable the build-up of the foreshore to continue, and erosion was taking place at the inner end of the mole on the eastern side, where it intersects with the beach face. The report recommended that the Long Mac be raised to above high water mark to prevent, "sand from washing over or through the wall into the channel", and that the wall be extended by a further 400 feet. There is no evidence to suggest this extension took place. However Bunting, Single and Kirk (2003) report that in 1910 – 1912, 1929 – 1935, and again during 1945 – 1946 the height of the Long Mac was raised above high tide level.

It was during December 1992 through to August 1993, that Port Otago Limited undertook repairs to a breach in the wall at the same time as raising the seaward end of the Long Mac to above low water mark. Rock obtained from berth deepening at both Dunedin and Port Chalmers was placed using split hopper barges. A total of 9135 cubic metres (in situ volume) was deposited along the wall.

The information presented above would suggest the wall does continue to settle with time.

5.0 More recent investigations

The changeable fortunes of the condition of Shelly Beach and "The Spit" have resulted in a number of studies being undertaken over the years, more particularly since the late 1970's. This has involved tracing the historical development of the area and also determining the complex interaction between and, the significance of, the natural and man-made features. This interaction is reflected in the erosional / depositional changes particularly along Shelly Beach and the single line of dunes.

How the health of the beach is affected by the presence of the mole; the Long Mac groyne and its associated rubble walls; dredging activities in the immediate vicinity; and the possibility of using dredged sand to nourish the natural sand supply to Shelly Beach has also been considered. Major storm events, notably in mid-1986 as well as 1992 caused significant damage to the dune system and resulted in localised breaching through the single row of dunes. Remedial works were undertaken, thereby also reducing the likelihood of damage to the Aramoana Ecological Area. In any event, this is discussed in more detail in a report prepared by N. Johnstone, Investigations Engineer - Otago Regional Council in 1997, "Consequences of Breaching of the Aramoana Spit Sand Dunes."

Johnstone concludes that,

> ". . . while the Long Mac training wall is effective in intercepting sand and building up the beach locally, it has negligible impact along most of the length of the spit (read Shelly Beach):. This is a view shared by Single and Stephenson (1998)."

Johnstone discusses a number of options to encourage growth of the dune system. Amongst those is an upgrade of the Long Mac groyne, but cautions that this could have detrimental effects, increasing wave energy in some areas and reducing the supply of sand to others. Other options include increasing the disposal of suitable sized dredging material and a continuation of sand fencing and planting.

Single and Stephenson undertook a study for Port Otago Limited in 1998, drawing together much of the available information in their report "Spit Beach 1998, South Spit Beach Assessment of erosion mitigation"

In that it is reported that;

> ". . . South Spit Beach (Shelly Beach and "The Spit") is a dynamic changing coastal environment, that appears to respond rapidly to changes in the processes and sediment availability. On at least five occasions in the last twenty three years, the beach has been in a depleted and eroded state."

Accretion has taken place between those periods as well. Single and Stephenson note,

> "The seaward limit of the dunes in 1987 appears to be close to where it is in 1998, while the size and shape of the spit, and the seaward limit of the dunes near its eastern end are similar in 1987 to the 1924 photograph."

The report attributes the more recent and noticeable infilling of the Shelly Beach foreshore within what is an effective embayment created between the Mole, and Long Mac as being the likely effect of the disposal of dredge spoil by Port Otago Limited.

The effect of dredge spoil disposal is discussed in more detail in a report by Single and Kirk (1994), "Impact of Dredge Spoil Discharge at the Entrance to Otago Harbour – Sand Transport processes." The report refers to observations by Armstrong (1978) that between 1941 and 1976 the Shelly Beach nearshore bathymetry displayed progressive deepening, accompanied by erosion of Shelly Beach and it was not until 1975 that some reversal of the erosional trend became evident.

The report concludes at the time of writing that,

> "Sediment discharged at South Spit (read Shelly Beach) has become dispersed towards the beach and across the nearshore seabed, contributing over 150,000 m^3, or 80% of the total sediment discharge at the site, to accretion of a previously eroding coastal environment. Significantly, very little of this material is moving east, back into the channel."

Spoil has been placed at the Shelly Beach site intermittently since 1986, primarily to facilitate the re-nourishment of the beach with the added benefit of reducing dredge turnaround times, thereby reducing cost to Port Otago Limited of the dredging operation.

The shoreline known as "The Spit" in particular, is currently experiencing erosion more so toward the southern end, which tends to coincide with a section of shoreline beyond any potential offshore sheltering effect due to the Long Mac from wind and localised wave conditions from the south and the southeast.

In a report to the Otago Harbour Board Kirk, (1980), "Sand Transport Processes at the Entrance to Otago Harbour," it is noted

> "that with the construction of the mole the tidal currents have forced the spit tip to 'recurve' into the harbour. Its location adjacent to the shipping channel, the scouring action due to the strong tidal currents and exposure to less attenuated southerly wave action will continue to result in ongoing alteration to the beach."

The 1994 Single and Kirk report was subsequently updated in 2003, by Bunting, Single and Kirk, "Effects of the Disposal of Dredge Spoil at Shelly Beach, Otago harbour."

The findings of this later study are that since the commissioning of the Shelly Beach disposal site in 1987 until 1998, some 371,000m^3 of sediment has been deposited, with 20% or 77,000m^3 accumulating in the nearshore. The report assumes that the balance of the material has either worked its way onshore to re-nourish the beach, reflected in a build-up of the upper foreshore and dunes, with some moving offshore from where it has the potential to re-enter the harbour.

However there was no noticeable increase in channel dredging required in the immediate area between 1978 and 2002. This finding is supported in 2005 by Javier Leon, "Coastal Evolution of Shelly Beach, Otago Harbour", in which the cumulative dredge demand volumes from the Entrance Channel and Howlett Point are plotted from 1975 to 2004. This report does however go on to suggest a link may exist between the dredged

sediment deposited at Shelly Beach and an increase in dredging demand at Harington Bend. No further explanation for this conclusion was provided.

The Bunting, Single, Kirk (2003) report also notes the predominant direction of sediment transport is alongshore other than closer into the beach where offshore / onshore sediment movement prevails, reflecting ongoing short term processes. While there was no evidence to suggest sediment was being carried across the Long Mac into the harbour channel at the time, the study does suggest that some of it moves offshore to be deposited on the ebb tide delta situated northwest from the mole, from where it can continue northward or find its way into the harbour subject to the state of the tide.

The report concludes that;

> "the spoil continues to move onshore to be deposited in the lee of the Mole and redistributes along Shelly Beach to form a secondary sink where Shelly beach abuts Long Mac . . . continues to effectively provide re-nourishment to the shore."

6.0 Existing State of the Long Mac

While there is not a large amount of information that remains available as to the construction details for the Long Mac groyne, its general location and alignment are shown on the drawing accompanying the Napier Bell report, refer Figure 1.6. These are also referred to in a sounding chart of the entrance to the harbour, surveyed by Blair Mason in 1904, with corrections to April 1905, refer Figure 1.8. There, referred to as the "Section of Wall at XY " the drawing shows "The Spit " at location A, and the beach face (in long section) extending out to a typical cross section of the Long Mac (referred to in the drawing as a Rubble Wall). A more detailed cross section of the Long Mac is shown directly beneath this diagram (entitled "Enlarged Plan of Rubble Wall") and shows a trapezoidal mounded rubble structure formed at the eastern extent of a low gradient nearshore, at the point where the seabed starts to dip more steeply toward the harbour channel. The drawing shows the crest of the rubble wall extending up to high water mark (HWM). The wall contains a rubble apron located on the channel side, presumably to provide protection against undermining through scour. In his paper to the "Otago Institute, Technological Branch", Blair Mason reported the Long Mac as having 12 feet of water alongside**.**

Recent surveys have been undertaken by Port Otago Limited both along and across the Long Mac toward the end of 2012. Soundings have been plotted, together with the resultant seabed contours relative to the Long Mac and " The Spit" and are presented in Figure 1.2.

The sand bed on the Shelly Beach (western) side of the Long Mac has built up to a level similar to that of the top of the groyne over much of its shoreward length, thereby limiting its ability to provide an effective barrier to sediment bypassing across the Long Mac to enter the harbour channel. Areas of deposition along the eastern (harbour) side of the Long Mac are evident in at least two locations where overtopping has taken place.

The contours indicate it is not until further northward along the Long Mac, seaward of the Shelly Beach intertidal zone, where the seabed level drops below the top of the groyne, that a localised build-up of sediment appears along the western side directly adjacent to and extending for some 200 metres beyond the outer end of the structure.

Seaward of this tongue of sediment the contours indicate that as well as material moving northward toward the harbour entrance, it also spills around the end of the groyne in an easterly direction toward the harbour channel. This feature is noted on Fig 1.2 as Deposit Zone A.

The sediment distribution patterns appear to reflect the presence of the anticlockwise gyre referred to in much of the literature, where the currents flowing in a south easterly direction along Shelly Beach eventually impinge on the groyne where it rises above the general seabed level. From there, sediments are re-directed northward along the groyne until reaching the end of the structure, where the flow then dissipates northward as well as in an easterly direction.

The location and shape of the depositional features suggest three prevailing sediment transport pathways exist in the immediate vicinity of the Long Mac at present. The most significant of these is the one located at the western outer end of the groyne as discussed previously.

On the eastern side of the groyne a delta has formed, extending in an easterly direction towards the harbour channel. The location of this delta coincides with the more active intertidal zone along Shelly Beach and its shape suggests sediment is carried across the Long Mac, particularly during the higher stages of the tide, supported by the anecdotal reports of strong current flows also referred to previously. This feature is noted on Fig 1.2 as Deposit Zone B.

The third such feature, also on the eastern side of the Long Mac, is located just south of the south eastern corner of Shelly Beach, within the vicinity of several secondary groynes. This suggests a residual flow splits from the anticlockwise gyre found along Shelly Beach, to move southward. This flow direction is supported by a build-up of sediment found on the up-drift side of the northern most secondary groyne, refer Figure 1.7. From there the sediment appears to move in an easterly direction across the Long Mac to form the delta like deposit of sediment on the harbour channel side. This feature is noted on Fig 1.2 as Deposit Zone C.

7.0 Proposed Alterations to the Long Mac

In reviewing the effect of the disposal of dredged material on Shelly Beach, Single and Stephenson (1998) noted, perhaps due to a change in conditions since the earlier 1994 reports and through the effect of an accumulation of dredge spoil, the possibility of, "increased passage of sediment into the harbour channel". They further suggest that maintenance of the Long Mac be considered to prevent this from occurring. As part of considering the ongoing disposal of sediment and the potential to increase the average annual volume discharged from 22,000 cubic metres per year to the consented 50,000 cubic metres, it was suggested that further investigations be carried out,

> "to accurately quantify the long term process and sediment dynamics of the spit area, so that predictions can be made of the long term stability of the South Spit beach, and the effects of raising the Long Mac wall".

Johnstone (1997) had also considered an upgrade of the Long Mac training wall noting;

> "This would be likely to have local benefit in terms of sand retention and reduced wave attack on the spit immediately westward of the training wall. There could however also be detrimental impacts to the east of the training wall if the overall height were increased. In this event possibly increased refracted wave energies and certainly reduced sand supply could result in increased instability on those sections of the spit most adjacent to the harbour channel."

Single and Stephenson (1998) support this view and go further to say that a higher wall would redirect currents such that increased scouring of the sediments may be possible near the wall during ebb and flood tides.

The evidence of the latest soundings suggest that over time the Long Mac as it is currently configured, has become less than effective in supporting the disposal of dredged material at the Shelly Beach site, resulting in sediment finding its way back into the channel. Given the nature of the observed sediment transport pathways and the variability of the currents, it is unlikely that this will be mitigated simply by increasing the height of the Long Mac in isolation. Dune management in conjunction with re-nourishment for example will both be necessary to ensure retention of sand on the dunes, beach and nearshore. Furthermore the concerns raised in relation to increasing the height of the groyne are likely to be realised, requiring further consideration of the potentially negative effects.

8.0 Effects of Raising the Long Mac

If areas of Shelly Beach and "The Spit" are to be in some way stabilised and Port Otago Limited is to retain the ability to dispose of at least some of its dredged material, an assessment of the effect of raising the Long Mac is necessary. Work to date has shown that without providing a more effective barrier such as might be created by the raising of the Long Mac, the materials deposited in the Shelly Beach disposal site will simply be recirculated to little effect back into the harbour channel, particularly as some erosion of Shelly Beach is already evident.

Given the concerns raised in earlier reports, and to better understand the existing environment and potential effects of any modification to the Long Mac, Port Otago Limited has commissioned several studies to establish the likely effects of raising the groyne. The findings of two bodies of work associated with wave and current modelling as well as an assessment of the geomorphological processes are summarised in the following sections.

9.0 Wave and Current modelling

The first of the studies undertaken involves determining the hydrodynamic / oceanographic effects within the vicinity of the Long Mac groyne and how these translate into the behaviour and distribution of sediments. A mathematical model was developed which was able to be calibrated and, the outputs subsequently verified using the considerable amount of information that already exists within this area.

The results generated from further testing using the qualitative numerical modelling, are presented in a report "Wave and Sediment Dynamics at Shelly Beach", prepared by Met

Ocean Solutions, June 2013. These support the observations recorded historically, as well as the findings presented in the various reports since the late 1970 and the more recent harbour soundings by Port Otago Limited, refer Figure 1.2.

The **net** effect of tides, wave action and currents created by hydraulic gradients through water level set up, are reflected in two distinct sediment transport patterns along the length of Shelly Beach. The first of these sediment pathways is located along the western half of the beach and extending across to the mole. This zone contains the South Spit dredging disposal ground. Beyond the immediate foreshore, the seabed contours turn sharply seaward indicating a general increase in bed level (decrease in water depth) and a gradual, uniformly sloping bed extends seaward along the mole for some two thirds of its length. Directly adjacent to the mole the contours take on a shoreward concave pattern suggesting there is a more localised movement of sediment in a shoreward direction.

The Met Ocean modelling suggests this is an active zone where sediment moves alongshore both to the east, to the west, onshore and offshore in response to the prevailing conditions. From the preliminary modelling results it would appear that the western half of the beach is a highly active zone of sediment movement.

Along the south eastern part of the beach, the nearshore gradient steepens considerably out to the 4 metre contour, which is located some 200 metres further shoreward than in the vicinity of the western part of the beach. Once seaward of this point the bed slope levels out. The modelling indicates the movement of sediment is generally south eastward along Shelly Beach toward the Long Mac groyne and from there continues to move either across the groyne into the shipping channel, or at other times is redirected toward the harbour entrance to extend beyond the seaward end of the groyne, from where it then moves in an easterly direction toward the channel.

What is not as obvious from the modelling, but is evident from the results of the soundings prepared by POL and from aerial photographs and visiting the site, is that at the extreme south eastern end of Shelly Beach, a component of the south easterly flow is redirected southward across the secondary groyne. This is discussed further in the geomorphological report, Single (2014).

Given the degree of consistency between the results of the modelling, the anecdotal reports and the results of previous investigations into the processes affecting the Harbour Entrance, the Mole and Shelly Beach area, the model may be used to predict the effect of changes to the Long Mac. Establishing a predictive tool was one of the stated aims of the work undertaken and reported in section 4 of the modelling report.

10 Geomorphological Processes

The final step in the investigation is to consider the information assembled to date within the context of the effects on the coastal geomorphology. This work has recently been completed and is presented in a report, "Long Mac groyne and Shelly Beach, geomorphological processes", by Dr M. Single (2014).

This report identifies a coastal environment that is influenced by the presence of a dredged material disposal site. As well as creating an area of shoaling (ie shallowing) within the immediate vicinity of the disposal site, the wave and current climate is modified as is the natural supply (or deficit) of sediment to Shelly beach, which along

with the pre-existing sediment distribution patterns either moves into temporary storage in the form of a single ridge of sand dunes or feeds into the coastal sediment transport system.

> "Single (2014) notes " Sand is freely exchanged between the nearshore and the beach and dunes, with periods of beach accumulation being punctuated by erosional phases during storm events ".

A further analysis of particle size characteristics along with the transportability (rollability) of sediments, reflects an onshore movement of dredge sediment which then moves alongshore to the north west toward the mole as well as to the south east, where in the vicinity of the Long Mac this sediment is either redirected offshore; across the Long Mac into the navigation channel; or to the south across a secondary groyne to become part of "The Spit" sediment circulation pattern. Single (2014) notes the potential for this sediment to also re - enter the navigation channel from the southern end of "The Spit".

Single (2014) considers the effect of raising the Long Mac along with the northernmost secondary groyne as modelled by Met Ocean (2014). While an increase in sediment transport may be expected at the Northern end of the Long Mac, with some increase in scour at the tip of the groyne and increased deposition immediately to the North, a reduction of sediment transport into the channel across the Long Mac is anticipated. Raising the secondary groyne however may further affect the supply of sediment to "The Spit " and a cautionary, or staged approach to undertaking this work, supported by field trials and monitoring is proposed.

11 Discussion and Summary

The results of the modelling undertaken by Met Ocean Solutions, the charted history of the development of the Long Mac groyne, and the most recent soundings by Port Otago Limited, all support the observations and concerns raised previously by a number of authors. Reports dating back to prior to the development of the Long Mac groyne and more latterly by Johnstone (1997) and Single and Stephenson (1998) identify the western mole, Shelly Beach, the Long Mac groyne, and "The Spit" together with the effect of the disposal of dredge spoil and the South Spit disposal site as all being part of an interactive set of environmental processes. The Otago Harbour Board resident engineer Wilkie (1917) reported the beneficial effects of the Long Mac on the adjacent harbour depth.

Any modifications to the Long Mac groyne need to be considered within the wider context of the pocket embayment formed by the western mole on one side and now to a lesser extent, due to the level of the seabed, the Long Mac groyne on the other. Due to the build-up of sediment along the Shelly Beach side, the groyne has with time become considerably less effective in retaining an increased supply of sediment, the result of the disposal of dredged material and as a possible by product of erosion. At best the groyne may bring about some wave shoaling due to a localised reduction in seabed level. Conversely this may increase the strength of the currents now flowing across the groyne toward the channel.

Similarly the effect on the shoreline of "The Spit" as a result of the build-up of sediment against the Long Mac and the secondary groyne needs to be considered, not only due to the influence of the redirected component of the south easterly flow along Shelly Beach,

but from the perspective that a lesser supply of sediment is now available to this section of shoreline. Sediment is being lost across the Long Mac toward the harbour channel before reaching this area. This material is no longer available to offset the erosion of the southern end of the spit, which has an exposure to less attenuated southerly wave action as suggested by Kirk (1980).

The investigations into state of the coastal environment within the vicinity of the Long Mac may be summarised as follows;

1. A number of approaches were used to characterise and provide what is now a comprehensive understanding of the natural processes that exist within the Long Mac / Shelly Beach coastal environment.

2. A strong correlation exists between the anecdotal reports that provide a record of the changes that have taken place historically, the results of the more recent technical studies, and the mathematical modelling as applied by Met Ocean. It has been shown that such models provide an effective tool in predicting the effect of making changes to the physical environment.

3. The Long Mac continues to play an integral part of the coastal environment, in providing stability to the position of the harbour channel, and protection to Shelly Beach, "The Spit" and Aramoana Ecological Area, the latter becoming less effective over time with the build-up of sediment on the Shelly Beach side of the groyne.

4. Options have been identified and tested that could with some further optimisation form part of an integrated coastal management plan. That would involve a three part solution involving the placement of dredge spoil to a volume that balances the natural losses to Shelly Beach and "The Spit ".

5. The loss of sediment can be slowed by implementing a comprehensive dune management and beach access plan.

6. If Shelly Beach and "The Spit" are to be stabilised, thereby also providing protection to the Aramoana Ecological Area a more effective barrier such as might be created by the raising of the Long Mac, at least in part, will be necessary. Without that, the materials deposited in the Shelly Beach disposal site will simply be recirculated to little effect back into the harbour channel.

7. The options modelled by Met Ocean included the raising of the secondary groyne. The effect on the shoreline of "The Spit" as a result of the build-up of sediment against the Long Mac and the secondary groyne needs to be considered, not only due to the influence of the redirected component of the south easterly flow along Shelly Beach, but from the perspective that a lesser supply of sediment is now available to this section of coastline.

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13. References (photographs)

Figure 1.1 Plan (annotated) showing sites referred to in text. (*Source: Single and Kirk 1994)*

Figure 1.2 POL drawing 11371/2. Soundings: Howlett Point 20/11/12

Figure 1.3 Herd's chart of Otago, 1926. *(Source McLean 1985)*

Figure 1.4 Entrance to Otago Harbour, Captain J L Stokes R N 1850. *(Source McLean 1985).*

Figure 1.5 Sir John Coode's proposal for works at the entrance to Otago Harbour 1880. *(Note also Coode's proposed new sailing course. (Source McLean 1985)*

Figure 1.6 *Plan by C Napier Bell dated 19 April 1898, showing the proposed training wall.* (Source Hocken Library)

Figure 1.7 Re-survey of Entrance to Otago Harbour, surveyed by J Blair Mason CE, June 1904, with corrections to April 1905. *Note: refer also to cross sections along the upper and lower margins of the figure. (Source Hocken Library)*

Figure 1.8 Extract of J Blair Mason survey June 1904. Note cross section of Long Mac as well as the proposed timber and wire fence. *(Source Hocken Library)*

Figure 1.9 Photograph showing the Long Mac, together with several of the remnant secondary groynes. *(Source Google Earth)*

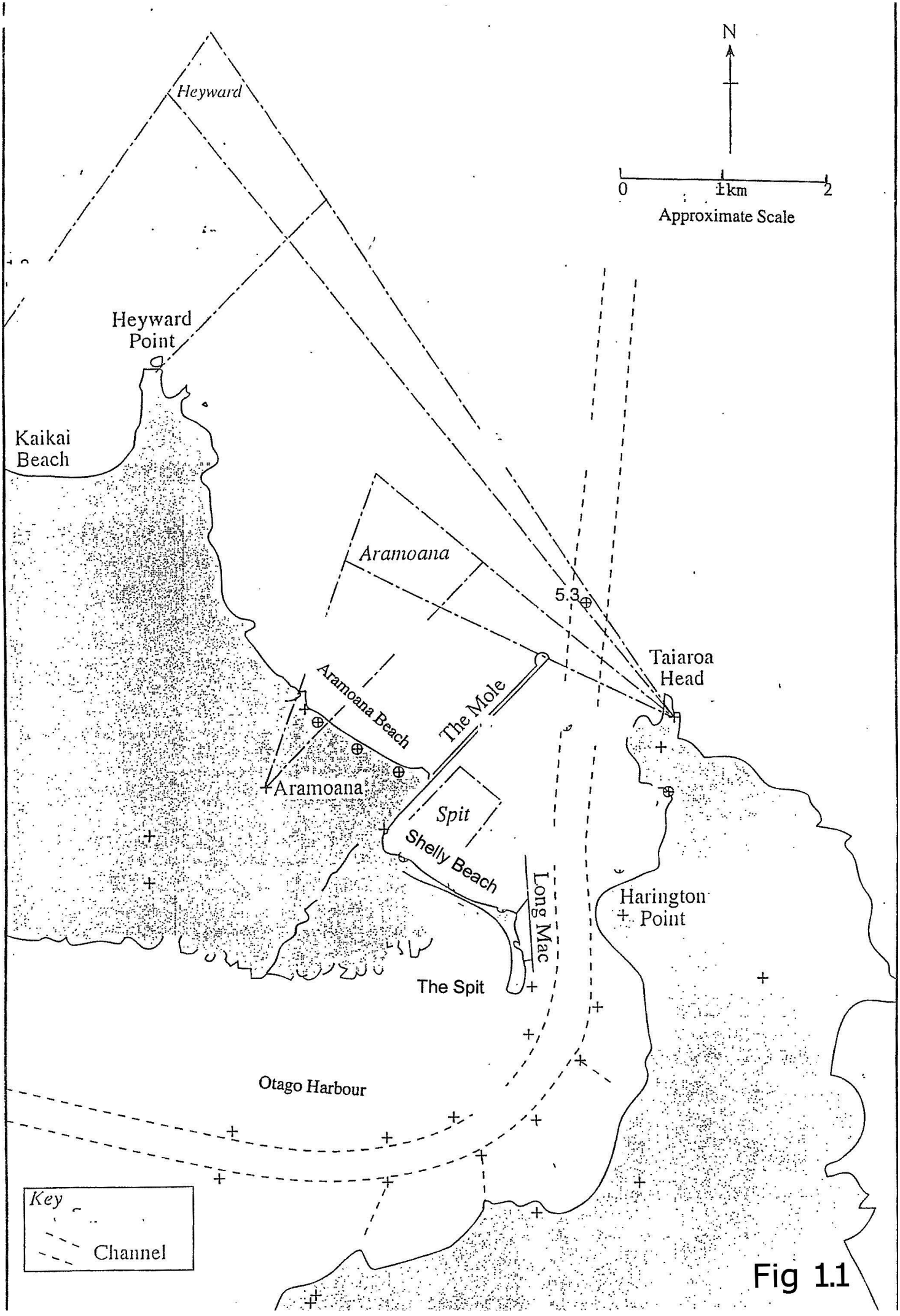

N
0
1km
2
Approximate Scale
Heyward
Heyward Point
Kaikai Beach
Aramoana
5.3
Taiaroa Head
Aramoana Beach
The Mole
Aramoana
Spit
Shelly Beach
Long Mac
Harington Point
The Spit
Otago Harbour
Key
Channel

Fig 1.1

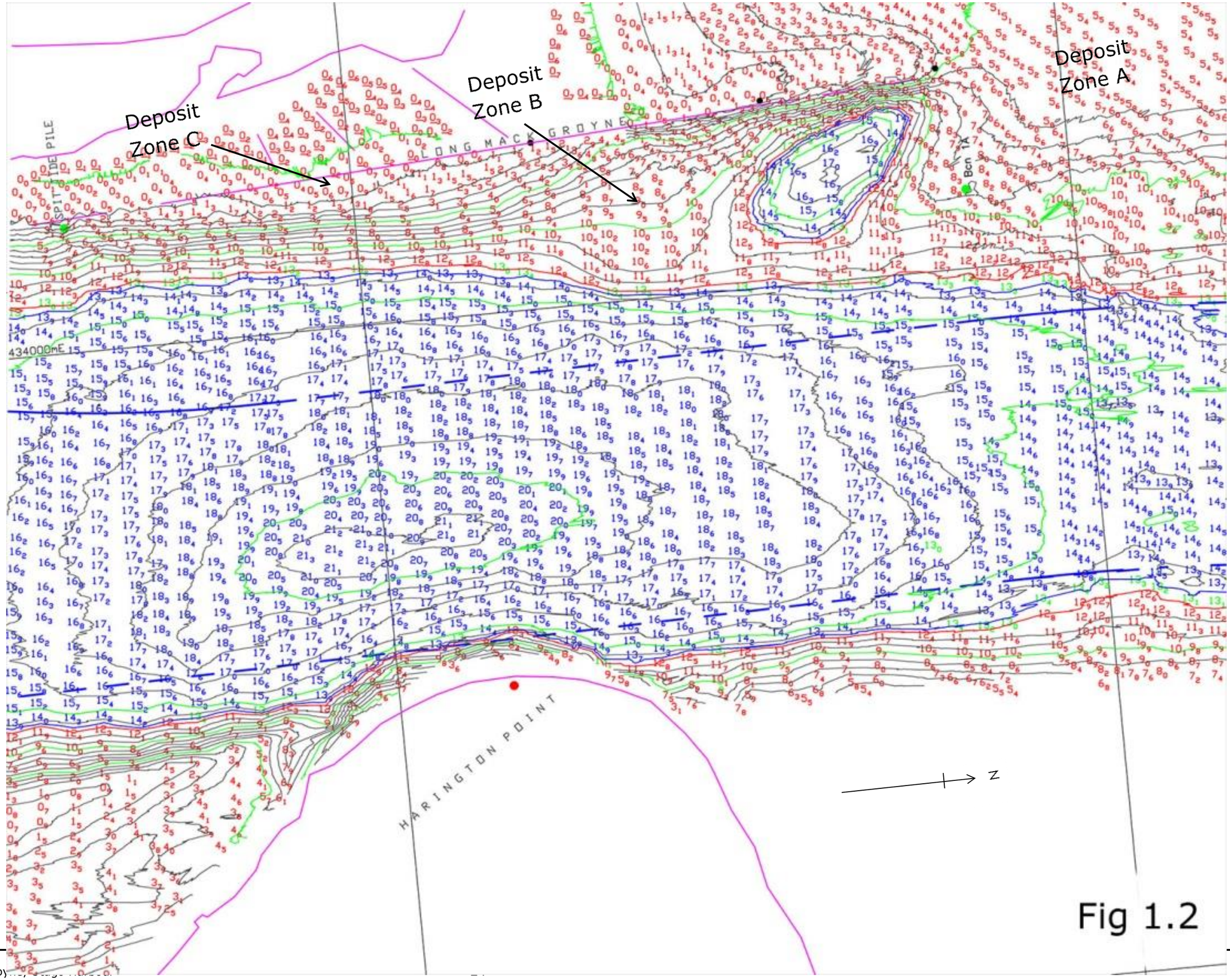
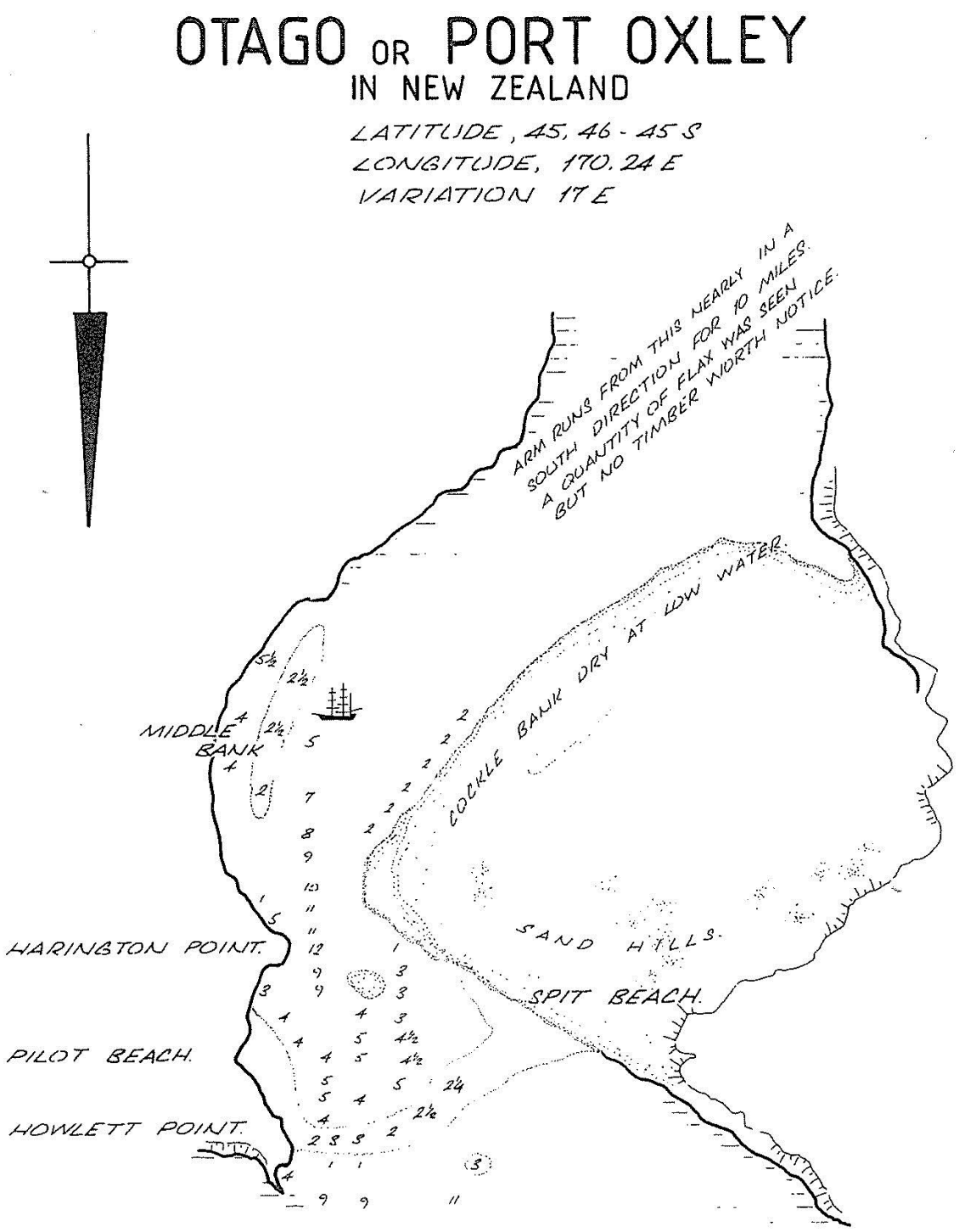

Deposit
Zone C
Deposit
Zone B
Deposit
Zone A
SPIT
PILE
LONG MAC GROYNE
Bcn 1A
434000mE
HARINGTON POINT
N

Fig 1.2



HERD'S CHART OF OTAGO 1826

Fig 1.3

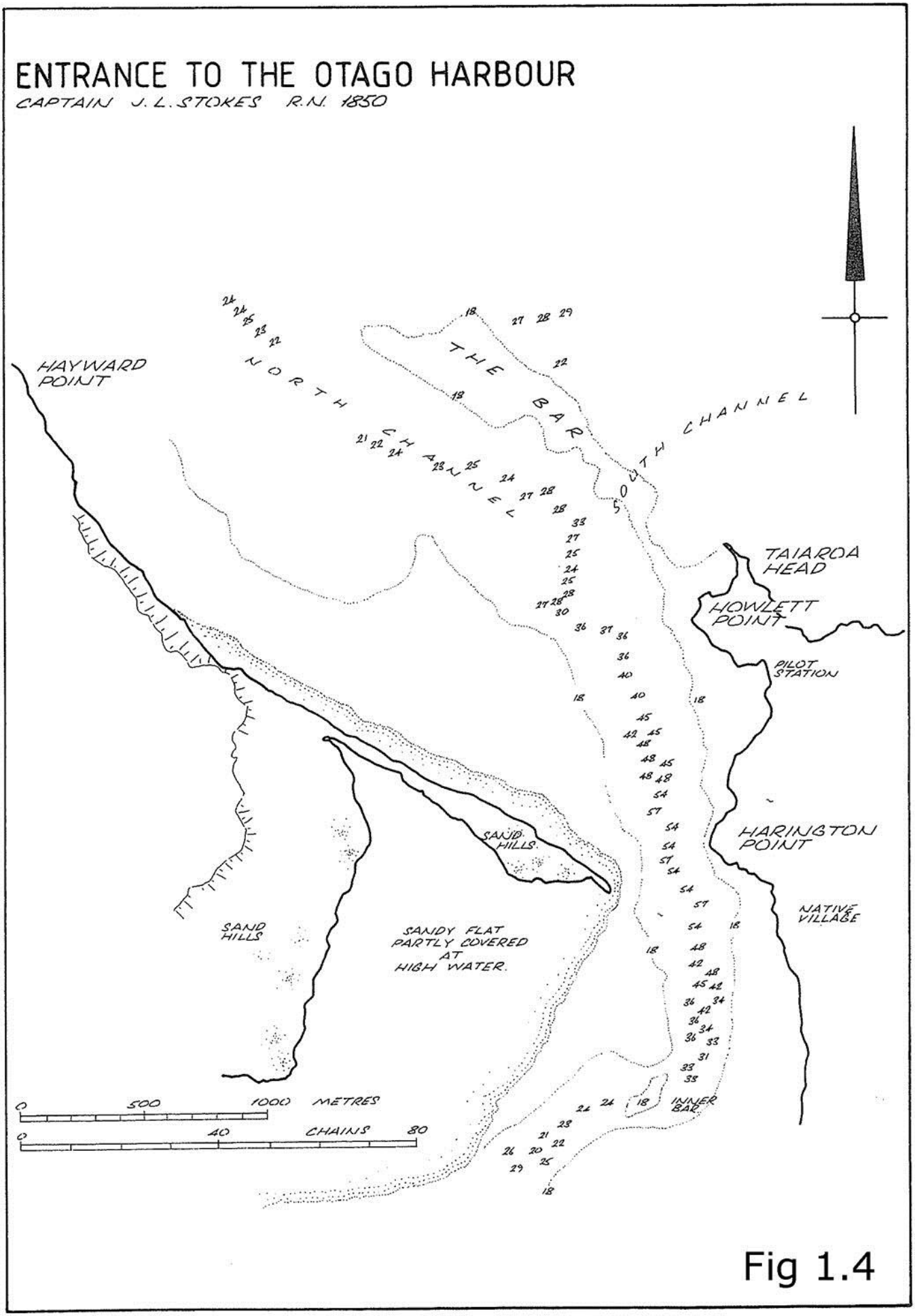

ENTRANCE TO THE OTAGO HARBOUR
CAPTAIN J.L.STOKES R.N. 1850
HAYWARD POINT
NORTH CHANNEL
THE BAR
SOUTH CHANNEL
TAIAROA HEAD
HOWLETT POINT
PILOT STATION
HARINGTON POINT
NATIVE VILLAGE
SAND HILLS
SAND HILLS
SANDY FLAT PARTLY COVERED AT HIGH WATER.
INNER BAR
0 500 1000 METRES
0 40 CHAINS 80

Fig 1.4

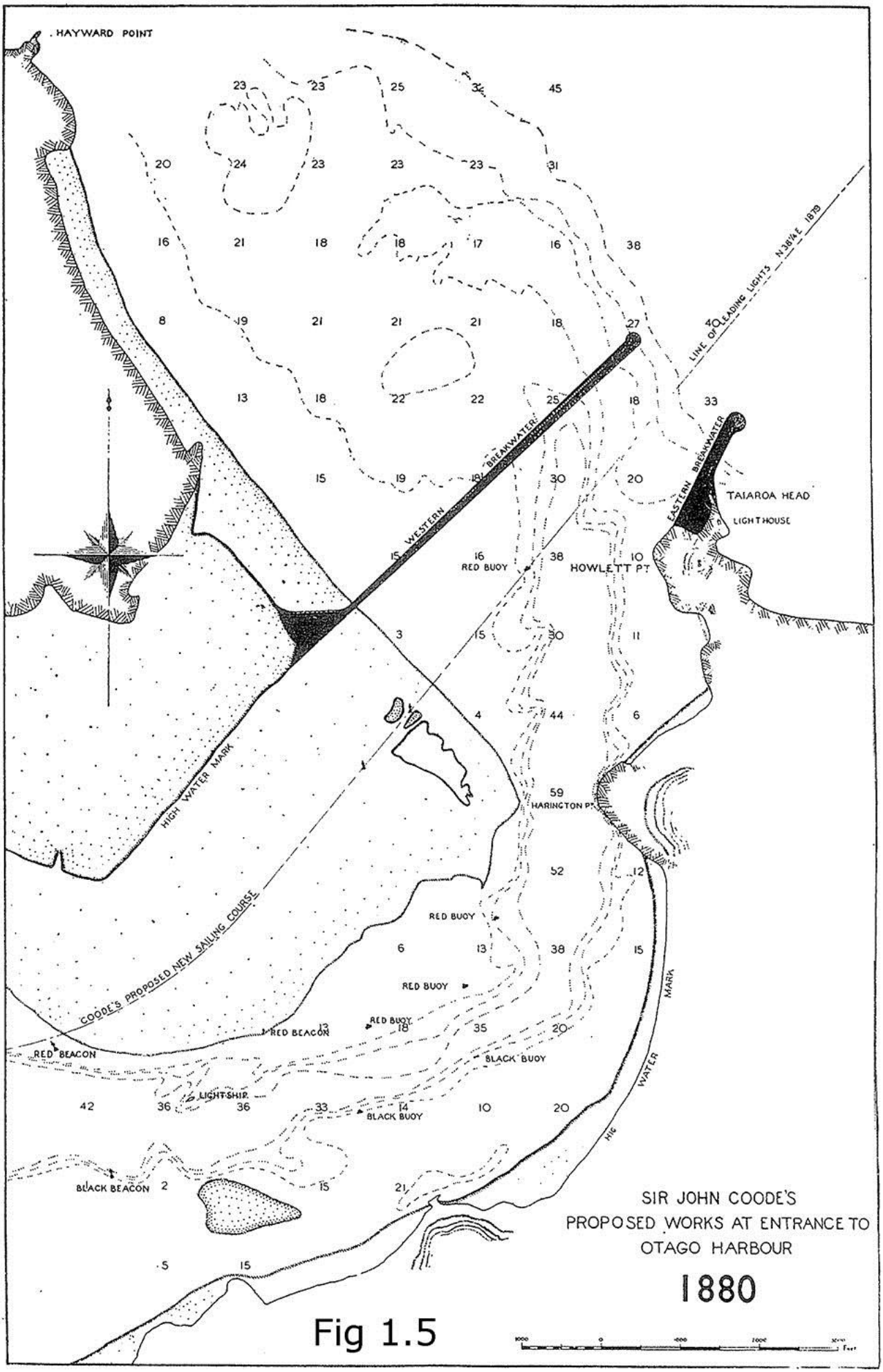

HAYWARD POINT
LINE OF LEADING LIGHTS N.38½E 1878
WESTERN BREAKWATER
EASTERN BREAKWATER
TAIAROA HEAD
LIGHTHOUSE
RED BUOY
HOWLETT PT
HARINGTON PT
HIGH WATER MARK
COODE'S PROPOSED NEW SAILING COURSE
RED BEACON
LIGHTSHIP
BLACK BUOY
BLACK BEACON
HIG WATER MARK
SIR JOHN COODE'S
PROPOSED WORKS AT ENTRANCE TO
OTAGO HARBOUR
1880

Fig 1.5

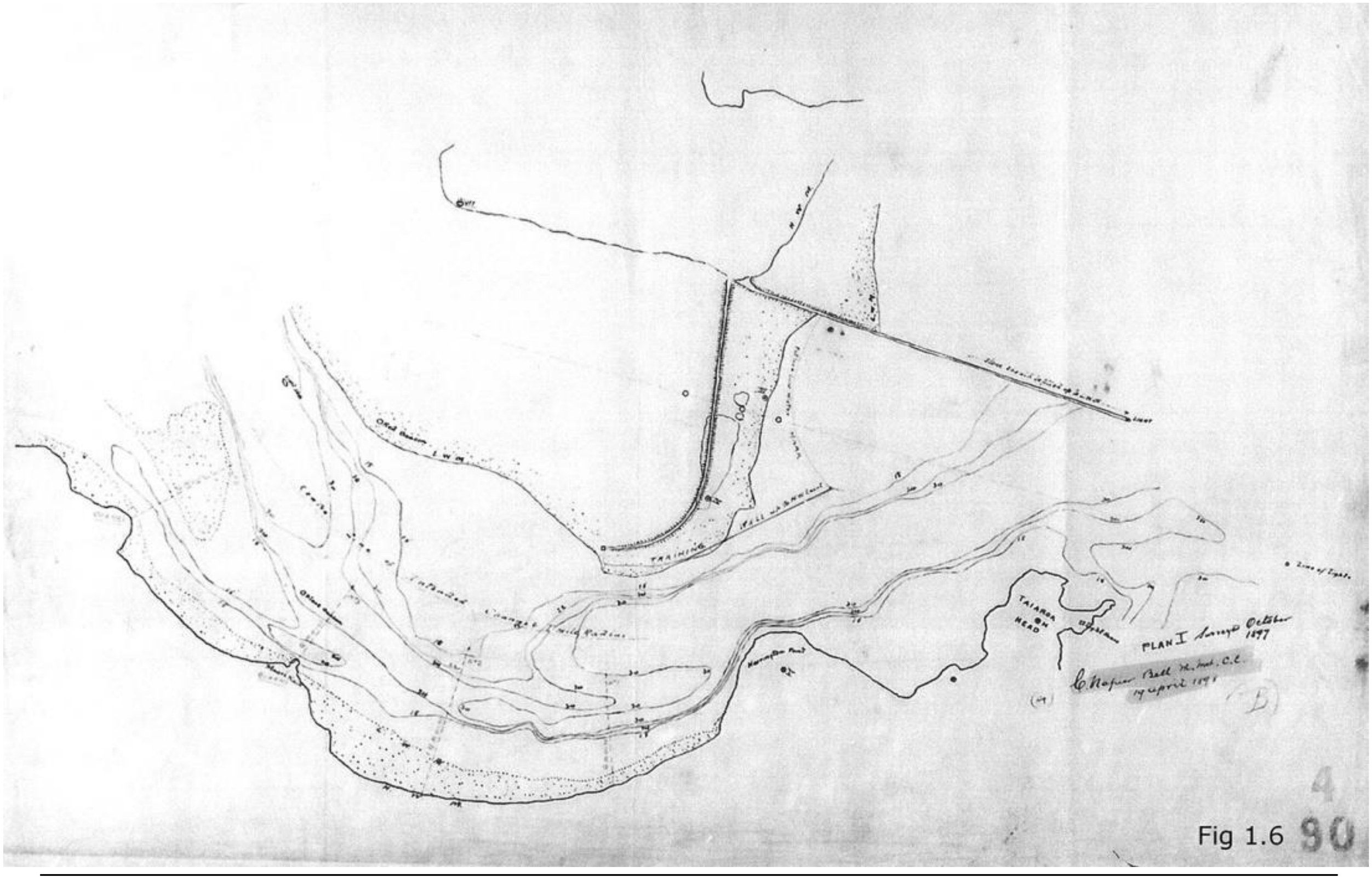

TAIAROA HEAD
PLAN I Survey'd October 1897
C. Napier Bell M. Inst. C.E.
19 April 1898

Fig 1.6

RE-SURVEY OF

ENTRANCE TO OTAGO HARBOUR

SURVEYED BY J. BLAIR MASON, C.E.

JUNE 1904

WITH CORRECTIONS TO APRIL 1905

Scale 300 feet to an inch

SOUNDINGS IN FEET

J. Blair Mason C.E.
Engineer to Board.
May 8th 1905

91

TAIAROA HEAD

HARRINGTON PT

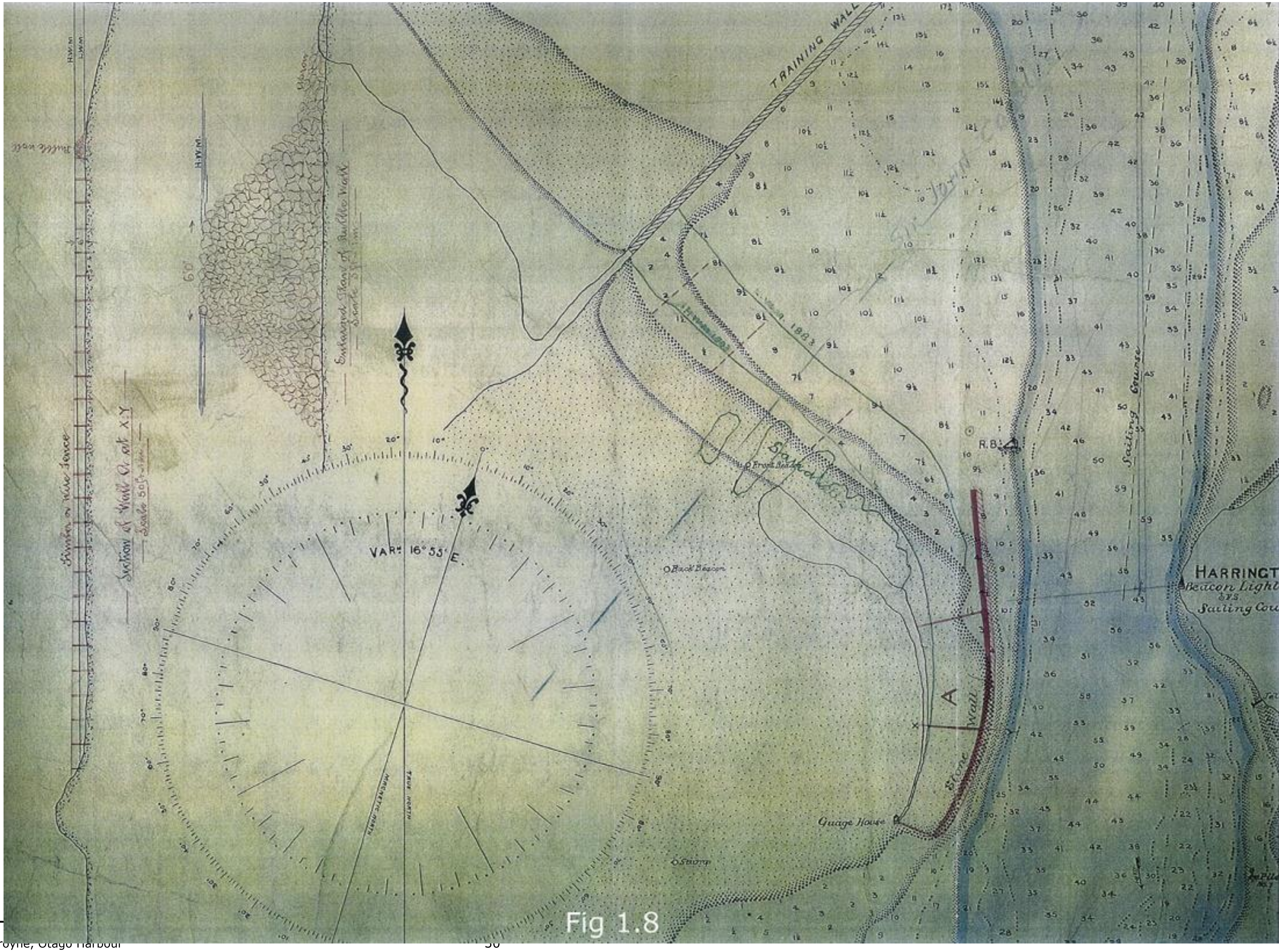
TRAINING WALL

16

SCALE OF FEET

SCALE OF SEA MILES

Fig 1.7



TRAINING WALL
VARⁿ 16° 55' E.
R.B.
HARRINGT
Beacon Light
Sailing Cou
Sailing Course
Back Beacon
Front Beacon
Guage House
Stone Wall
A
Stump
TRUE NORTH
MAGNETIC NORTH
Section of Wall A at XY

Fig 1.8


Fig 1.9