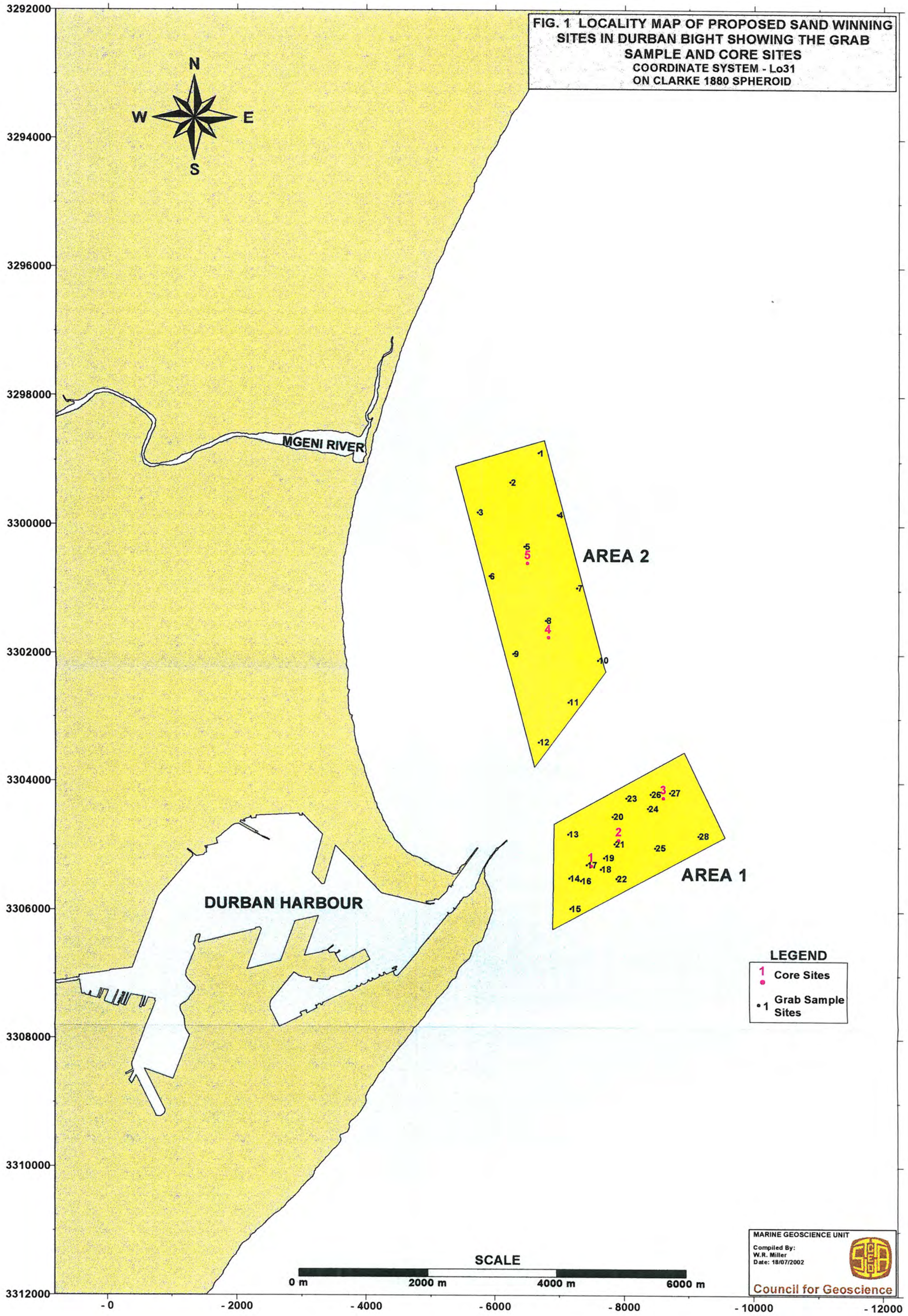

FIG. 1 LOCALITY MAP OF PROPOSED SAND WINNING SITES IN DURBAN BIGHT SHOWING THE GRAB SAMPLE AND CORE SITES
COORDINATE SYSTEM - Lo31
ON CLARKE 1880 SPHEROID
N
W
E
S
MGENI RIVER
AREA 2
AREA 1
DURBAN HARBOUR
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
25
26
27
28
LEGEND
1 Core Sites
• 1 Grab Sample Sites
SCALE
0 m
2000 m
4000 m
6000 m
3292000
3294000
3296000
3298000
3300000
3302000
3304000
3306000
3308000
3310000
3312000
- 0
- 2000
- 4000
- 6000
- 8000
- 10000
- 12000
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4. DATA PROCESSING

4.1 Navigation and Bathymetric Data

Navigation data were corrected for transducer offsets from the DGPS antenna position and bathymetry data were edited for anomalous values, corrected for tidal variation and reduced to Mean Sea Level (MSL) in the *Navlog Systems* software. The corrected bathymetric data were imported as ASCII text files into the *Surfer 7* software package for gridding and contouring. A total of 14379 data points were gridded using the kriging method, an octant search pattern and a search radius of 300 metres to produce a 50 m by 50 m grid file from which the final bathymetric map was produced.

4.2 Side-scan sonar data

The taped System 2000 side-scan sonar data were converted to Klein 5000 format using an Exabyte tape drive installed on a high-specification PC running Windows NT and a proprietary software application designed by Klein Associates, Inc. The Klein software allows the time varied gain (TVG) of the sonar data to be manipulated and the image enhanced. The 5KD format was then converted to Q-MIPS format using the *Navlog Systems* software. This software was also used to mosaic the sonograph data which was then filtered using an algorithm in the *ER Mapper* software. The mosaic was saved in a GeoTIFF format and imported into the *Surfer 7* software where it was geo-referenced and used to digitize different acoustic facies as separate polygons, which were integrated to produce a seafloor geology map.

4.3 Pinger sub-bottom profiling data

The navigation data were corrected for the Pinger transducer offsets in the *Navlog* software and then exported to the *Surfer 7* software as an ASCII spreadsheet. The minimum unconsolidated sediment thickness values were measured directly from the sub-bottom profiling analogue records at regularly spaced event marks (30 second intervals) and then manually incorporated into the navigation spreadsheet. These values of unconsolidated sediment thickness were then posted as point data onto the seafloor geology map in their true geographic location.

4.4 Sediment Samples

A total of 74 samples (28 grab samples & 46 samples from the sediment cores) of ± 130g each were taken for laboratory analysis. Sub-samples of the sediment were taken and dried at 100°C and then subjected to a suite of laboratory analyses. Wet sieving was undertaken to determine the mud fraction (% < 63 µm), dry sieving was undertaken to determine the gravel fraction (% > 2mm), settling tube analysis was undertaken to determine the graphic statistical parameters of the sand fraction (63 µm - 2 mm), and carbonate bomb analysis to determine calcium carbonate content. The dried sediment was poured into a 100 ml volumetric flask from a fixed height (200 mm) and weighed to determine the "loose" dry density and then subjected to 50 blows from a height of 50 mm and the new volume was measured to determine the "compact" dry density. A tabulated list of laboratory analyses is presented in Appendix 1 and cumulative frequency curves for the sand fractions are presented in Appendix 2.

4.5 Graphic Sediment Statistics

The basic descriptive element of all sediments is grain-size, which can be characterised in terms of mm or phi units (φ). A geometric scale was devised by Wentworth in 1922 to subdivide sediments into a number of classes based on grain-size measurements in mm. The phi unit (φ) is the logarithmic transformation of this scale. A number of statistical parameters can be deduced from grain-size distribution curves or directly from grain-size data, these are: mean grain-size, median grain-size, sorting and skewness. The statistical parameters are calculated using the Folk & Ward formulae given in Table 4.1 below (Folk & Ward, 1957). The statistical parameters were calculated with a BASIC based software package and a computer linked settling tube which yields results comparable to standard sieving techniques.

PARAMETER	FOLK & WARD FORMULA
Median	$Md = d_{50}$
Mean	$M = \frac{d_{16} + d_{50} + d_{84}}{3}$
Sorting	$\sigma\varphi = \frac{\varphi_{84} - \varphi_{16}}{4} + \frac{\varphi_{95} - \varphi_{5}}{6.6}$
Skewness	$Sk = \frac{\varphi_{16} + \varphi_{84} - 2\varphi_{50}}{2(\varphi_{84} - \varphi_{16})} + \frac{\varphi_{5} + \varphi_{95} - 2\varphi_{50}}{2(\varphi_{95} - \varphi_{5})}$

Table 4.1 Formulae for the calculation of sediment grain-size parameters from grain-size data.

4.5.1 Median & Mean Grain-size

The median grain-size is simply the grain-size at 50% of the grain-size distribution, whereas the mean grain-size is an average value calculated from the 16^{th}, 50^{th} and 84^{th} percentiles of the grain-size distribution (Table 4.1). These grain-size parameters are useful for subdividing sediments into a number of different classes according to the measured/calculated median or mean of a grain-size distribution (Table 4.2).

GRAIN-SIZE	φ VALUE	mm VALUE
Very fine-grained sand	> 3.0	0.063 to 0.125
Fine-grained sand	2.0 to 3.0	0.125 to 0.25
Medium-grained sand	1.0 to 2.0	0.25 to 0.5
Coarse-grained sand	0 to 1.0	0.5 to 1.0

Table 4.2 Grain-size scale for sand sediments.

4.5.2 Sorting

Sorting is a measure of the spread of the grain-size distribution. A well sorted sediment in terms of geological principles, is a sediment with a narrow spread of the grain-size distribution and a poorly sorted sediment is one with a broad spread of the grain-size distribution. The reverse is true when sorting is considered in terms of engineering principles i.e. a well sorted sediment has a broad grain-size distribution and a poorly sorted sediment has a narrow grain-size distribution. All references to sediment sorting in the text are made in terms of **geological** principles and are summarised in Table 4.3 below.

SORTING	φ VALUE
Very well sorted	< 0.35
Well sorted	0.35 to 0.5
Moderately well sorted	0.51 to 0.7
Moderately sorted	0.71 to 1.00

Table4.3 A summary of the categories of sand sorting.

4.5.3 Skewness

Skewness is the measure of the coarse or fine bias of a grain-size distribution. Apart from being useful to describe a sediment sample, skewness is also a reflection of the depositional process. In general sediment becomes more fine skewed (finer grained) along its sediment transport path whereas the source sediment (lag) becomes more coarse skewed (coarse grained) as the finer sediment is winnowed from it. The various classes of sediment skewness are summarised in Table 4.4 below.

SKEWNESS	φ VALUE	SURFACE AREA
Near symmetrical	-0.10 to 0.10	26.3 km^2
Coarse skewed	-0.10 to -0.30	42.7 km^2
Strongly coarse skewed	< -0.30	5.0 km^2

Table 4.4 A summary of classes of sediment skewness discussed in the text.

Sediment skewness is of limited importance in terms of engineering properties of sediments and this parameter receives little mention in the text. The analyses are however included in this report for sake of completeness.

5. BATHYMETRY

The bathymetry of the two borrow sites and adjacent seafloor in the Durban Bight was contoured at 1 m intervals and is illustrated in Figure 2. The bathymetry varies from a minimum depth of - 19 m to a maximum depth of -32 m in Area 1 and between - 18 m and - 23 m in Area 2 (Fig. 2). The bathymetric chart indicates that the seafloor in Area 1 is dominated by the presence of two discrete sand mounds, a northern mound which measures ± 2000 m in length, ± 750 m in width and ± 10 m in height and a southern mound which measures ± 1500 m in length, 700m in width and 2 - 3 m in height. These positive relief features are orientated roughly southwest - northeast and represent the old dredge dumping ground, which saw active dumping for 10 - 15 years during the late 1800's and early 1900's. While dumping has certainly played a role in the sea-floor morphology in this area it is unlikely that the shallow nature of the sea-floor in this area can be attributed entirely to sediment dumping. The shallow pinnacles of No. 1 Reef which are evident as a series of bullseyes defining a ridge which strikes roughly 224 ° to the northeast of the Area 1 borrow site, suggest that the reef may be continuous below the shallow sediment mounds in Area 1 (Fig. 2). The bathymetry is otherwise gently undulating with bathymetric gradients steepening towards the east. Bathymetric gradients vary from 0.14° in the central and western parts of Area 1 to 0.69° in the eastern part of this borrow site.

Area 2 is characterised by a very uniform bathymetry which indicates a very flat sea-floor that dips gently towards the northeast. Bathymetric gradients in Area 2 vary from 0.13° - 0.19° in northern and central areas and steepen to a maximum gradient of 0.23° further towards the south.

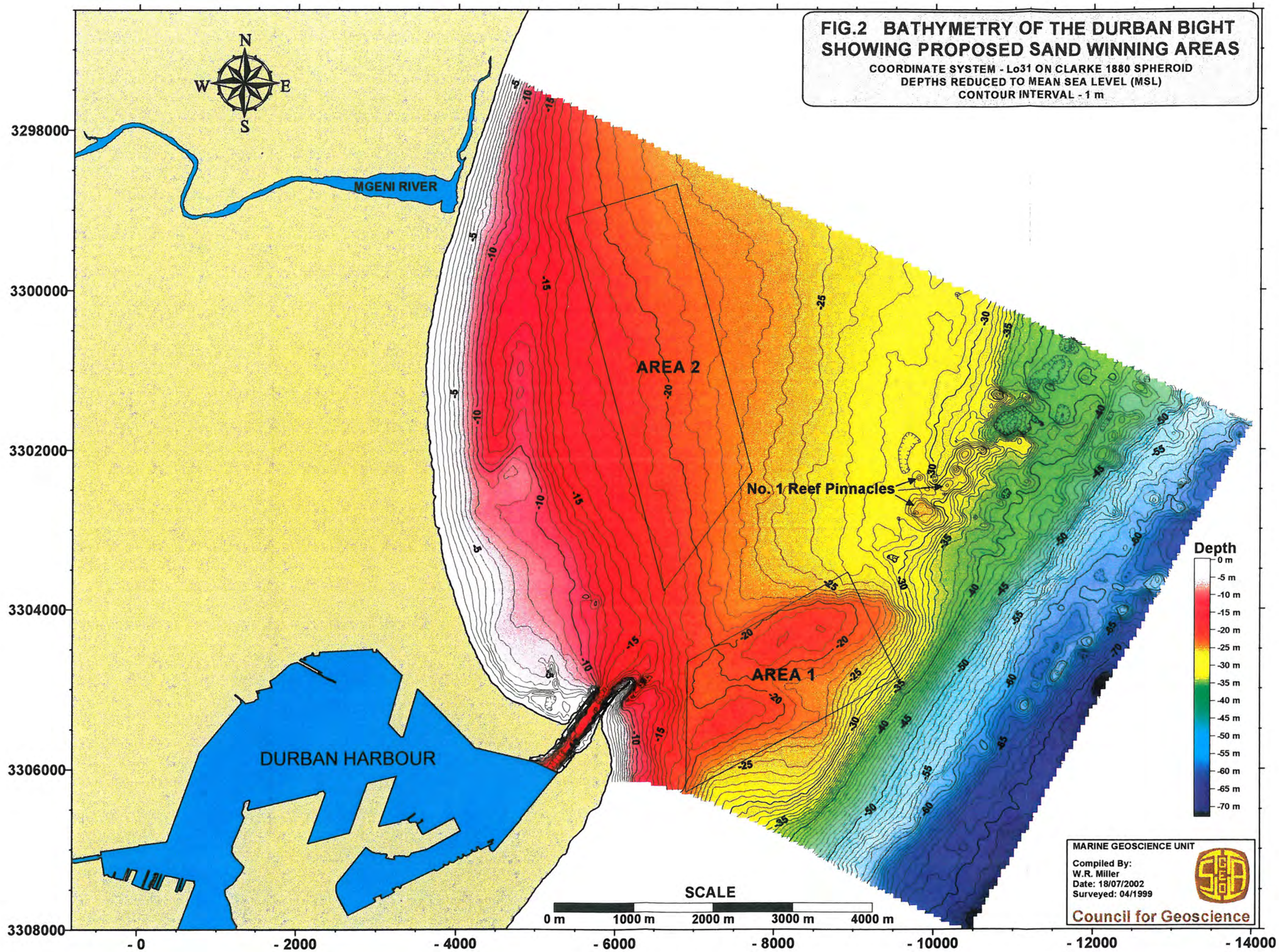
FIG.2 BATHYMETRY OF THE DURBAN BIGHT SHOWING PROPOSED SAND WINNING AREAS
COORDINATE SYSTEM - Lo31 ON CLARKE 1880 SPHEROID
DEPTHS REDUCED TO MEAN SEA LEVEL (MSL)
CONTOUR INTERVAL - 1 m
MGENI RIVER
AREA 2
AREA 1
No. 1 Reef Pinnacles
DURBAN HARBOUR
Depth
0 m
-5 m
-10 m
-15 m
-20 m
-25 m
-30 m
-35 m
-40 m
-45 m
-50 m
-55 m
-60 m
-65 m
-70 m
SCALE
0 m
1000 m
2000 m
3000 m
4000 m
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Compiled By:
W.R. Miller
Date: 18/07/2002
Surveyed: 04/1999
Council for Geoscience
3298000
3300000
3302000
3304000
3306000
3308000
- 0
- 2000
- 4000
- 6000
- 8000
- 10000
- 12000
- 14000

6. SURFICIAL SEAFLOOR GEOLOGY

This section deals with the geological interpretation of shelf acoustic facies interpreted from the side-scan sonar mosaic (Fig. 3). Seven acoustic facies were identified from the side-scan sonar mosaic and these include:

A. Description: Weak to moderately reflective, smooth, even-toned planar acoustic facies.
Interpretation: Fine- to medium-grained, unconsolidated shelf sand.

B. Description: Highly reflective acoustic facies with a scattered distribution and small acoustic shadows.
Interpretation: Scattered reef outcrop with moderate to little relief.

C. Description: Moderate to highly reflective acoustic facies surrounded by lager patches of granular moderately reflective acoustic sediments.
Interpretation: Reef buried beneath a thin coarse-grained or bioclastic rich sediment veneer.

D. Description: Small and localised examples of highly reflective objects with little or no acoustic shadow on the seafloor.
Interpretation: Metal debris or man-made artefacts which have been thrown overboard by passing ships.

E. Description: Moderately to strongly reflective granular acoustic facies with a random and often linear distribution pattern.
Interpretation: Silty dredge spoil.

F. Description: Moderately reflective acoustic facies with no shadows and diffuse irregular margins.
Interpretation: Isolated patches of marine weed growth.

G. Description: Highly reflective, cigar-shaped object with high reflectivity and a moderate acoustic shadow.
Interpretation: Ship wreck.

The seven acoustic facies were digitised as discrete polygons and compiled to form a side-scan sonar interpretation maps for each of the proposed borrow sites (Figs. 4 & 5).

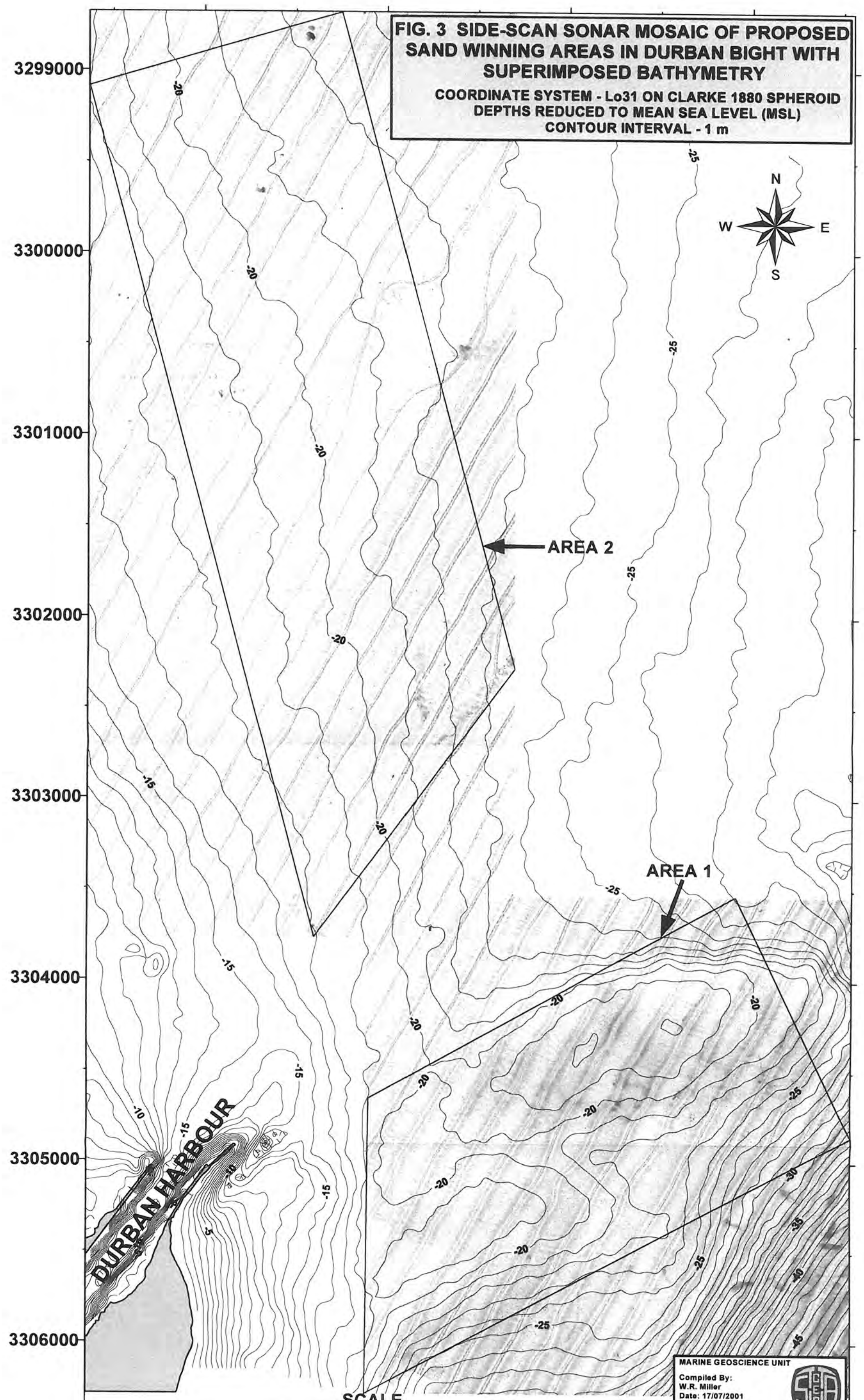
FIG. 3 SIDE-SCAN SONAR MOSAIC OF PROPOSED SAND WINNING AREAS IN DURBAN BIGHT WITH SUPERIMPOSED BATHYMETRY
COORDINATE SYSTEM - Lo31 ON CLARKE 1880 SPHEROID
DEPTHS REDUCED TO MEAN SEA LEVEL (MSL)
CONTOUR INTERVAL - 1 m
N
W
E
S
AREA 2
AREA 1
DURBAN HARBOUR
-25
-20
-15
-10
-5
-30
-35
-40
-45
3299000
3300000
3301000
3302000
3303000
3304000
3305000
3306000
- 6000
- 7000
- 8000
- 9000
SCALE
0 m
1000 m
2000 m
3000 m
MARINE GEOSCIENCE UNIT
Compiled By:
W.R. Miller
Date: 17/07/2001
Surveyed: 04/1999
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The weak to moderately reflective, even toned planar acoustic facies is by far the most abundant acoustic facies in both of the borrow areas (Figs. 4 & 5). This acoustic facies is typical of fine- to medium - grained unconsolidated shelf sand (i.e. normal near-shore marine sediments). It is evident from studying the side-scan sonar mosaic (Fig. 3) that there are subtle differences between this facies between the two potential borrow areas. The sonographs in Area 2 are uniform and even toned whereas the sonographs from Area 1 show slightly darker patches and are more granular in texture. This is a function of grain-size of the sediments and indicates that the sediments in Area 1 and particularly on the northern sediment mound are coarser grained than the sediments in Area 2. This observation is supported by the analyses conducted on the sediment samples (Sections 8 & 9). The presence of a group of moderately reflective granular lineations at the centre of the northern sand mound in Area 1 indicates the presence of a subaqueous bedform field. The lineations measure between 50 m and 150 m in length and represent subaqueous bedform crests which are oriented roughly northeast - southwest (Fig. 4). The bedforms have a wavelength of ± 10 - 20 m and have an estimated amplitude of ± 0.5 m. These are essentially ephemeral features which are instrumental in transporting sediment southwards under the influence of the Agulhas current.

The areas of scattered reef outcrop are sparse and form a scattered outcrop pattern in the Area 1 borrow site (Fig. 4). The scattered reef exposures are characterised by, isolated, highly reflective, granular to blotchy, sometimes linear sonograph images with or without shadow areas (white) on their leeward side. Small acoustic shadows associated with this acoustic facies suggests that the reef exposures are subdued, with less than 2m of microtopography. The distribution pattern of scattered reef outcrop in Area 1 is haphazard but occurrences are concentrated in a broad band in the central to northeastern part of the Area 1 borrow site (Fig.4). The largest occurrences of scattered reef outcrop measure ± 100m by 100m, 50 m by 30 m and 300m by 10m. The broad band of scattered reef outcrop in Area 1 is roughly on strike with the shallow pinnacles of No.1 Reef (Figs. 2 & 4). No scattered reef outcrops were identified in the Area 2 borrow site.

An acoustic facies, measuring ± 100m by 75 m, which is characterised by moderate to high reflectivity and granular to nodular texture to the southwest of the largest exposure of scattered reef in Area 1is interpreted as reef that is buried beneath a thin sediment veneer.

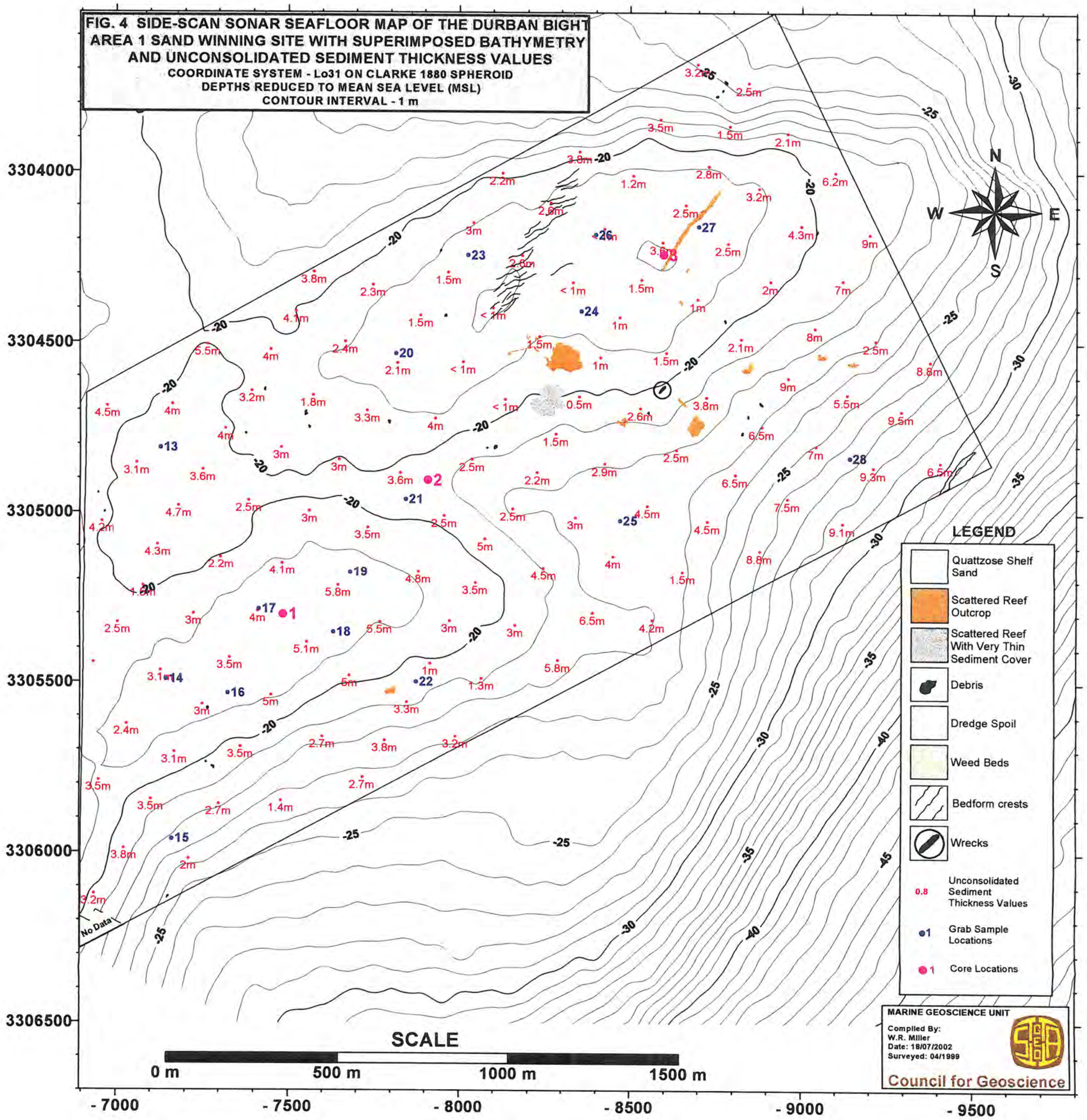

FIG. 4 SIDE-SCAN SONAR SEAFLOOR MAP OF THE DURBAN BIGHT AREA 1 SAND WINNING SITE WITH SUPERIMPOSED BATHYMETRY AND UNCONSOLIDATED SEDIMENT THICKNESS VALUES

COORDINATE SYSTEM - Lo31 ON CLARKE 1880 SPHEROID

DEPTHS REDUCED TO MEAN SEA LEVEL (MSL)

CONTOUR INTERVAL - 1 m

It is very likely that all the reef in Area 1 (exposed /buried) forms a southern extension of the No. 1 Reef complex which is now largely buried. No. 1 Reef is an aeolianite Reef complex which consists of carbonate cemented fine to medium grained sand with a typical uniaxial compressive strength of ± 70 Mpa (pers. comm. Dr. P.J. Ramsay). The reef areas represent ancient linear coastal dune deposits which accumulated during periods of lower sea-level. By virtue of the shell fragment content of the coastal dune sediments, the dune core underwent cementation by a mechanism of dissolution of calcium carbonate on dune crests by rainwater and re-precipitation of the calcium carbonate at depth when the calcium rich pore waters encountered the meteoric interface. A subsequent rise in sea-level has left the now lithified dune sediments (aeolianite) as linear reefs on the seafloor.

Both Area 1 and Area 2 are characterised by a very scattered and random distribution of small highly reflective sonar contacts with little or no acoustic shadow (Figs. 4 & 5). The reflective objects are highly variable in size and shape and none have a characteristic shape that could lead to an unequivocal identification of what these objects represent. The random distribution of these contacts over large areas of unconsolidated shelf sediment precludes the possibility that these contacts represent small reef exposures. The objects in question are probably man-made and their occurrence and distribution are probably related to debris being thrown overboard by passing ship traffic. The objects have a random arrangement but some occur in fairly dense clusters. The debris in Area 1 has a very scattered distribution and the objects are usually less than 10 m in diameter. Area 2 also shows a random and scattered pattern of smaller debris (< 10 m in diameter) but also shows two clusters of larger more elongate debris contacts near the centre of the borrow site (Fig. 5). Individual debris contacts in these clusters reach a maximum of ± 50 m in length. The largest debris contact is located in the northeastern corner of Area 2 and measures 55m by 45 m. This sonar contact is a composite of several small contacts surrounding a larger central object, but has been digitized as a single contact as it is impossible to resolve individual objects.

Dredge spoil takes the form of linear, dark patches of moderately reflective sediment of variable size and orientation on the seafloor (Miller, 2000). Only one example of dredge spoil is evident in the southeastern corner of Area 1, adjacent to the modern dump site. The dredge spoil measures ± 165 m in length by 15 m wide. The size of the dredge spoil site and degree of acoustic reflection are probably an indication of how long the dredge spoil has been resting on

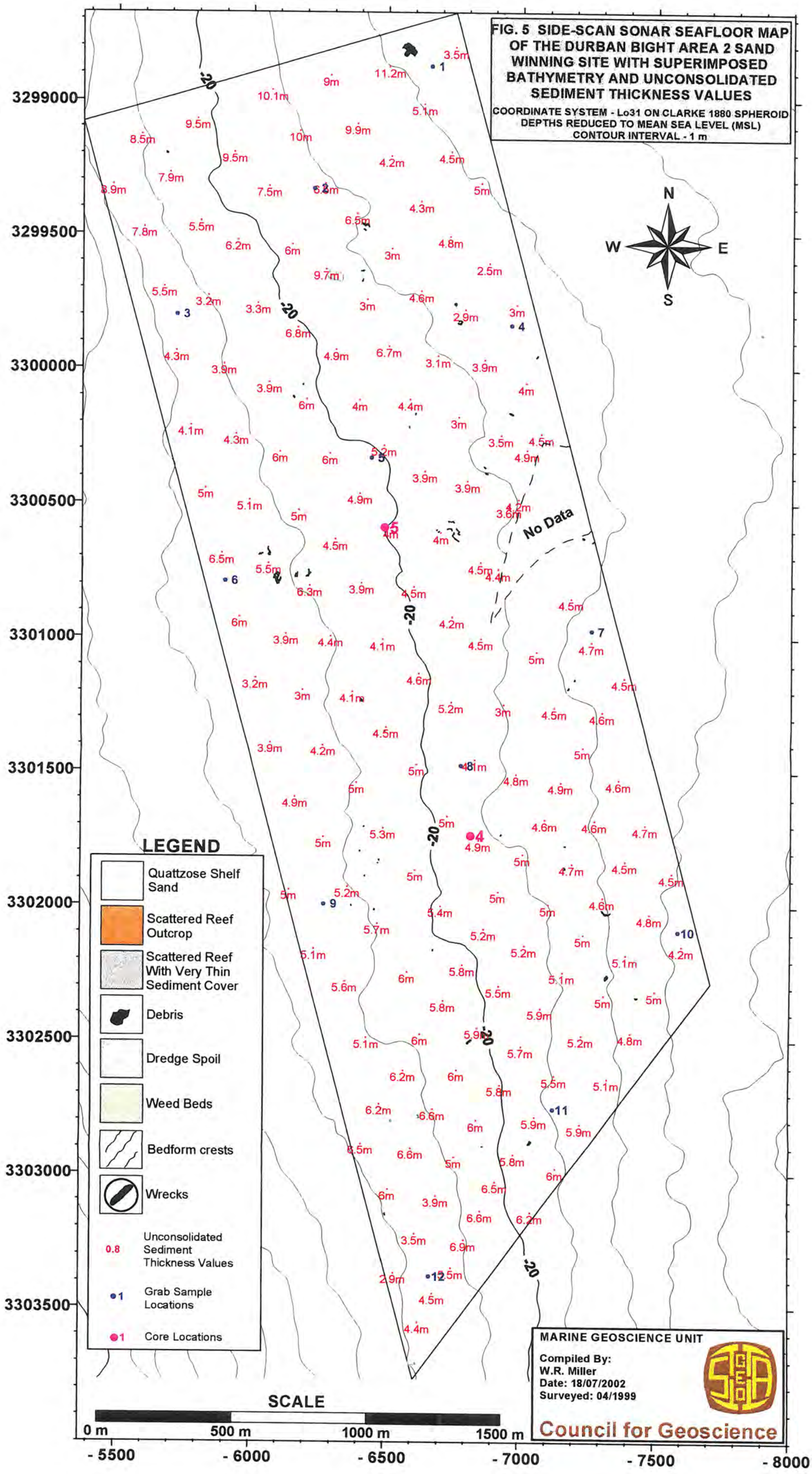

FIG. 5 SIDE-SCAN SONAR SEAFLOOR MAP OF THE DURBAN BIGHT AREA 2 SAND WINNING SITE WITH SUPERIMPOSED BATHYMETRY AND UNCONSOLIDATED SEDIMENT THICKNESS VALUES
COORDINATE SYSTEM - Lo31 ON CLARKE 1880 SPHEROID
DEPTHS REDUCED TO MEAN SEA LEVEL (MSL)
CONTOUR INTERVAL - 1 m
N
W
E
S
No Data
-20
LEGEND
Quattzose Shelf Sand
Scattered Reef Outcrop
Scattered Reef With Very Thin Sediment Cover
Debris
Dredge Spoil
Weed Beds
Bedform crests
Wrecks
0.8 Unconsolidated Sediment Thickness Values
1 Grab Sample Locations
1 Core Locations
SCALE
0 m
500 m
1000 m
1500 m
3299000
3299500
3300000
3300500
3301000
3301500
3302000
3302500
3303000
3303500
- 5500
- 6000
- 6500
- 7000
- 7500
- 8000
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Surveyed: 04/1999
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the seafloor i.e. recent deposits of dredge spoil being more compact in size and more reflective in nature (darker) than dredge spoil that has been lying on the seafloor for longer periods of time.

Weed beds take the form of small, spherical to larger more irregularly shaped sonar contacts with no acoustic shadows. These acoustic contacts are highly reflective at the centre and become less reflective towards the margins. The weed beds are all located on the more stable sea-floor conditions of Area 2 and are always characterised by diffuse or "fuzzy" margins on the sonographs. The largest weed bed is located in the central northern part of Area 2 and measures ± 60 m in length by 40 m in width. Several smaller examples are located in the southwestern part of Area 2.

Only one wreck is evident in the survey areas and is located in the central-eastern part of Area 1 (Fig. 4). The wreck measures 30 m in length by 7.5 m in width and stands ± 1.5 m off the sea-floor. The high acoustic reflectivity and intact nature of the wreck image suggest that it is a steel hull vessel.

The primary objective of this report is to identify areas that are most suitable for sand winning and to delineate problem areas where dredging activity might be ill advised. Such problem areas in the context of the identified acoustic facies are; exposed reef areas, areas of reef that are covered with a thin sediment veneer, wreck sites and sites of debris accumulation. The dredge spoil located in the southeastern corner of Area 1 should also be avoided as this represents an area of the seafloor which has elevated mud concentrations in the sediments (Miller *et al*, 2001). Areas delineated with the above mentioned acoustic facies on the seafloor maps (Figs. 4 & 5) should not be considered as areas suitable for sand winning.

7. UNCONSOLIDATED SEDIMENT THICKNESS

Unconsolidated sediment thickness values are illustrated as point data on the side-scan sonar seafloor maps (Figs. 4 & 5). Unconsolidated sediment thickness values range from 0 m in Area 1 to as much as 11.2 m in the northern part of Area 2. Sediment thickness values are at a minimum in the vicinity of reef or scattered reef outcrop and in areas where the aeolianite reef is continuous beneath the sediment.

Unconsolidated sediment thickness values in Area 1 vary from 0 m in areas of reef outcrop to as much as 9.5 m, with an average thickness of 3.6 m. The thickest accumulations of unconsolidated sediment occur in the southeastern corner of Area 1 where sediments attain a thickness of between 5.5m and 9.5 m (Fig. 4). Consistently thick accumulations of unconsolidated sediment occur in the western extremity of Area 1 where sediment accumulations of between 1.4 m and 5.8 m are evident. The sediment thins markedly in the central part of the borrow site, particularly in the vicinity of the reef outcrops (Fig. 4). Sediment thickness values range from 0 m to 4.5 m in this area and northern part of this borrow site. The average sediment thickness in Area 1 is ± 3.6 m.

Unconsolidated sediment accumulations in Area 2 vary from a minimum of 2.5 m to a maximum of 11.2 m, with a mean value of 5.2 m. The thickest sediment accumulations occur in the northern part of Area 2 adjacent to the Mgeni estuary. Unconsolidated sediment accumulation ranges from 2.9 m to 6.9 m in the southern part of Area 2 with the thickest accumulations occurring in water deeper than 19 m. The central and northern central part of Area 2 is characterised by variable unconsolidated sediment accumulations and average sediment thickness in this area averages ± 4.5 m. There is no reef exposure in Area 2 and in general there is a significant thickness of unconsolidated sediment throughout this borrow site.

8. GRAB SAMPLES

Twenty eight grab samples were collected to investigate the sedimentary character of the shelf sand in the proposed sand winning areas. Twelve samples were collected in Area 2 and sixteen were collected in Area 1 (Figs. 4 & 5). A full set of laboratory analyses including; sample position, gravel %, mud %, median, mean, sorting, skewness, dry density and carbonate % are presented in Appendix 1. Cumulative frequency curves and photographs of representative sediment samples are presented in Appendices 2 &3. **Note:** Sediment sorting is reported in terms of geological principles, whereby a well sorted sand has a very narrow grain-size distribution and a poorly sorted sand has a broader grain-size distribution.

8.1 Sediment Description - Area 1

The grab samples in Area 1 were collected in water depths ranging from 18 m to 27 m (Fig. 4). The grab samples from Area 1are characterised by light olive to light reddish brown, moderately well sorted to very well sorted, subangular to well rounded, medium-grained, clean free flowing sands with high calcium carbonate contents, low gravel contents and low interstitial mud (< 63 μm) contents. The sediments have an average "loose" dry density of 1.572 T/m^3 and an average "compact" (50 blows of compaction) dry density of 1.622 T/m^3. The sedimentary characteristics of the Area 1 grab samples are summarised in the Table 8.1 below.

$n = 16$	**Median** mm	**Mean** mm	**Sorting**	**Gravel** %	**Mud** %	**Dry Density**	**$CaCO_3$** %
Min.	0.213	0.227	0.25	0	0.97	1.525 T/m^3	8.85
Max.	0.444	0.474	0.62	1.35	1.75	1.689 T/m^3	23.47
Ave.	0.304	0.322	0.45	0.49	1.34	1.622 T/m^3	12.77
Color	Light olive - light reddish brown						
Sediment Type	Well sorted medium-grained sand						
Sediment Maturity	Subangular to rounded						

Table 8.1 Sedimentary characteristics of Area 1 grab samples.

8.2 Sediment Description - Area 2

The grab samples in Area 2 were collected in water depths ranging from -18 m to -23 m (Fig. 5). The grab samples from Area 2 are characterised by dark reddish brown to light grey, well sorted to very well sorted, subangular to rounded, fine-grained, clean free flowing sands with high calcium carbonate contents, low gravel contents and low interstitial mud contents. The sediments have an average "loose" dry density of 1.468 T/m³ and an average "compact" dry density of 1.536 T/m³. The sedimentary characteristics of the Area 2 grab samples are summarised in Table 8.2 below.

$n = 12$	**Median** mm	**Mean** mm	**Sorting**	**Gravel** %	**Mud** %	**Dry Density**	**$CaCO_3$** %
Min.	0.123	0.122	0.29	0	1.44	1.502 T/m³	3.19
Max.	0.203	0.217	0.45	0.34	2.62	1.610 T/m³	23.47
Ave.	0.147	0.149	0.34	0.04	2.04	1.535 T/m³	15.93
Color	Dark reddish brown - light grey						
Sediment Type	Very well sorted fine-grained sand						
Sediment Maturity	Subangular to rounded						

Table 8.2 Sedimentary characteristics of Area 2 grab samples.

8.3 Summary

On average the gravel, mud and calcium carbonate contents of the grab samples from the two borrow sites are fairly similar. The Area 1 grab samples are however, coarser-grained, less well sorted and have higher dry densities than the Area 2 sediments.

9. CORE SAMPLES

A total of five sediment cores measuring between 4.29 m and 4.57 m were collected in the proposed borrow sites, Cores 1, 2 & 3 from Area 1 and Cores 4 & 5 from Area 2. Laboratory analyses, cumulative frequency curves and representative sediment photographs are presented in Appendices, 1, 2 & 3. Core logs with laboratory analyses are presented below.

9.1 Core 1

Core 1 consists of light olive to dark reddish brown, moderately well sorted to very well sorted, subangular to rounded, fine-to medium-grained, clean free flowing sands with high calcium carbonate content, and low interstitial mud (< 63 μm) and gravel contents. The sediments have an average "loose" dry density of 1.490 T/m³ and an average "compact" (50 blows of compaction) dry density of 1.543 T/m³. The sedimentary succession of Core 1 consists of numerous upward fining sedimentary units, which are interbedded with more homogenous sedimentary units. The sediments are rich in shell fragments and contain occasional subangular to well rounded pebbles which are normally concentrated at the base of the upward fining units. Individual sedimentary units vary between 0.4 m to 1.0 m in thickness and are probably related to ancient dumping activity. The sedimentary characteristics of Core 1 samples are illustrated in Figure 6 and summarised in Table 9.1 below.

$n = 13$	**Median** mm	**Mean** mm	**Sorting**	**Gravel** %	**Mud** %	**Dry Density**	$CaCO_3$ %
Min.	0.186	0.191	0.35	0	0.58	1.464 T/m³	14.04
Max.	0.25	0.269	0.65	8.63	2.84	1.631 T/m³	29.61
Ave.	0.216	0.23	0.49	0.81	1.67	1.543 T/m³	19.48
Color	Light olive - dark reddish brown						
Sediment Type	Well sorted fine- to medium-grained sand						
Sediment Maturity	Subangular to rounded						

Table 9.1 Sedimentary characteristics of Core 1 sediment samples.

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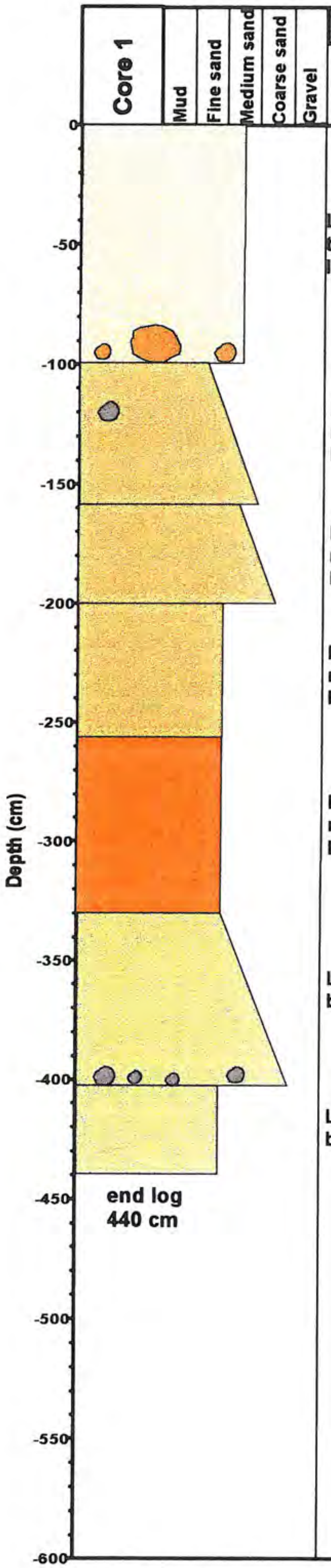

Colour	Sand (mm) Stats: Median	Mean	Sorting	Skewness	% <63 µ	% $CaCO_3$	Dry T/m³ Density	% Gravel	Comments
Light olive to light brown	0.250	0.260	0.46	-0.13	0.58	16.4	1.580	0.28	
	0.224	0.221	0.35	0.04	1.28	20.64	1.509	0.00	
	0.203	0.213	0.43	-0.16	1.76	21.59	1.508	0.27	Large pebbles & shell fragments (max. 40 mm)
Light reddish brown	0.210	0.237	0.56	-0.30	1.80	16.4	1.558	0.32	Clay ball
	0.248	0.269	0.61	-0.20	1.40	19.23	1.596	0.18	
Light reddish brown	0.186	0.191	0.39	-0.10	1.64	14.98	1.531	0.00	
	0.228	0.263	0.65	-0.31	1.16	14.51	1.631	0.72	
Light reddish brown	0.199	0.208	0.42	-0.16	1.31	20.17	1.556	0.10	
Dark reddish brown	0.187	0.196	0.44	-0.17	2.84	21.11	1.494	0.00	
	0.218	0.226	0.48	-0.11	2.60	20.64	1.492	0.00	
Light brown	0.218	0.238	0.53	-0.24	1.76	23.94	1.539	0.00	
	0.203	0.222	0.48	-0.27	1.87	29.61	1.464	8.63	Pebbles (up to 20 mm diam.)
Light brown	0.233	0.247	0.51	-0.17	1.72	14.04	1.600	0.00	

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Surveyed: 27/05/97 - 05/06/97
Coordinates: X+3305300;Y-7485.2

FIG. 6 Core 1

9.2 Core 2

Core 2 consists of light reddish brown, moderately well sorted to well sorted, subangular to rounded, medium-grained, clean free flowing sands with high calcium carbonate content and low interstitial mud (< 63 μm) contents. The sediments have an average "loose" dry density of 1.584 T/m^3 and an average "compact" dry density of 1.641 T/m^3. The sedimentary succession of Core 1 consists of an upper unit of upward fining sand, rich in shell fragments with a gravel base containing sub angular to rounded pebbles of up to 20 mm in diameter. The upper unit measures 1.35 m in thickness and overlies a more homogenous basal unit consisting of massive, medium grained, shell rich sand with occasional subangular to well rounded pebbles. The upward fining nature of the upper unit is probably related to historical dumping activity and later reworking by normal marine processes. The sedimentary characteristics of Core 2 are illustrated in Figure 7 and summarised in Table 9.2 below.

n =7	**Median** mm	**Mean** mm	**Sorting**	**Gravel** %	**Mud** %	**Dry Density**	**$CaCO_3$** %
Min.	0.238	0.239	0.43	0	0.51	1.599 T/m^3	13.57
Max.	0.463	0.52	0.83	7.29	2.17	1.720 T/m^3	18.76
Ave.	0.285	0.306	0.53	2.49	1.3	1.641 T/m^3	15.59
Color	Light reddish brown						
Sediment Type	Moderately well sorted medium-grained sand						
Sediment Maturity	Subangular to rounded						

Table 9.2 Sedimentary characteristics of Core 2 sediment samples.

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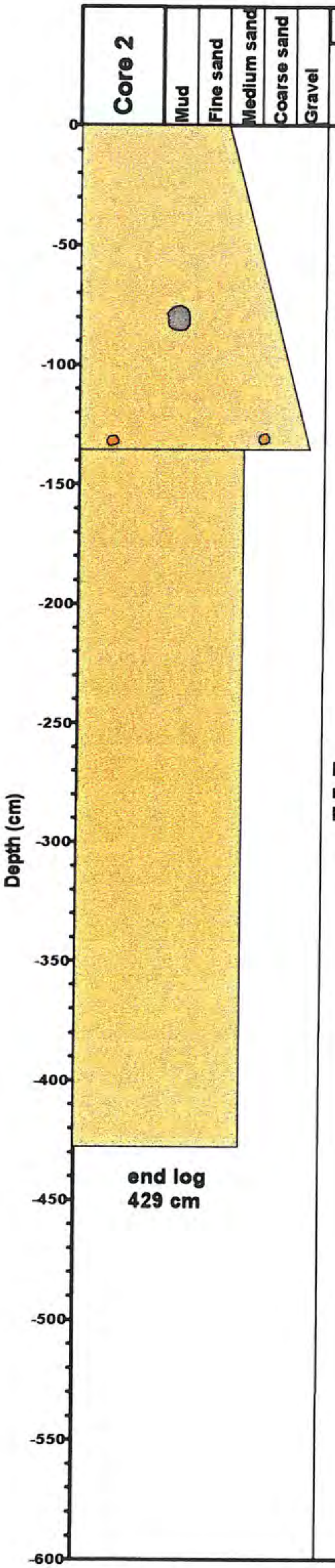

Colour	Median (Sand (phi) Stats)	Mean	Sorting	Skewness	% <63 µ	% $CaCO_3$	Dry T/m³ Density	% Gravel	Comments
	0.270	0.295	0.50	-0.26	1.06	14.51	1.612	2.29	
Light reddish brown	0.243	0.277	0.58	-0.32	2.17	15.93	1.605	3.15	20 mm clay ball
	0.463	0.520	0.83	-0.20	0.84	17.81	1.720	7.29	Isolated pebbles max 10 mm diam.
	0.255	0.261	0.43	-0.08	1.35	13.57	1.647	2.71	
	0.283	0.289	0.46	-0.07	0.51	14.98	1.638	0.34	
Light reddish brown									
	0.238	0.239	0.43	-0.01	1.84	13.57	1.599	0.00	
	0.243	0.259	0.48	-0.18	1.32	18.76	1.663	1.68	

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Fig. 7 Core 2

9.3 Core 3

Core 3 consists of light reddish brown to dark yellow, moderately sorted to well sorted, subangular to rounded, medium-grained, free flowing sands with high calcium carbonate contents and low interstitial mud contents. The core consists of an upper, upward fining unit which is 0.9 m thick and has a well defined gravel base. This unit overlies three homogenous sedimentary units which range in thickness from 0.1 m - 0.35 m. The basal part of the sedimentary succession comprises an upward fining sedimentary unit which has a minimum thickness of 2.65 m. The gravel content of this core is fairly high and is concentrated at the base of the upper upward fining unit and in the sedimentary units which have a dark yellow colouration. The basal unit has very low gravel contents and is believed to represent normal marine sedimentation while the upper unit is probably related to dumping activity. Exposed reef was sited adjacent to this core site by the commercial diver in attendance during the coring procedure. Core refusal was encountered at a depth of 4.30 m probably due to the core barrel striking the buried reef surface. The elevated gravel content of this core is probably related to the higher concentration of bioclastic gravel in close proximity to the reef (Fig. 4). The sedimentary character of Core 3 is illustrated in Figure 8 and summarised in Table 9.3 below.

$n = 10$	**Median** mm	**Mean** mm	**Sorting**	**Gravel** %	**Mud** %	**Dry Density**	**$CaCO_3$** %
Min.	0.213	0.211	0.35	0	0.27	1.554 T/m^3	9.32
Max.	0.387	0.432	0.77	34.54	4.85	1.779 T/m^3	32.91
Ave.	0.289	0.314	0.52	8.4	1.83	1.651 T/m^3	16.68
Color	Light reddish brown to dark yellow						
Sediment Type	Moderately well sorted medium-grained sand with subordinate gravel lenses						
Sediment Maturity	Subangular to rounded						

Table 9.3 Sedimentary characteristics of Core 3 sediment samples.

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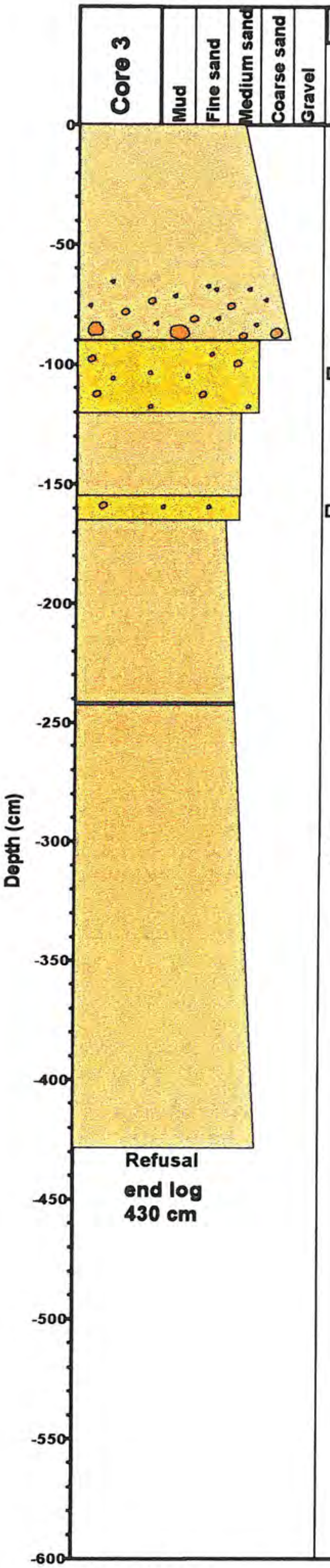

Colour	Sand (phi) Stats Median	Mean	Sorting	Skewness	% <63 µ	% CaCO3	Dry T/m³ Density	% Gravel	Comments
	0.323	0.360	0.54	-0.30	0.91	12.62	1.625	1.80	
Light reddish brown	0.328	0.369	0.62	-0.28	0.27	14.04	1.718	5.60	
	0.387	0.432	0.77	-0.21	3.27	32.91	1.760	34.54	Pebbles & shell gravel (max 10 mm diam.)
Dark yellow	0.316	0.371	0.69	-0.34	1.56	27.25	1.779	26.44	Pebbles up to 5 mm
Light reddish brown	0.314	0.349	0.51	-0.30	1.35	14.98	1.681	2.35	
Dark yellow	0.259	0.269	0.58	-0.09	4.85	18.76	1.617	11.06	
	0.224	0.229	0.36	-0.09	1.63	9.32	1.554	0.00	
	0.213	0.211	0.35	0.05	1.78	9.79	1.565	0.00	Clay lamminae
Light reddish brown									
	0.235	0.242	0.38	-0.10	1.67	14.51	1.563	0.00	
	0.291	0.305	0.41	-0.16	1.01	12.62	1.645	2.20	

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Fig. 8 Core 3

9.4 Core 4

Core 4 consists of dark reddish brown to light grey, well sorted to very well sorted, subangular to rounded, fine-grained, free flowing sands with high calcium carbonate contents and moderate to low interstitial mud contents. Gravel content of the sediments is typically low with the only exception being a shelly gravel lag which is evident at a core depth of -0.7 m to -0.8 m. The sediments have an average "loose" dry density of 1.411 T/m^3 and an average "compact" dry density of 1.475 T/m^3. The sedimentary succession is divided into a thin (0.57 m), dark reddish brown to light grey upper unit and a thick (3.58 m), light grey basal unit which are separated by the moderately well developed shelly gravel lag deposit (Fig.9). The sedimentary nature of Core 4 is illustrated in Figure 9 and summarised in Table 9.4 below.

$n = 7$	**Median** mm	**Mean** mm	**Sorting**	**Gravel** %	**Mud** %	**Dry Density**	**$CaCO_3$** %
Min.	0.131	0.131	0.21	0	2.2	1.391 T/m^3	22.53
Max.	0.15	0.172	0.43	8.35	3.57	1.628 T/m^3	32.44
Ave.	0.142	0.149	0.31	1.56	2.91	1.475 T/m^3	26.71
Color	Dark reddish brown to light grey						
Sediment Type	Well sorted to very well sorted fine-grained sand with subordinate shelly gravel lags						
Sediment Maturity	Subangular to rounded						

Table 9.4 Sedimentary characteristics of Core 4 sediment samples.

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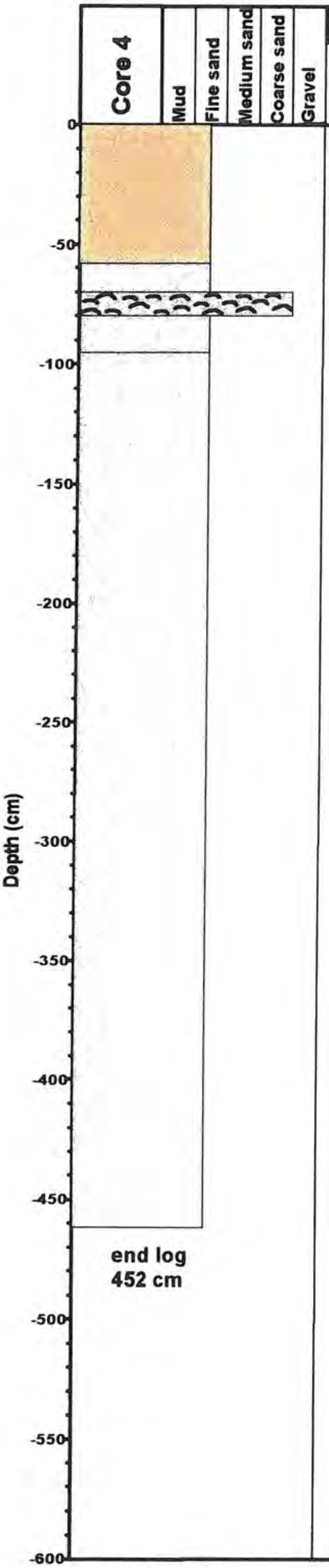

Colour	Sand (phi) Stats: Median	Mean	Sorting	Skewness	% <63 µ	% $CaCO_3$	Dry T/m³ Density	% Gravel	Comments
Dark red brown to light grey	0.144	0.152	0.37	-0.22	3.51	23.0	1.444	0.36	
Light grey	0.148	0.163	0.39	-0.38	3.57	22.53	1.490	1.47	
	0.150	0.172	0.43	-0.46	2.97	32.44	1.628	8.35	Shell lag
	0.146	0.151	0.28	-0.19	2.63	27.25	1.481	0.37	
	0.142	0.143	0.27	-0.07	2.28	28.19	1.461	0.12	
Light grey	0.133	0.132	0.21	0.07	2.20	28.19	1.391	0.00	
	0.131	0.131	0.22	-0.03	3.23	25.36	1.433	0.25	

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Fig. 9 Core 4.

9.5 Core 5

Core 5 consists of dark reddish brown to light grey, moderately well sorted to well sorted, fine-grained sand with high calcium carbonate contents and moderate to low interstitial mud contents. The sediments have an average "loose" dry density of 1.460 T/m^3 and an average "compact" dry density of 1.526 T/m^3. Gravel content of the sediments is typically low except at the base of the core where gravel concentrations of 8 % - 14 % are encountered (Fig. 10). The sedimentary succession consists of a 1.15 m thick upper unit which is characterised by a dark reddish brown to light grey colour and a lower, light grey unit which measures 3.23 m in thickness. The sedimentary units are very similar in sedimentary character except for the base of the lower unit where there is an increase in the mean grain-size, gravel content and dry density. The base of Core 5 is characterised by a light olive gravel rich horizon which is believed to be the top of a much older sedimentary unit identified from the sub-bottom profiling records. The sedimentary nature of Core 5 is illustrated in Figure 10 and summarised in Table 9.5 below.

$n = 9$	**Median** mm	**Mean** mm	**Sorting**	**Gravel** %	**Mud** %	**Dry Density**	**$CaCO_3$** %
Min.	0.13	0.13	0.22	0	0.73	1.382 T/m^3	17.34
Max.	0.401	0.438	0.88	14.04	2.99	1.818 T/m^3	34.32
Ave.	0.173	0.19	0.46	3.44	2.15	1.526 T/m^3	24.57
Color	Dark reddish brown to light grey						
Sediment Type	Moderately well sorted to well sorted, fine-grained sand with subordinate gravel lenses						
Sediment Maturity	Subangular to rounded						

Table 9.5 Sedimentary characteristics of Core 5 sediment samples.

9.6 Summary

The Area 1 cores show more textural variation with depth than the Area 2 cores and on average the Area 1 sediments are coarser grained, show poorer sorting, have lower interstitial mud contents, higher dry densities and lower calcium carbonate contents than the Area 2 sediments.

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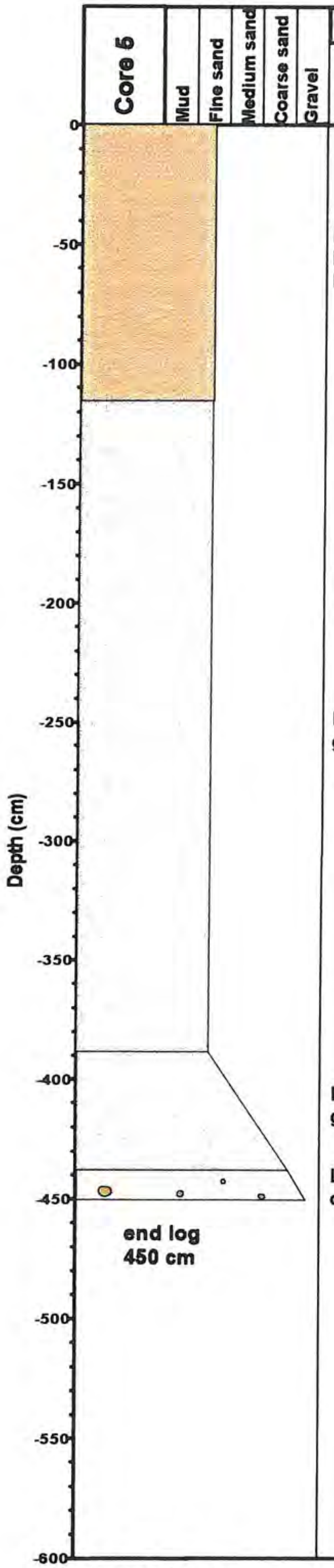

Colour	Sand (phi) Stats: Median	Mean	Sorting	Skewness	% <63 µ	% CaCO3	Dry T/m³ Density	% Gravel	Comments
	0.138	0.136	0.26	0.08	2.99	26.3	1.382	0.89	
Dark red brown to light grey	0.146	0.159	0.39	-0.32	2.31	22.53	1.516	0.45	
	0.157	0.168	0.41	-0.22	2.98	24.42	1.527	0.51	
	0.151	0.161	0.35	-0.28	1.24	27.72	1.490	4.56	
Light grey	0.130	0.130	0.22	0.03	2.38	23.47	1.439	1.99	
	0.138	0.165	0.49	-0.53	2.29	20.64	1.488	0.57	
Light grey	0.139	0.147	0.37	-0.24	2.47	17.34	1.459	0.00	
	0.159	0.205	0.73	-0.51	1.92	24.42	1.612	7.99	
Light olive	0.401	0.438	0.88	-0.14	0.73	34.32	1.818	14.04	Pebbles up to 15 mm diam.

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Surveyed: 27/05/97 - 05/06/97
Coordinates: X+3300589;Y-6489.1

Fig. 10 Core 5

10. DISCUSSION

In terms of weighing up the potential sand winning areas up against each other, there are several factors which must be considered in determining which of the areas will ultimately be favoured. Important criterion include; the nature of the sediments to be dredged, water depth, proximity to "hard" substrates, availability of sufficient sediment volumes, predictability of dredge conditions with increased sediment depth, proximity to the area where the sediments will be used and the potential environmental consequences of dredging.

The geophysical data from the Council for Geoscience's data base were used to assess water depth, unconsolidated sediment thickness and seafloor conditions in each of the potential borrow areas and to highlight the presence of any "hard" objects or substrates that could be detrimental to dredging activity. The bathymetry data shows similar water depths in both survey blocks with depths ranging from -19 m to -32 m in Area 1 and depths ranging from -18 m to -23 m in Area 2. Both potential sand winning areas have large areas of sediment cover on gently sloping seafloor in shallow water and therefore the bathymetric data neither favours nor rejects either of the borrow sites.

Of the seven acoustic facies identified from the side-scan sonar data, only four can be viewed as potential hazards for dredging activity. The most significant of these are the areas of scattered reef exposure and areas where reef is buried beneath a thin veneer of sediment. These substrates are confined to the Area 1 survey block, in particular the northeastern section (Fig. 4). The reef exposures are probably aeolianite which characteristically have unconfined uniaxial compressive strengths in the order of 70 Mpa. These "hard" substrates should be avoided by dredging activity. The smaller sonar contacts which comprise, debris occurrences and ship wrecks also represent "hard" (probably metal) objects resting on the seafloor and present obvious problems for sediment dredging. These objects should also be avoided during sand dredging activity. The side-scan sonar data interpretation would seem to favour Area 2 as the better sand winning site as there are no reef occurrences in that survey block.

EDL used this

The unconsolidated sediment thickness in the proposed sand winning areas was measured from sub-bottom profiling records and represents the minimum thickness of sediment that can be removed by dredging. Unconsolidated sediment thickness varies from 0 m in areas of reef outcrop to as much as 9.5 m in Area 1 and averages 3.6 m. The presence of the shallow No. 1 reef pinnacles to the northeast and the presence of reef exposure within the Area 1 borrow site, is cause for concern as it implies that the reef complex is continuous beneath the Area 1 sediments. The line spacing of 150 m which was used during the collection of the geophysical data, precludes the possibility of knowing the location of all buried reef pinnacles, but is still adequate enough to highlight safe dredging areas. These areas are represented by the thick sediment accumulations in the southeastern corner of the Area 1 borrow site and the area adjacent to its western boundary (Fig. 4). Unconsolidated sediment thickness in Area 2 varies from a minimum of 2.5 m to a maximum of 11.2 m and averages 5.2 m. Area 2 is characterised by regionally developed thick sediment accumulations and inadequate sediment thickness is not perceived to be a problem in this borrow site.

Probably the most important criterion to be considered when weighing up the two potential sand winning areas, is the nature of the sediments. The sediments are, after all, to be dredged for a specific purpose (backfill in this case). The emphasis of this report has therefore been to describe the sediments from each borrow site in great detail and to arrive at a set of sedimentary parameters which best describes the sediments.

A total of 74 sediment samples were taken as grab samples or as sub-samples from sediment cores, 46 from Area 1 and 28 from Area 2. The samples were subjected to a suite of laboratory tests and numerous sedimentary parameters including, median grain-size, mean grain-size, sediment sorting, sediment skewness, mud content, gravel content, calcium carbonate content and dry density were measured. Representative values for each of the sedimentary parameters for each survey area were calculated by averaging all the sedimentary analyses for each group of samples i.e. grab samples and core samples. Tables 10.1 and 10.2 compare the representative sedimentary parameters calculated from the grab samples and core samples from each of the borrow sites, and then combines all laboratory analyses to produce a final set of analyses, which is believed to be representative of the sedimentary succession for each of the potential sand winning areas.

	Median mm	Mean mm	Sorting	Gravel %	Mud %	Dry Density	$CaCO_3$ %
Grabs (*n* = 16)	0.304	0.322	0.45	0.49	1.34	1.622 T/m^3	12.77
Cores (*n* = 30)	0.256	0.276	0.51	3.73	1.64	1.602 T/m^3	17.64
All (*n* = 46)	**0.273**	**0.292**	**0.49**	**2.6**	**1.54**	**1.609 T/m^3**	**15.95**

Table 10.1 Representative sediment characteristics of Area 1 sediment samples.

	Median mm	Mean mm	Sorting	Gravel %	Mud %	Dry Density	$CaCO_3$ %
Grabs (*n* = 12)	0.147	0.149	0.34	0.04	2.04	1.535 T/m^3	12.77
Cores (*n* = 16)	0.16	0.172	0.39	2.62	2.48	1.504 T/m^3	25.51
All (*n* = 28)	**0.154**	**0.162**	**0.37**	**1.51**	**2.29**	**1.517 T/m^3**	**21.4**

Table 10.2 Representative sediment characteristics of Area 2 sediment samples.

Tables 10.1 and 10.2 show that Area 1 sediments are in general coarser grained and less well sorted than Area 2 sediments. Area 1 sediments have on average marginally higher gravel contents and marginally lower interstitial mud contents than Area 2 sediments, but have significantly lower calcium carbonate contents and significantly higher "compact" dry densities that the Area 2 sediments. In terms of sediment predictability, Area 2 sediments are more homogenous than Area 1 sediments, the latter shows significant variation in texture with depth.

The coarser grain-size, poorer sorting, lower interstitial mud content and higher dry densities of the Area 1 sediments probably makes these sediments more suitable for use as backfill than the Area 2 sediments. In terms of environmental considerations the Area 1 sediments are also favored, as large volumes of these sediments represent artificially dumped material. Dredging of this material is considered favourable to disturbing the more pristine seafloor underlain by Area 2 sediments.

11. RECOMMENDATIONS

Based on all the above arguments, the most promising sand winning sites (in the author's opinion) have been selected from each of the borrow sites and are illustrated in Figures 11 & 12. The most favourable area for sand winning in Area 1 is a ± 800m wide corridor of adjacent to the western boundary of the survey area (Fig. 11). The lack of reef exposure, close proximity to the harbour entrance, the sparse nature of debris accumulations and availability of adequate sediment thickness (3 - 4 m) are criterion which support this statement.

The lack of reef exposure, sparse distribution of debris and almost regional availability of thick unconsolidated sediment deposits in Area 2, makes the borrow site suitable for sand winning. In light of economic considerations, the southern part of Area 2 (Fig. 12), is by virtue of the closer proximity to the harbour entrance considered the most favourable area for sand winning in the Area 2 borrow site.

Ultimately the engineering properties of the sediments will determine which of the borrow sites is actually used. Determination of which sediments are more attractive in terms of engineering principles, is however beyond the scope of this report. This report highlights potential sand winning areas from each of the larger borrow sites, which are deemed as the most desirable for sediment dredging. These smaller areas are, however, not entirely free of potentially hazardous dredge conditions due to the random and scattered nature of debris. All areas of debris accumulation within the proposed sand winning areas (Figs. 11 & 12) should be avoided, as these are probably metal objects capable of damaging dredging equipment.

Dredging sediment from both areas and mixing them prior to emplacement may improve the sedimentary character of the backfill material. As a rough guideline a sample of Area 1 sediments (G21) was mixed with Area 2 sediments (G8) in varying proportions and the dry density of this sediment was recalculated to assess the effect of sediment mixing. An optimum mixing proportion of 30 % Area 2 sediments and 70 % Area 1 sediments brought about an increase in "compact" dry density from 1.6097 T/m^3 to 1.6495 T/m^3 of 2.47 % which represents an increase ± 2.5 %.

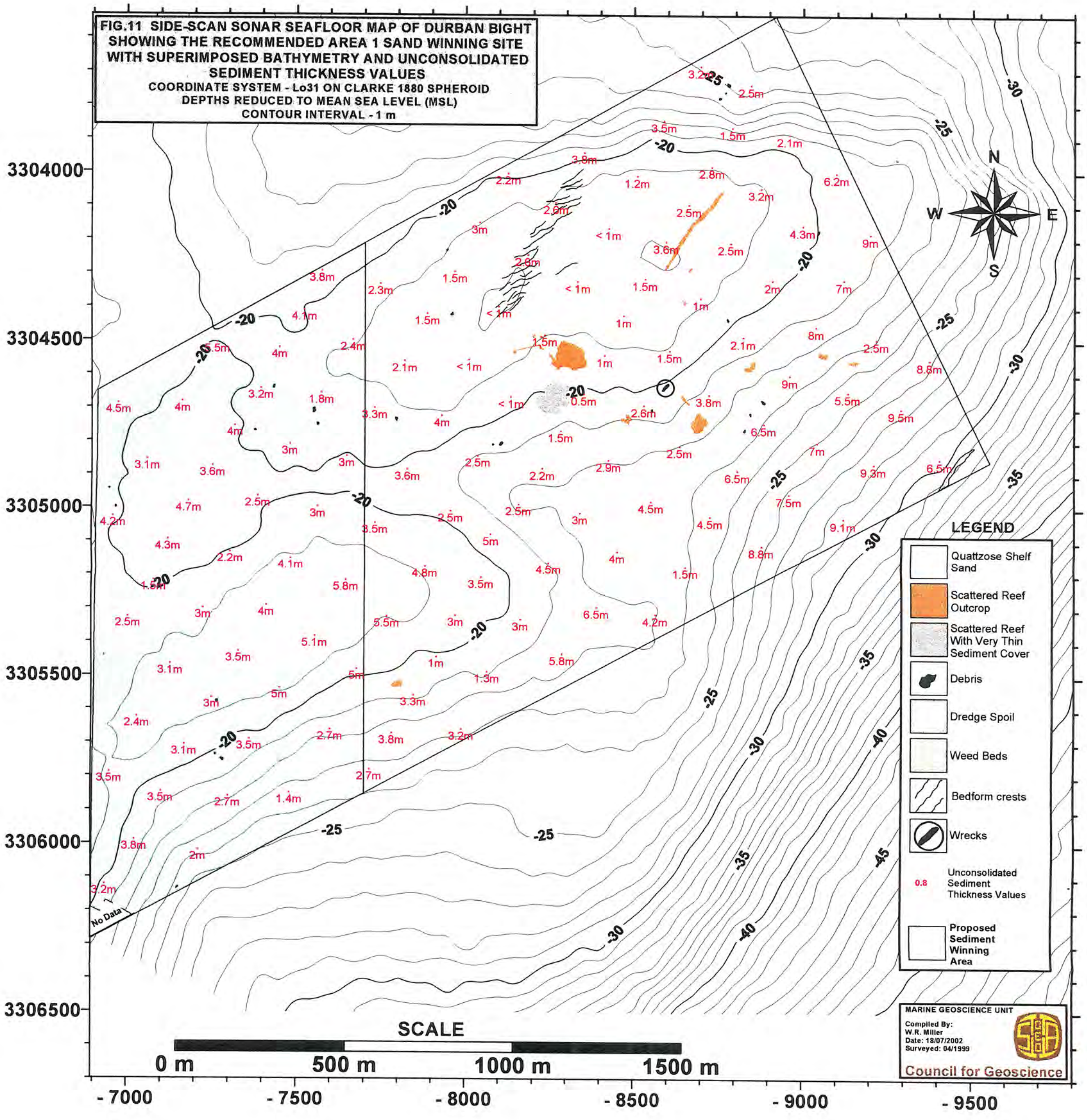

FIG.11 SIDE-SCAN SONAR SEAFLOOR MAP OF DURBAN BIGHT SHOWING THE RECOMMENDED AREA 1 SAND WINNING SITE WITH SUPERIMPOSED BATHYMETRY AND UNCONSOLIDATED SEDIMENT THICKNESS VALUES

COORDINATE SYSTEM - Lo31 ON CLARKE 1880 SPHEROID
DEPTHS REDUCED TO MEAN SEA LEVEL (MSL)
CONTOUR INTERVAL - 1 m

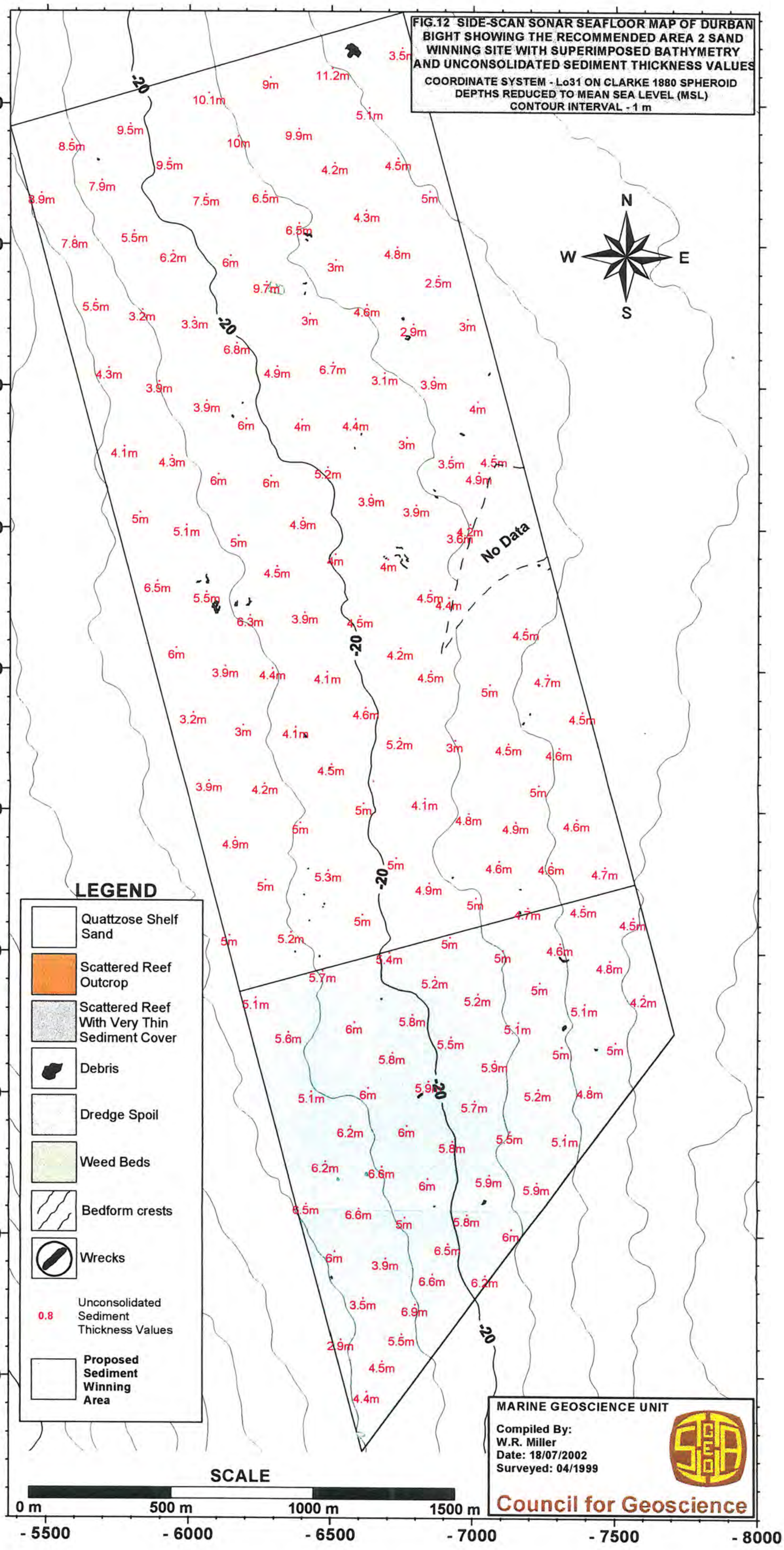
FIG.12 SIDE-SCAN SONAR SEAFLOOR MAP OF DURBAN BIGHT SHOWING THE RECOMMENDED AREA 2 SAND WINNING SITE WITH SUPERIMPOSED BATHYMETRY AND UNCONSOLIDATED SEDIMENT THICKNESS VALUES
COORDINATE SYSTEM - Lo31 ON CLARKE 1880 SPHEROID
DEPTHS REDUCED TO MEAN SEA LEVEL (MSL)
CONTOUR INTERVAL - 1 m
N
E
S
W
No Data
-20
LEGEND
Quattzose Shelf Sand
Scattered Reef Outcrop
Scattered Reef With Very Thin Sediment Cover
Debris
Dredge Spoil
Weed Beds
Bedform crests
Wrecks
0.8
Unconsolidated Sediment Thickness Values
Proposed Sediment Winning Area
SCALE
0 m
500 m
1000 m
1500 m
MARINE GEOSCIENCE UNIT
Compiled By:
W.R. Miller
Date: 18/07/2002
Surveyed: 04/1999
Council for Geoscience
3299000
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3302500
3303000
3303500
- 5500
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- 7000
- 7500
- 8000

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APPENDIX 1.

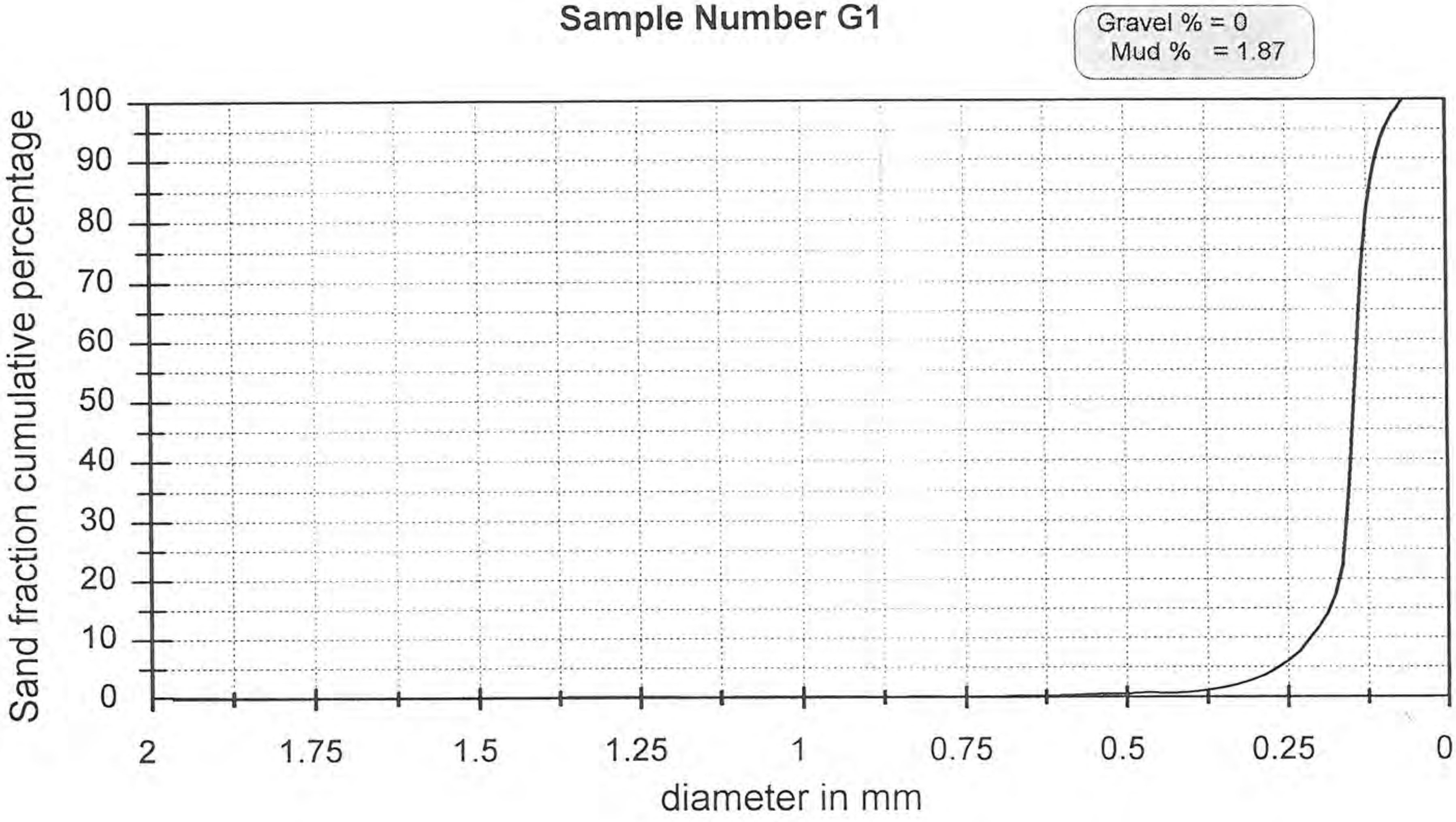
SEDIMENTARY LABORATORY ANALYSES

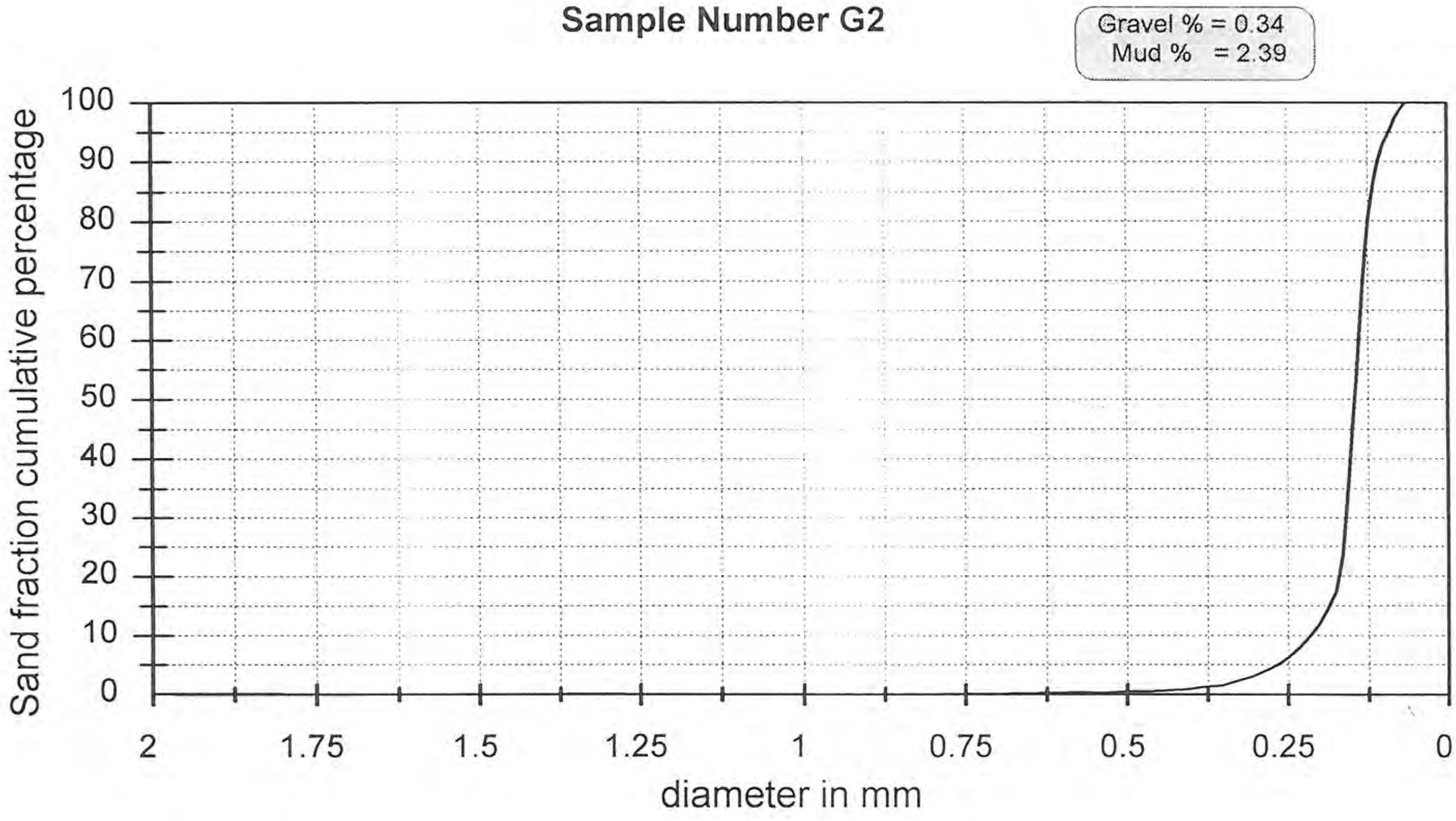
Sample	Lo 31	Coordinates	Gravel%	Mud%	Graphics Statistics from Sand Fraction						Dry Density	Carbonate
No.	X	Y	(>2000μ)	(<63μ)	Median	Mean	mm-Mn	mm-Med	Sorting	Skewness	(Tons/m3)	%
G1	3298870.9	-6656.77	0	1.87	2.87	2.85	0.139	0.137	0.29	-0.07	1.515	23.47
G2	3299329.3	-6222.43	0.34	2.39	2.87	2.86	0.138	0.137	0.3	-0.04	1.52	21.59
G3	3299799.2	-5715.7	0	1.88	2.65	2.66	0.158	0.159	0.39	0.02	1.512	3.19
G4	3299836.1	-6957.76	0	2.26	2.81	2.78	0.146	0.143	0.32	-0.11	1.518	21.11
G5	3300330.1	-6439.6	0	2.17	2.94	2.96	0.129	0.130	0.31	0.05	1.529	12.62
G6	3300788.6	-5897.31	0.16	2.62	3.02	3.03	0.122	0.123	0.38	0.04	1.502	8.38
G7	3300968.9	-7260.02	0	1.85	2.81	2.77	0.146	0.143	0.34	-0.12	1.531	19.23
G8	3301475.6	-6777.42	0	1.84	2.77	2.8	0.144	0.147	0.34	0.08	1.555	15.93
G9	3301993.8	-6270.69	0	1.85	2.83	2.85	0.139	0.141	0.32	0.05	1.567	14.51
G10	3302090.3	-7585.14	0	2.29	2.77	2.78	0.146	0.147	0.32	0.02	1.527	16.4
G11	3302753.3	-7126.67	0	1.98	2.66	2.59	0.166	0.158	0.35	-0.2	1.54	17.34
G12	3303380.6	-6668.2	0	1.44	2.3	2.2	0.217	0.203	0.45	-0.22	1.61	17.34
G13	3304809.4	-7126.67	0	1.64	2.03	2.01	0.248	0.245	0.44	-0.04	1.602	13.1
G14	3305490.1	-7144.45	1.15	1.07	1.6	1.51	0.35	0.330	0.44	-0.21	1.675	12.62
G15	3305960	-7162.23	1.04	1.57	2	1.88	0.271	0.250	0.61	-0.18	1.559	23.47
G16	3305532	-7324.79	0	1.75	1.93	1.9	0.268	0.262	0.36	-0.08	1.592	12.62
G17	3305285.6	-7414.96	0.56	1.09	1.6	1.5	0.355	0.330	0.47	-0.21	1.629	12.15
G18	3305351.7	-7632.13	0.35	1.27	1.17	1.08	0.474	0.444	0.62	-0.15	1.671	10.27
G19	3305176.4	-7680.39	0.13	1.43	1.66	1.61	0.327	0.316	0.4	-0.13	1.621	11.21
G20	3304531.3	-7813.74	0.66	1.34	1.39	1.28	0.412	0.382	0.52	-0.22	1.644	13.57
G21	3304959.3	-7842.95	0	1.52	1.71	1.62	0.326	0.306	0.44	-0.2	1.61	12.15
G22	3305496.5	-7873.43	0.47	1.21	1.42	1.27	0.416	0.374	0.59	-0.26	1.658	11.21
G23	3304243	-8024.56	0.17	1.15	1.79	1.7	0.308	0.289	0.39	-0.23	1.663	11.21
G24	3304405.5	-8356.03	1.35	1.27	1.82	1.73	0.302	0.283	0.39	-0.23	1.656	12.15
G25	3305020.2	-8470.33	0	1.49	2.15	2.14	0.227	0.225	0.25	-0.04	1.553	11.21
G26	3304182	-8397.94	1.16	0.97	1.65	1.53	0.347	0.319	0.53	-0.24	1.689	14.51
G27	3304157.9	-8698.93	0.47	1.1	1.79	1.73	0.301	0.289	0.41	-0.14	1.6	8.85
G28	3304833.5	-9139.62	0.25	1.6	2.23	2.14	0.227	0.213	0.39	-0.23	1.525	14.04
Cores												
C1-1	3305300	-7485.2	0.28	0.58	2	1.94	0.26	0.250	0.46	-0.13	1.58	16.4
C1-2			0	1.28	2.16	2.18	0.221	0.224	0.35	0.04	1.51	20.64
C1-3			0.27	1.76	2.3	2.23	0.213	0.203	0.43	-0.16	1.508	21.59
C1-4			0.32	1.8	2.25	2.08	0.237	0.210	0.56	-0.3	1.558	16.4
C1-5			0.18	1.4	2.01	1.89	0.269	0.248	0.61	-0.2	1.596	19.23
C1-6			0	1.64	2.43	2.39	0.191	0.186	0.39	-0.1	1.531	14.98
C1-7			0.72	1.16	2.13	1.93	0.263	0.228	0.65	-0.31	1.631	14.51
C1-8			0.1	1.31	2.33	2.27	0.208	0.199	0.42	-0.16	1.556	20.17
C1-9			0	2.84	2.42	2.35	0.196	0.187	0.44	-0.17	1.494	21.11
C1-10			0	2.6	2.2	2.14	0.226	0.218	0.48	-0.11	1.492	20.64
C1-11			0	1.76	2.2	2.07	0.238	0.218	0.53	-0.24	1.539	23.94
C1-12			8.63	1.87	2.3	2.17	0.222	0.203	0.48	-0.27	1.464	29.61
C1-13			0	1.72	2.1	2.02	0.247	0.233	0.51	-0.17	1.6	14.04

Sample	Lo 31	Coordinates	Gravel%	Mud%	Graphics Statistics from Sand Fraction						Dry Density	Carbonate
No.	X	Y	(>2000µ)	(<63µ)	Median	Mean	mm-Mn	mm-Med	Sorting	Skewness	(Tons/m3)	%
C2-1	3304902	-7906.7	2.29	1.06	1.89	1.76	0.295	0.270	0.5	-0.26	1.612	14.51
C2-2			3.15	2.17	2.04	1.85	0.277	0.243	0.58	-0.32	1.605	15.93
C2-3			7.29	0.84	1.11	0.94	0.52	0.463	0.83	-0.2	1.72	17.81
C2-4			2.71	1.35	1.97	1.94	0.261	0.255	0.43	-0.08	1.647	13.57
C2-5			0.34	0.51	1.82	1.79	0.289	0.283	0.46	-0.07	1.638	14.98
C2-6			0	1.84	2.07	2.06	0.239	0.238	0.43	-0.01	1.599	13.57
C2-7			1.68	1.32	2.04	1.95	0.259	0.243	0.48	-0.18	1.663	18.76
C3-1	3304240	-8596.4	1.8	0.91	1.63	1.47	0.36	0.323	0.54	-0.3	1.625	12.62
C3-2			5.6	0.27	1.61	1.44	0.369	0.328	0.62	-0.28	1.718	14.04
C3-3			34.54	3.27	1.37	1.21	0.432	0.387	0.77	-0.21	1.76	32.91
C3-4			26.44	1.56	1.66	1.43	0.371	0.316	0.69	-0.34	1.779	27.25
C3-5			2.35	1.35	1.67	1.52	0.349	0.314	0.51	-0.3	1.681	14.98
C3-6			11.06	4.85	1.95	1.89	0.269	0.259	0.58	-0.09	1.617	18.76
C3-7			0	1.63	2.16	2.12	0.229	0.224	0.36	-0.09	1.554	9.32
C3-8			0	1.78	2.23	2.24	0.211	0.213	0.35	0.05	1.565	9.79
C3-9			0	1.67	2.09	2.05	0.242	0.235	0.38	-0.1	1.563	14.51
C3-10			2.2	1.01	1.78	1.71	0.305	0.291	0.41	-0.16	1.645	12.62
C4-1	3301736	-6815.4	0.36	3.51	2.8	2.72	0.152	0.144	0.37	-0.22	1.444	23
C4-2			1.47	3.57	2.76	2.61	0.163	0.148	0.39	-0.38	1.49	22.53
C4-3			8.35	2.97	2.74	2.54	0.172	0.150	0.43	-0.46	1.628	32.44
C4-4			0.37	2.63	2.78	2.73	0.151	0.146	0.28	-0.19	1.481	27.25
C4-5			0.12	2.28	2.82	2.8	0.143	0.142	0.27	-0.07	1.461	28.19
C4-6			0	2.2	2.91	2.93	0.132	0.133	0.21	0.07	1.391	28.19
C4-7			0.25	3.23	2.93	2.93	0.131	0.131	0.22	-0.03	1.433	25.36
C5-1	3300589	-6489.1	0.89	2.99	2.86	2.88	0.136	0.138	0.26	0.08	1.382	26.3
C5-2			0.45	2.31	2.78	2.65	0.159	0.146	0.39	-0.32	1.516	22.53
C5-3			0.51	2.98	2.67	2.58	0.168	0.157	0.41	-0.22	1.527	24.42
C5-4			4.55	1.24	2.73	2.63	0.161	0.151	0.35	-0.28	1.49	27.72
C5-5			1.99	2.38	2.94	2.95	0.13	0.130	0.22	0.03	1.439	23.47
C5-6			0.57	2.29	2.86	2.6	0.165	0.138	0.49	-0.53	1.488	20.64
C5-7			0	2.47	2.85	2.76	0.147	0.139	0.37	-0.24	1.459	17.34
C5-8			7.99	1.92	2.65	2.28	0.205	0.159	0.73	-0.51	1.612	24.42
C5-9			14.04	0.73	1.32	1.19	0.438	0.401	0.88	-0.14	1.818	34.32

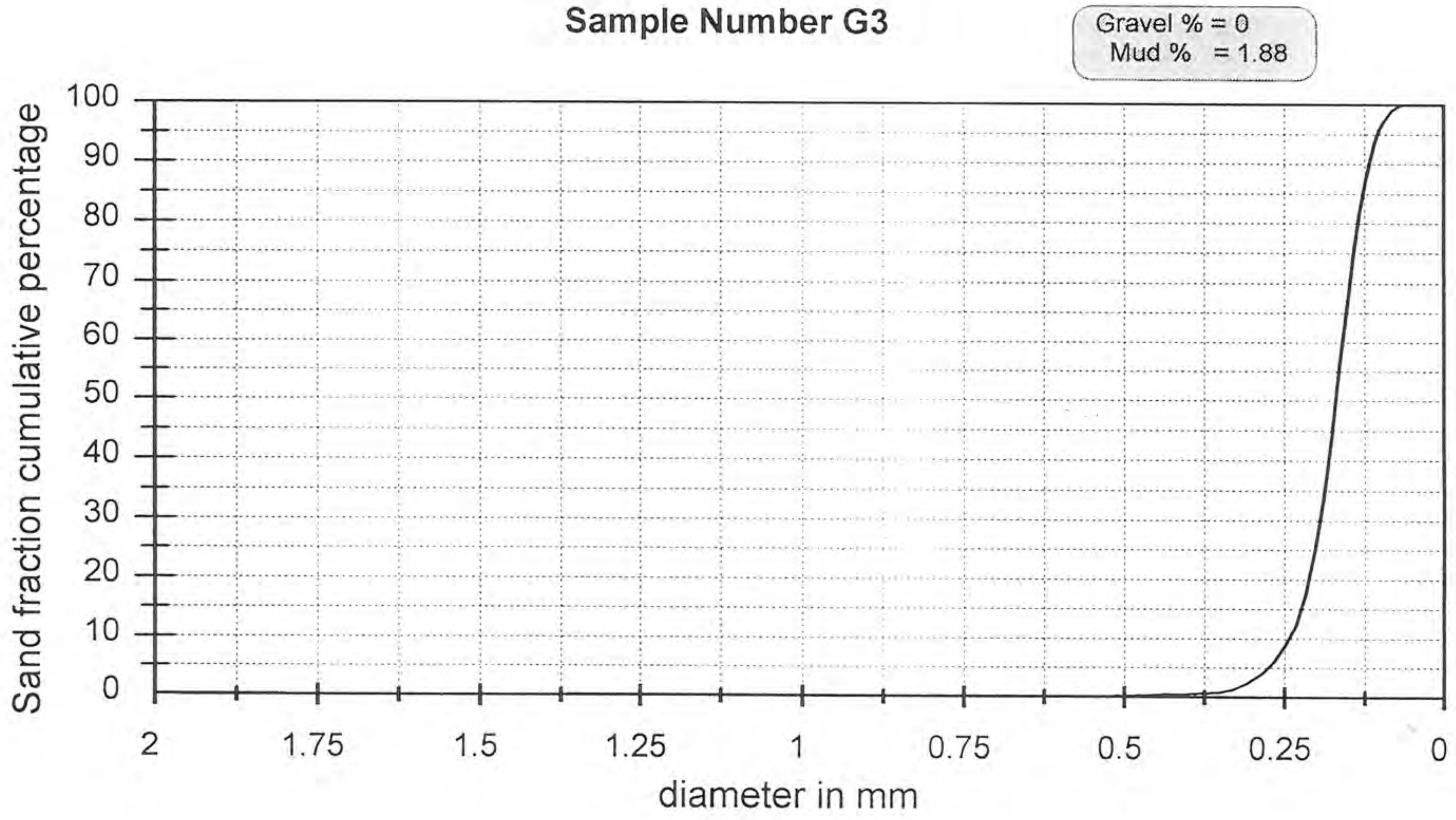
APPENDIX 2

CUMULATIVE FREQUENCY DISTRIBUTION CURVES

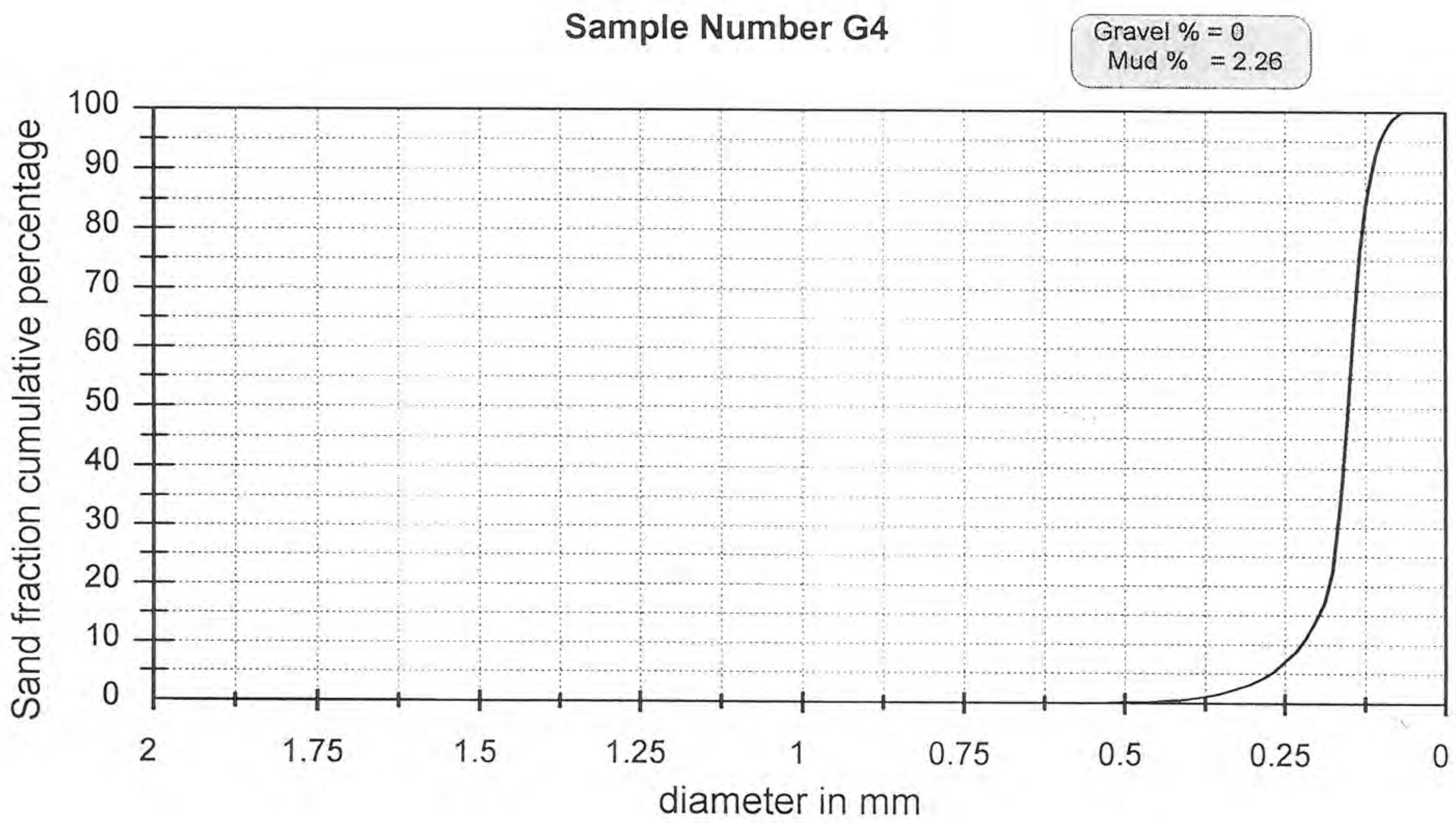

Sample Number G1
Gravel % = 0
Mud % = 1.87
100
90
80
70
60
50
40
30
20
10
0
Sand fraction cumulative percentage
2
1.75
1.5
1.25
1
0.75
0.5
0.25
0
diameter in mm

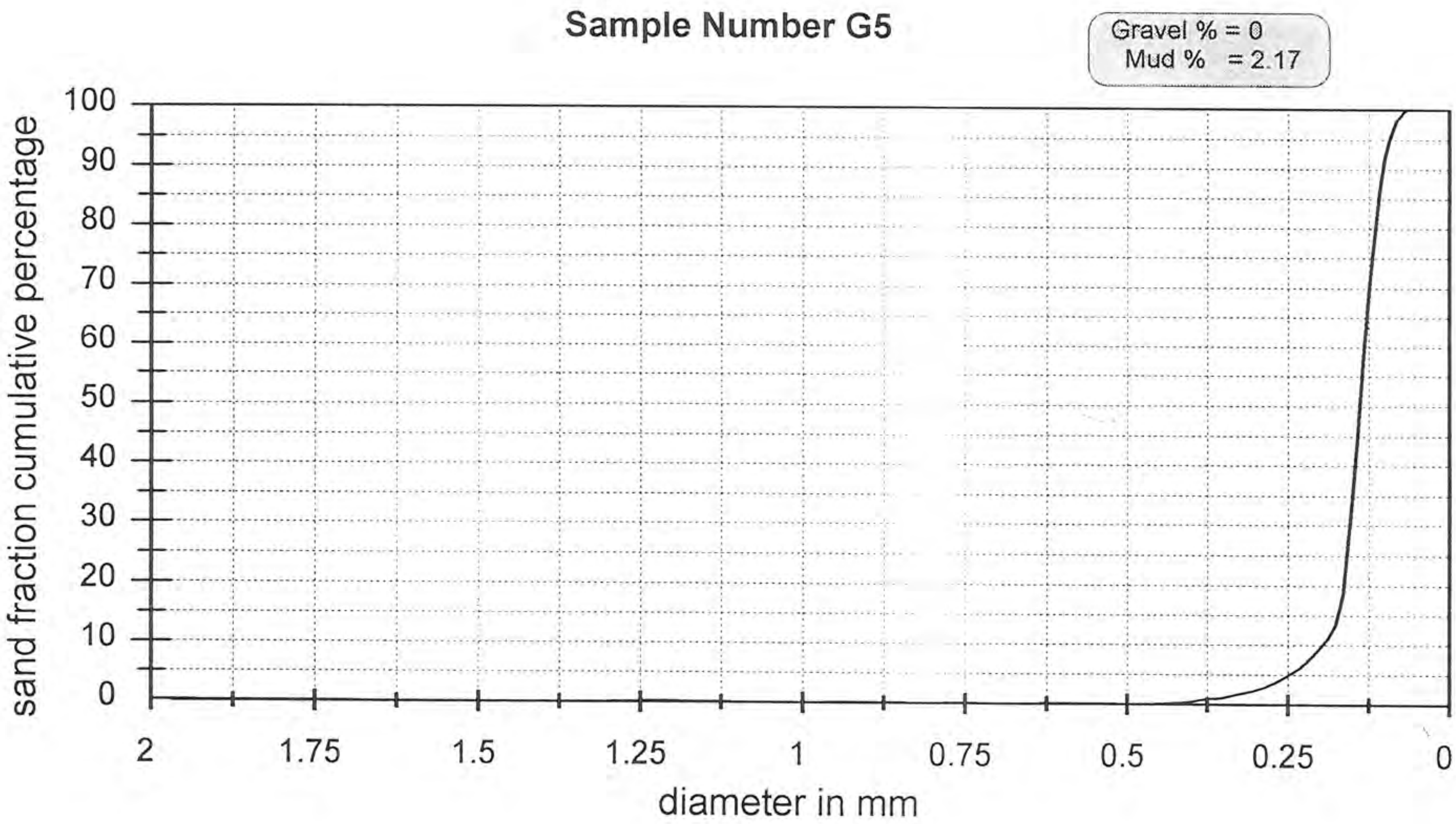


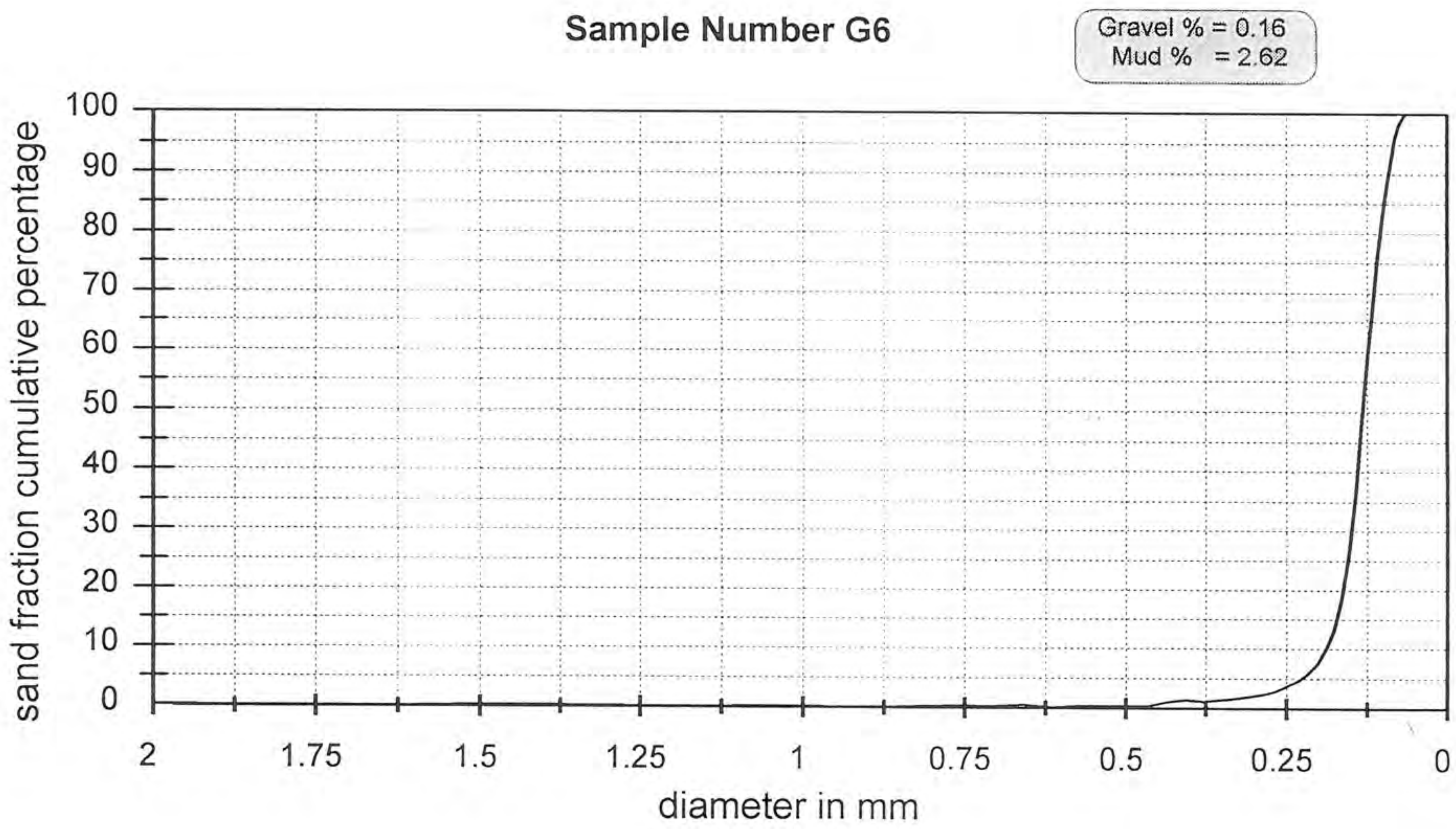
Sample Number G2
Gravel % = 0.34
Mud % = 2.39
100
90
80
70
60
50
40
30
20
10
0
Sand fraction cumulative percentage
2
1.75
1.5
1.25
1
0.75
0.5
0.25
0
diameter in mm

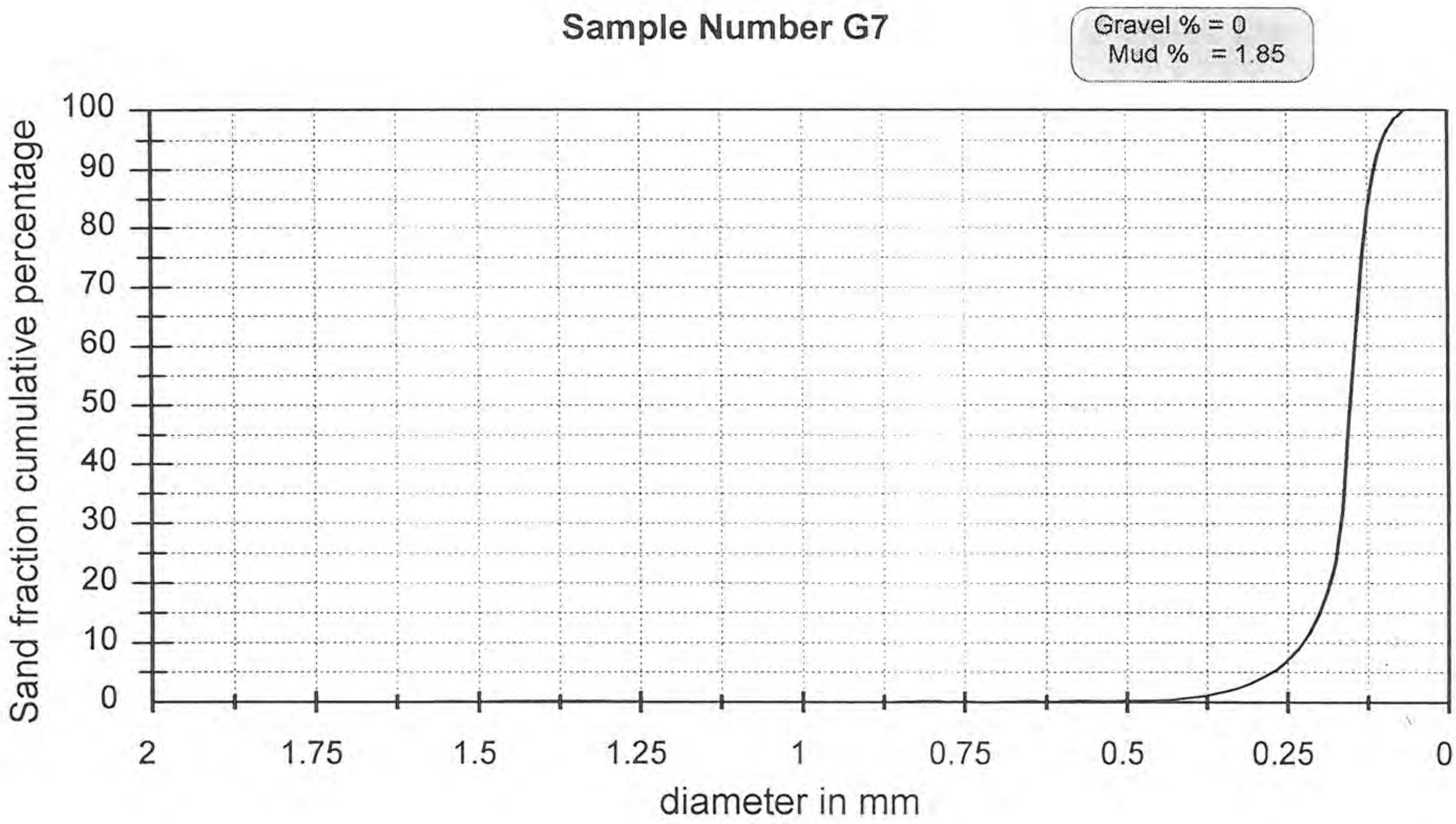


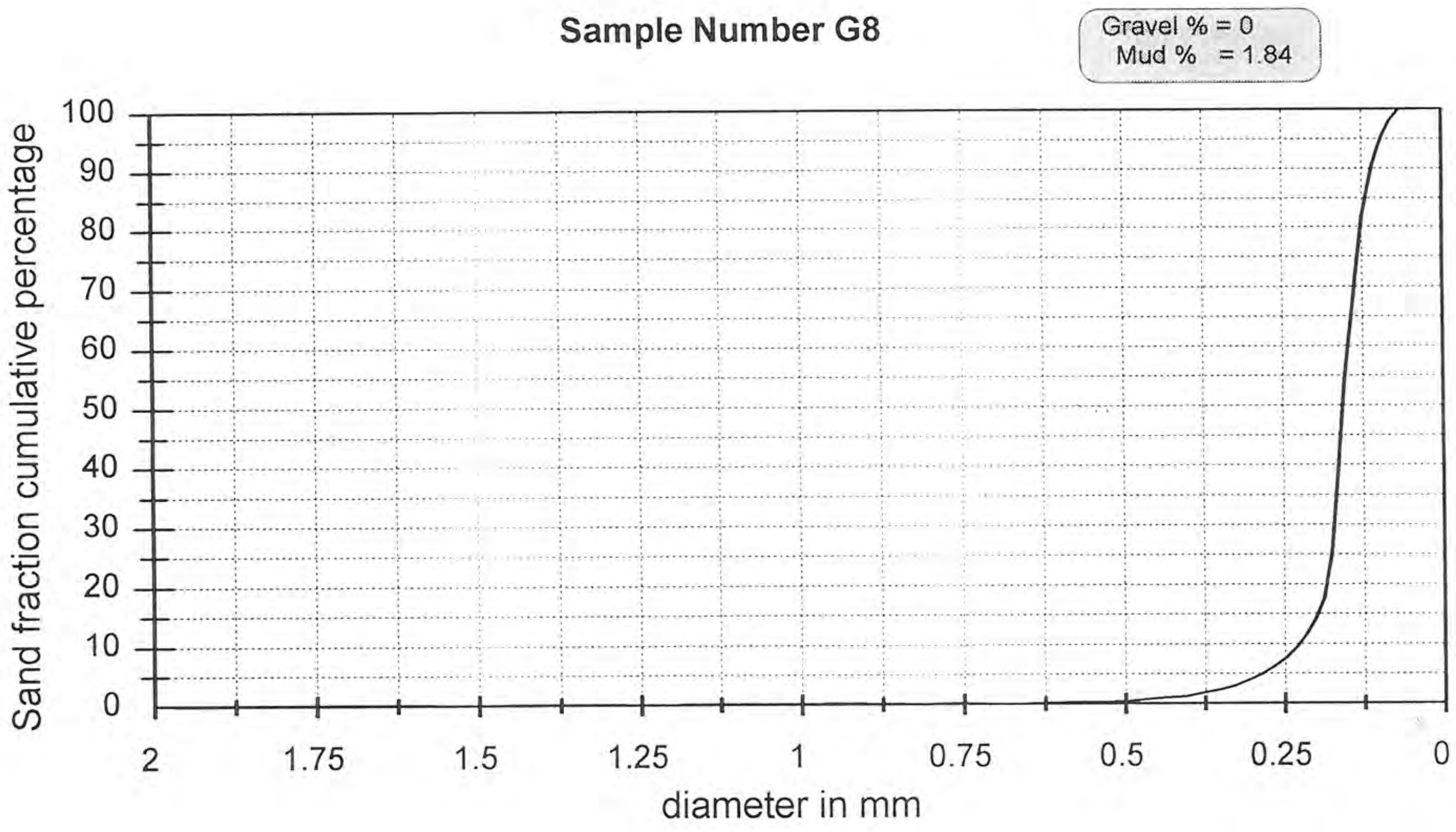
Sample Number G3
Gravel % = 0
Mud % = 1.88
Sand fraction cumulative percentage
100
90
80
70
60
50
40
30
20
10
0
2
1.75
1.5
1.25
1
0.75
0.5
0.25
0
diameter in mm


Sample Number G4
Gravel % = 0
Mud % = 2.26
Sand fraction cumulative percentage
100
90
80
70
60
50
40
30
20
10
0
2
1.75
1.5
1.25
1
0.75
0.5
0.25
0
diameter in mm

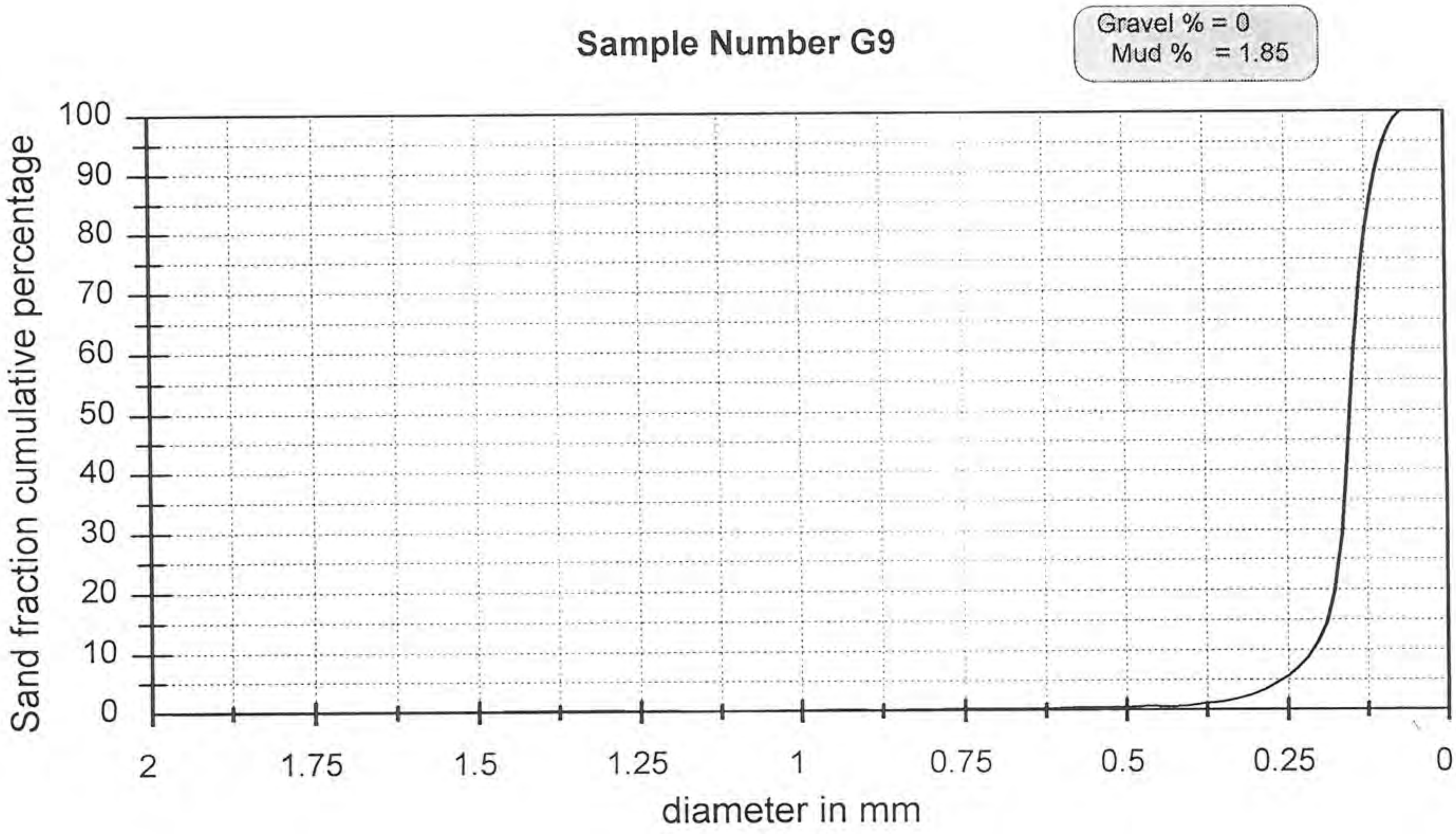

Sample Number G5
Gravel % = 0
Mud % = 2.17
sand fraction cumulative percentage
100
90
80
70
60
50
40
30
20
10
0
2
1.75
1.5
1.25
1
0.75
0.5
0.25
0
diameter in mm

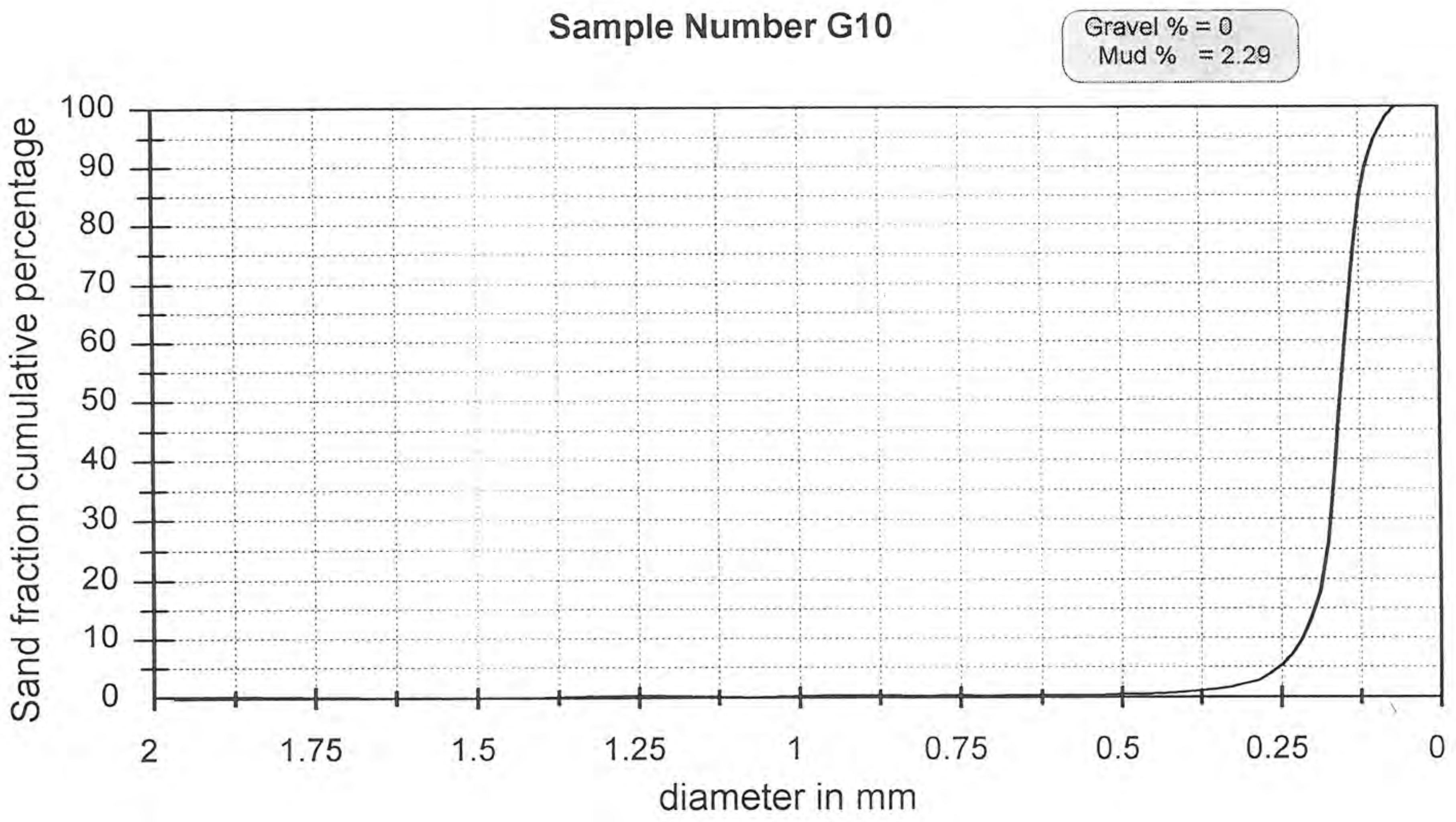

Sample Number G6
Gravel % = 0.16
Mud % = 2.62
sand fraction cumulative percentage
100
90
80
70
60
50
40
30
20
10
0
2
1.75
1.5
1.25
1
0.75
0.5
0.25
0
diameter in mm


Sample Number G7
Gravel % = 0
Mud % = 1.85
Sand fraction cumulative percentage
100
90
80
70
60
50
40
30
20
10
0
2
1.75
1.5
1.25
1
0.75
0.5
0.25
0
diameter in mm

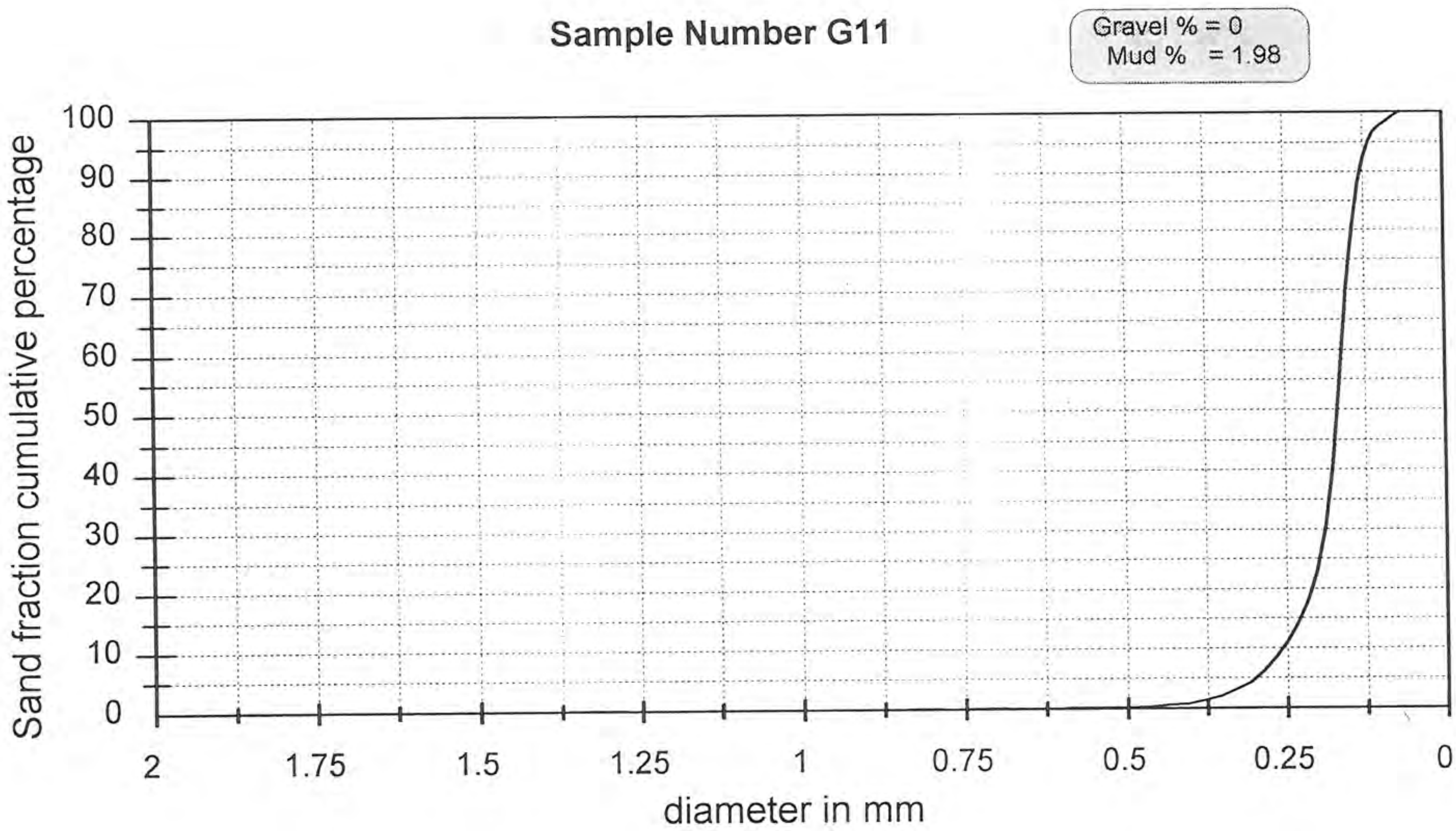


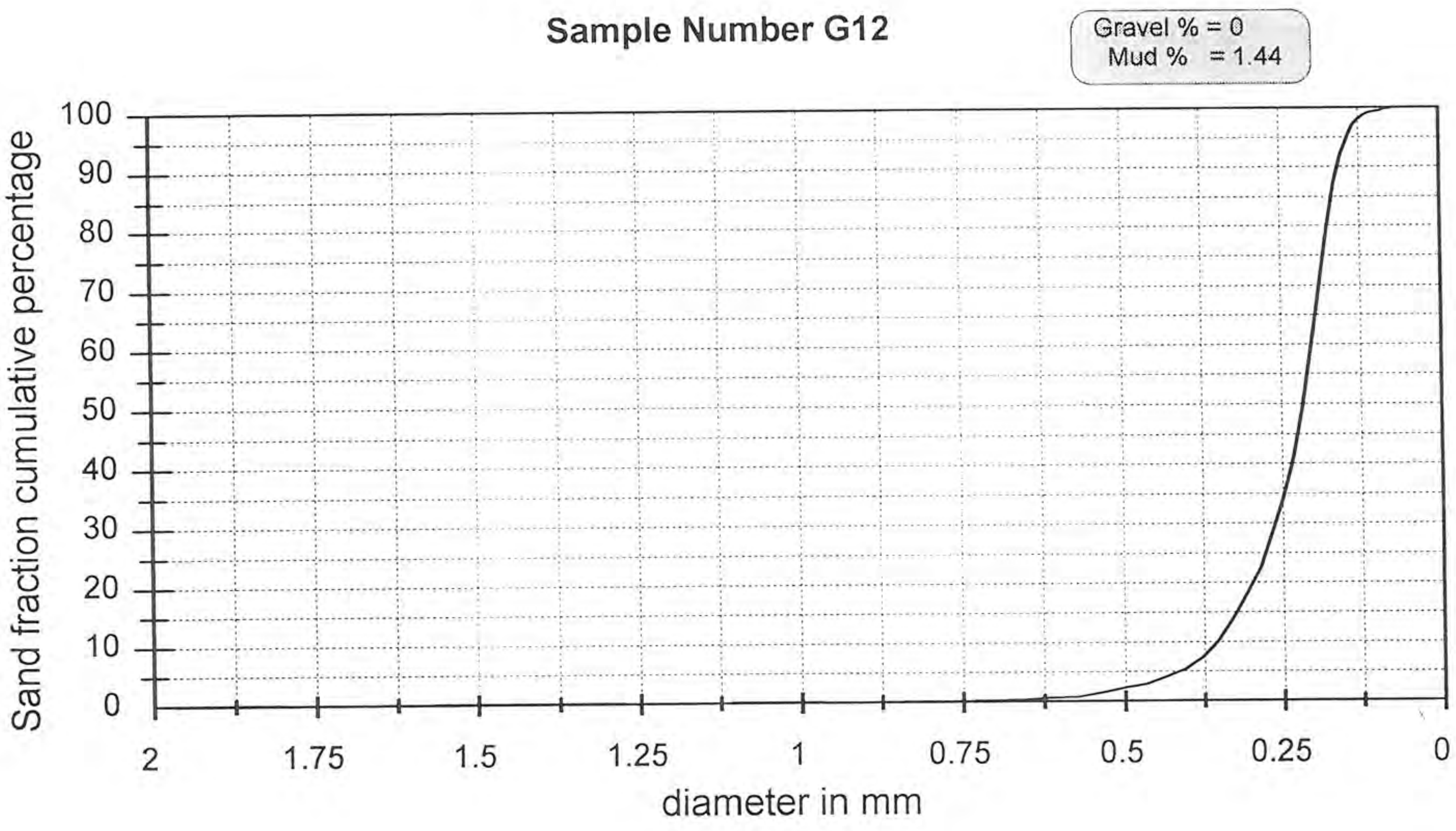
Sample Number G8
Gravel % = 0
Mud % = 1.84
Sand fraction cumulative percentage
100
90
80
70
60
50
40
30
20
10
0
2
1.75
1.5
1.25
1
0.75
0.5
0.25
0
diameter in mm

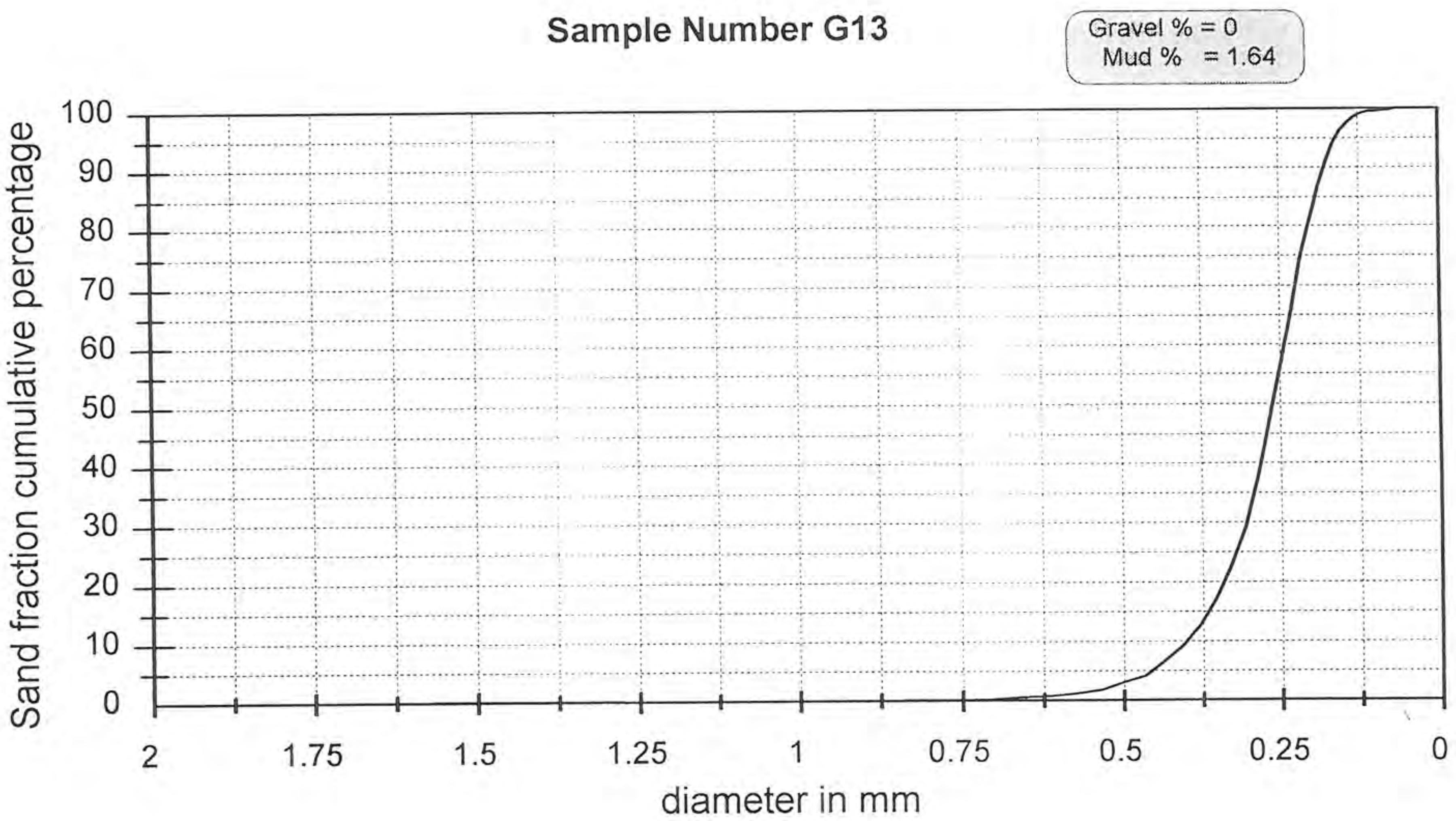

Sample Number G9
Gravel % = 0
Mud % = 1.85
Sand fraction cumulative percentage
100
90
80
70
60
50
40
30
20
10
0
2
1.75
1.5
1.25
1
0.75
0.5
0.25
0
diameter in mm

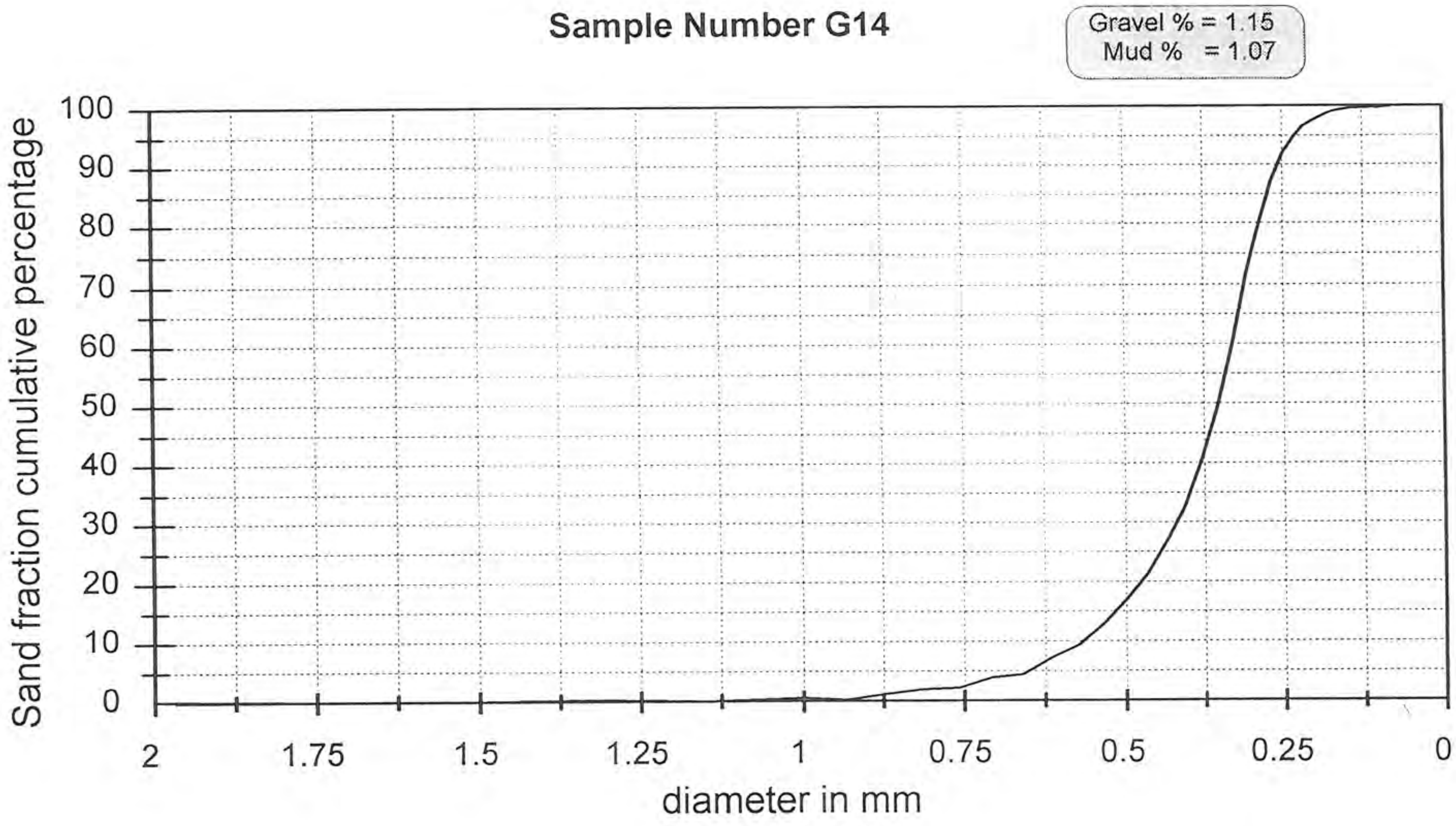


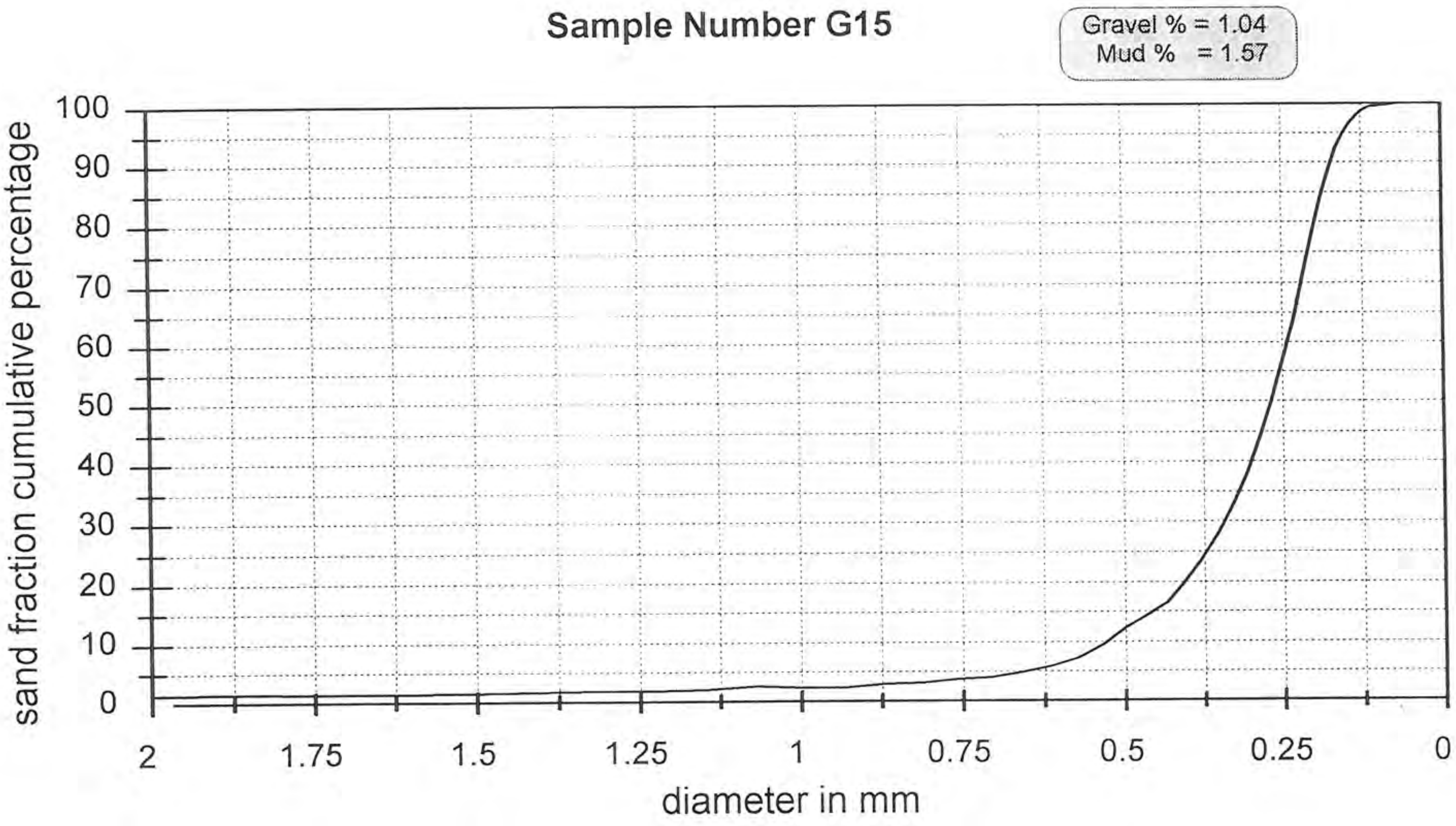
Sample Number G10
Gravel % = 0
Mud % = 2.29
Sand fraction cumulative percentage
100
90
80
70
60
50
40
30
20
10
0
2
1.75
1.5
1.25
1
0.75
0.5
0.25
0
diameter in mm

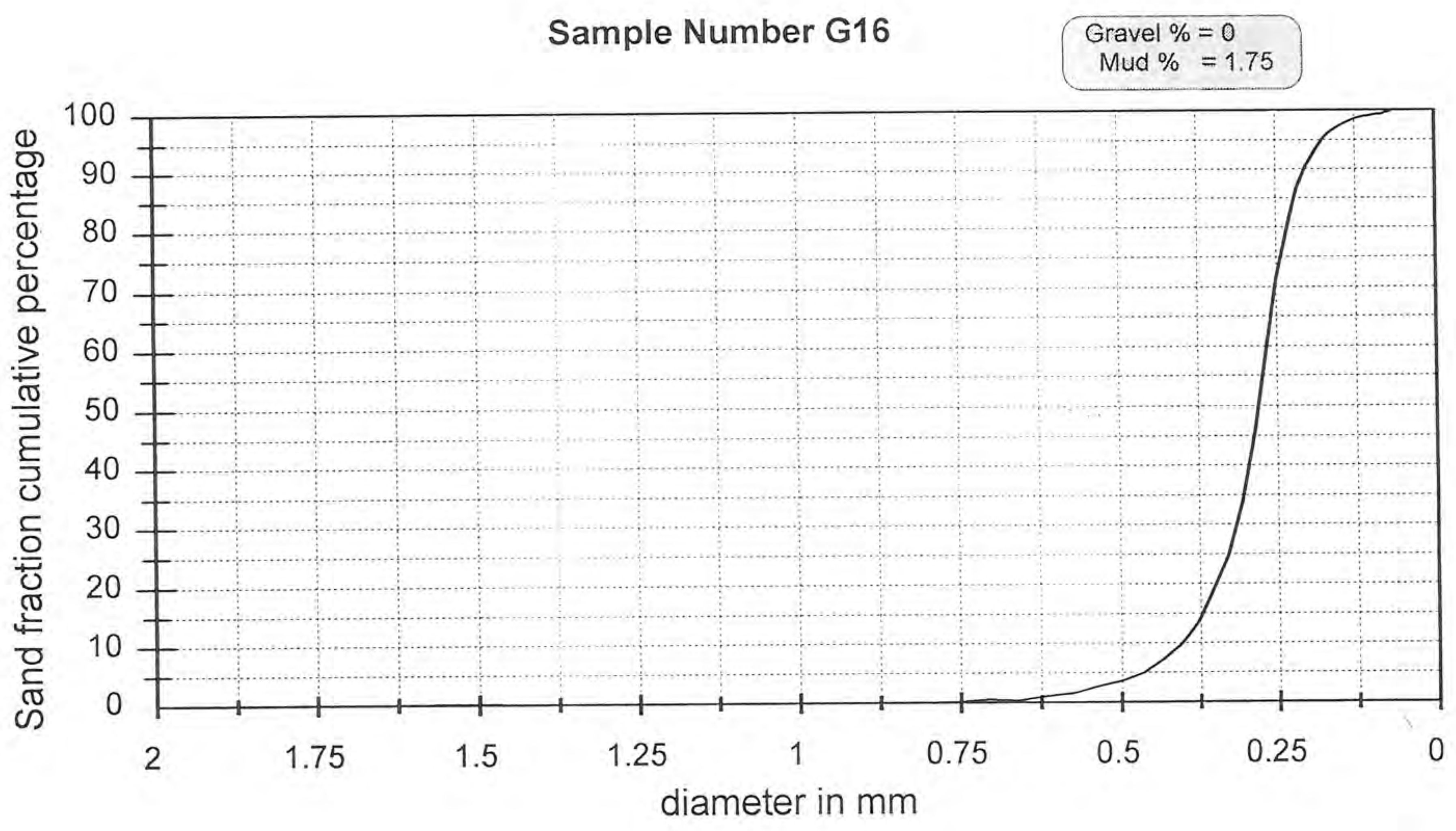

Sample Number G11
Gravel % = 0
Mud % = 1.98
Sand fraction cumulative percentage
100
90
80
70
60
50
40
30
20
10
0
2
1.75
1.5
1.25
1
0.75
0.5
0.25
0
diameter in mm


Sample Number G12
Gravel % = 0
Mud % = 1.44
Sand fraction cumulative percentage
100
90
80
70
60
50
40
30
20
10
0
2
1.75
1.5
1.25
1
0.75
0.5
0.25
0
diameter in mm

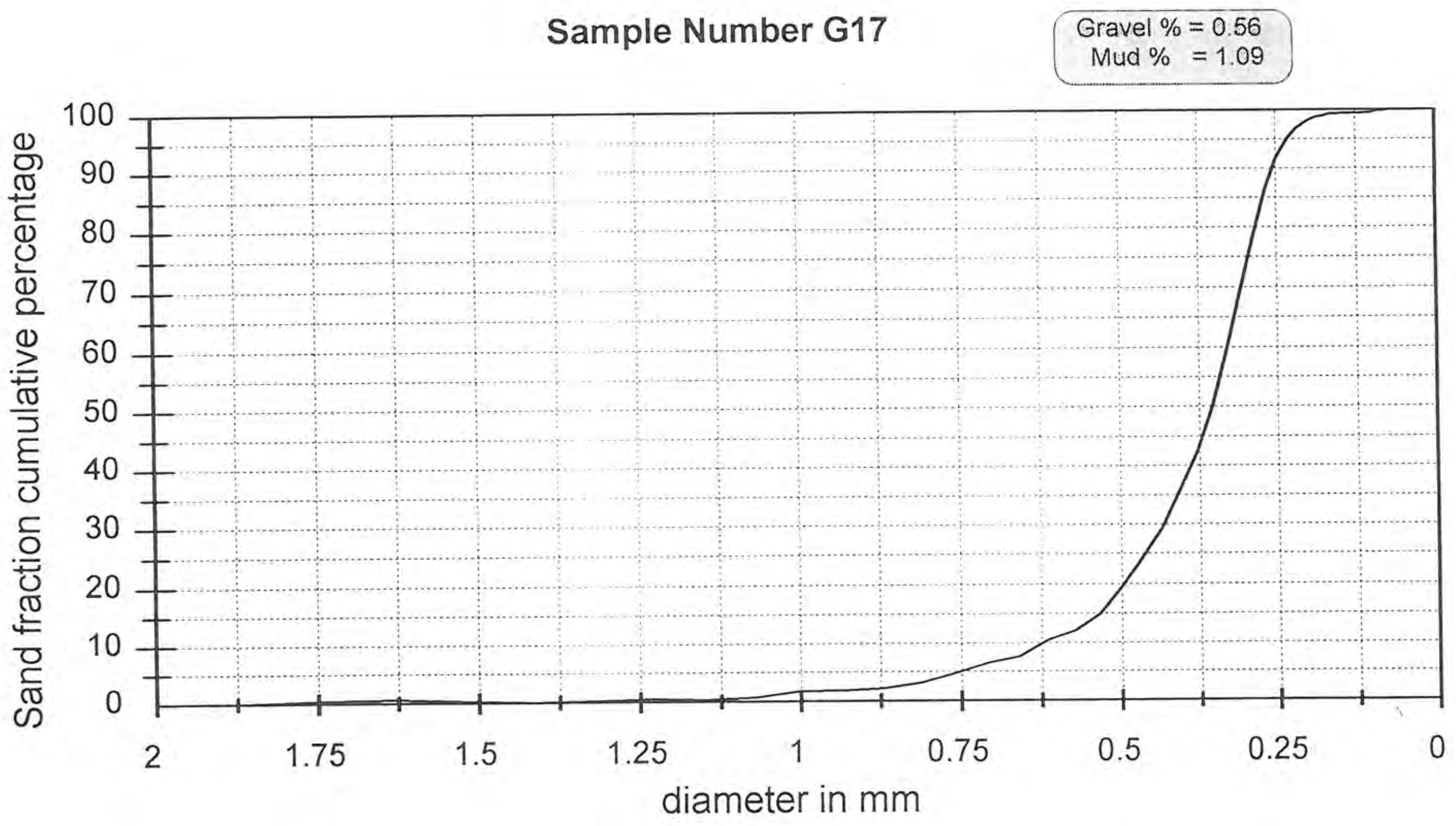

Sample Number G13
Gravel % = 0
Mud % = 1.64
Sand fraction cumulative percentage
100
90
80
70
60
50
40
30
20
10
0
2
1.75
1.5
1.25
1
0.75
0.5
0.25
0
diameter in mm

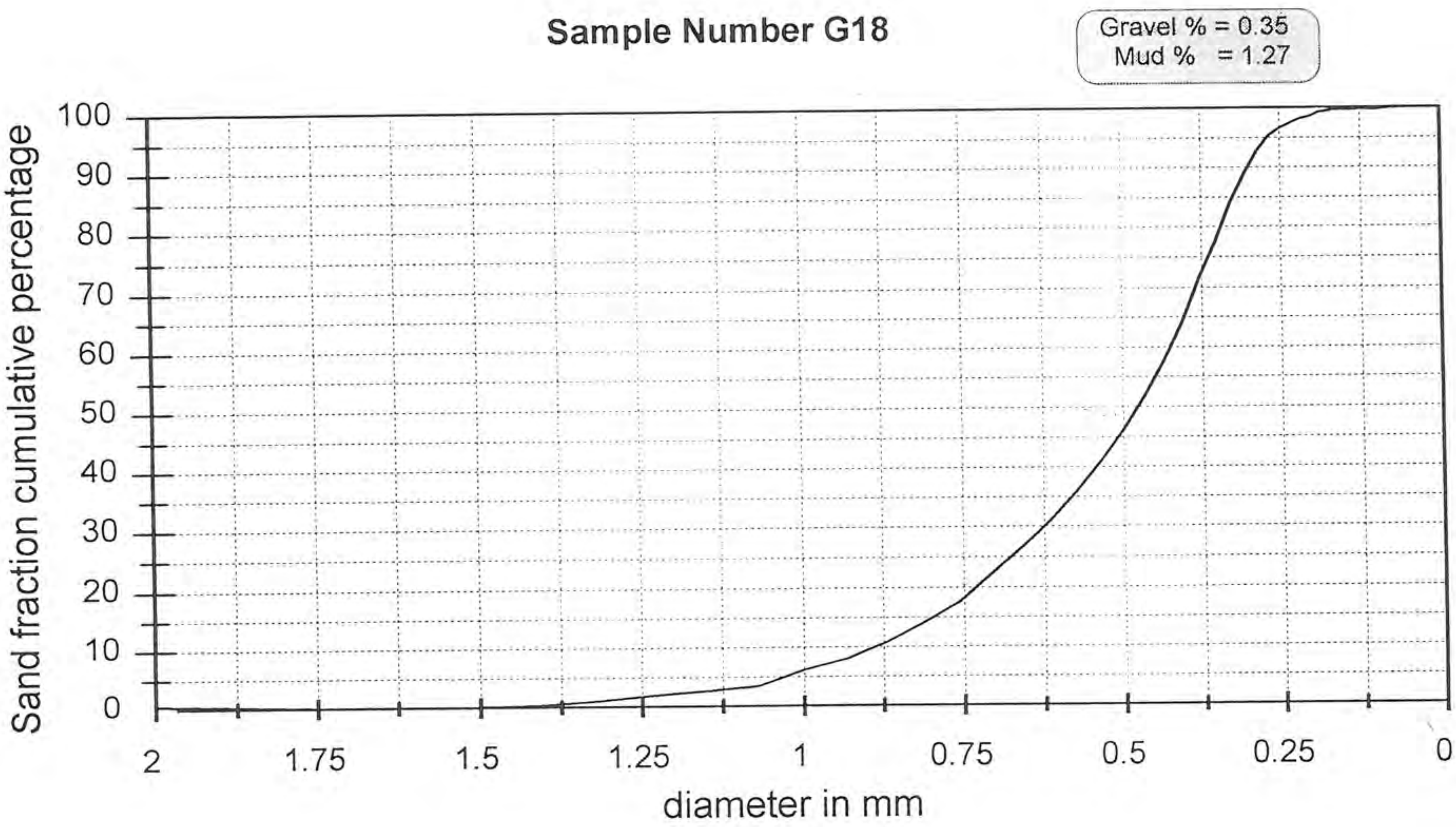

Sample Number G14
Gravel % = 1.15
Mud % = 1.07
Sand fraction cumulative percentage
100
90
80
70
60
50
40
30
20
10
0
2
1.75
1.5
1.25
1
0.75
0.5
0.25
0
diameter in mm

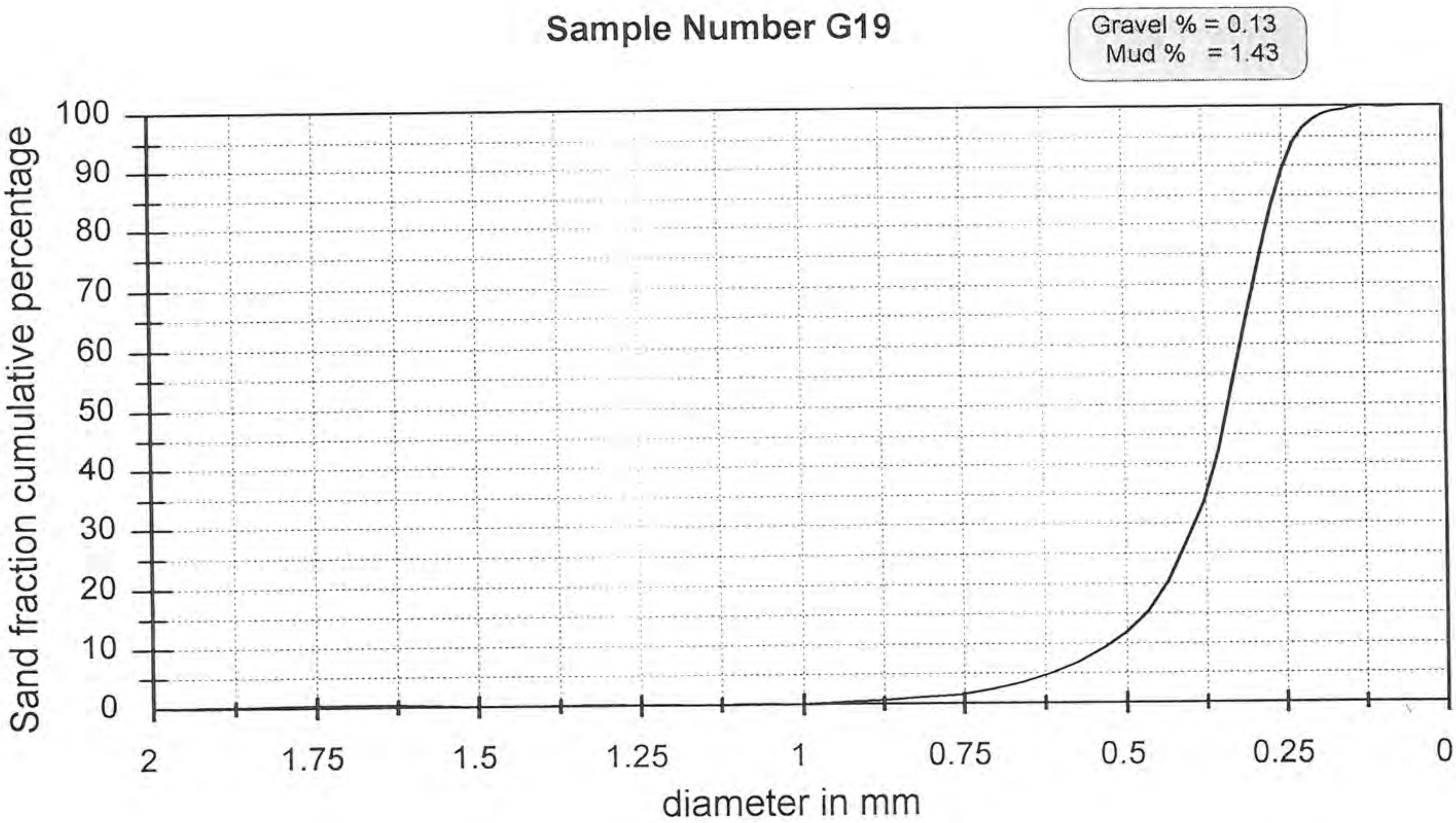

Sample Number G15
Gravel % = 1.04
Mud % = 1.57
sand fraction cumulative percentage
100
90
80
70
60
50
40
30
20
10
0
2
1.75
1.5
1.25
1
0.75
0.5
0.25
0
diameter in mm

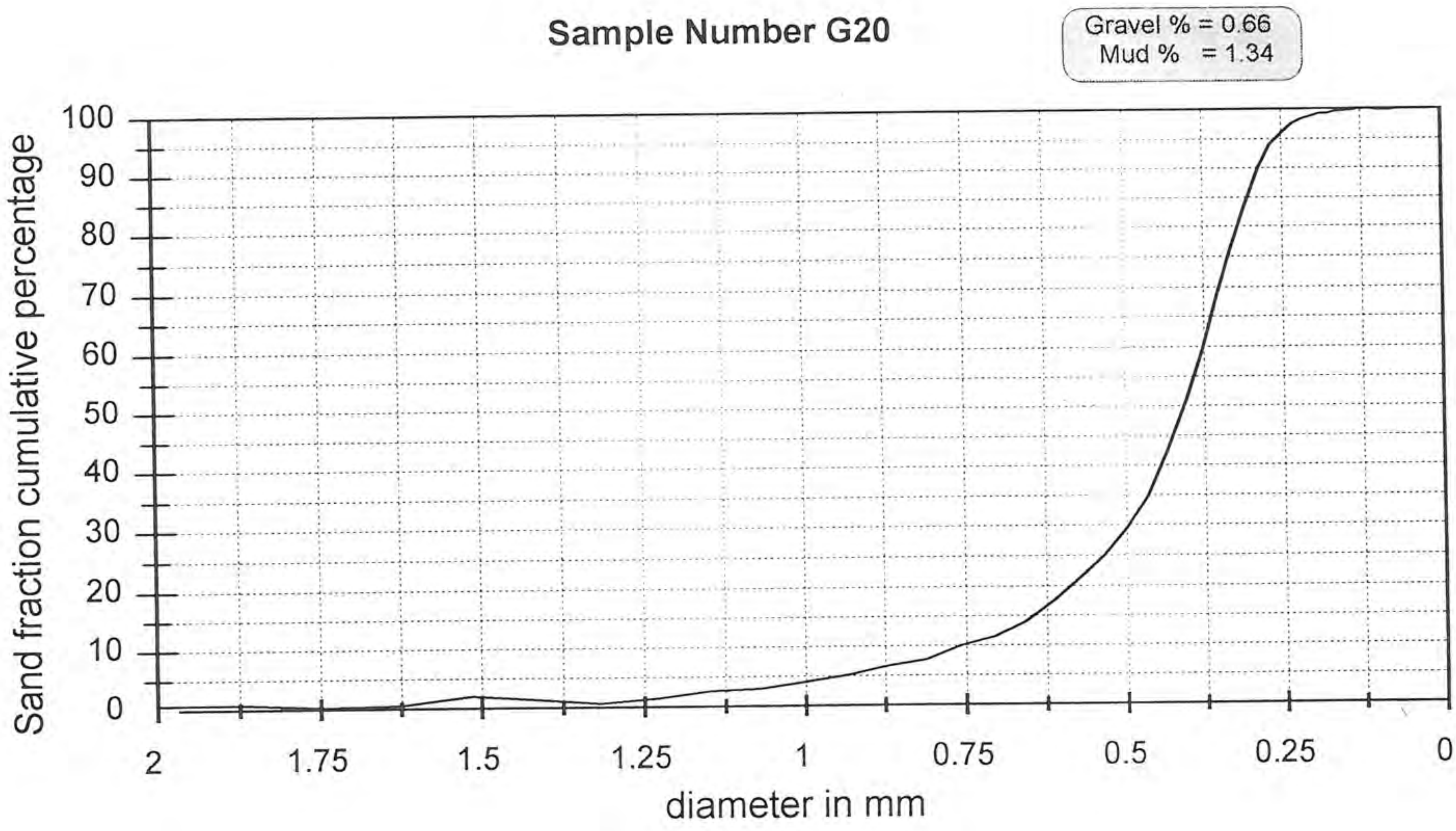


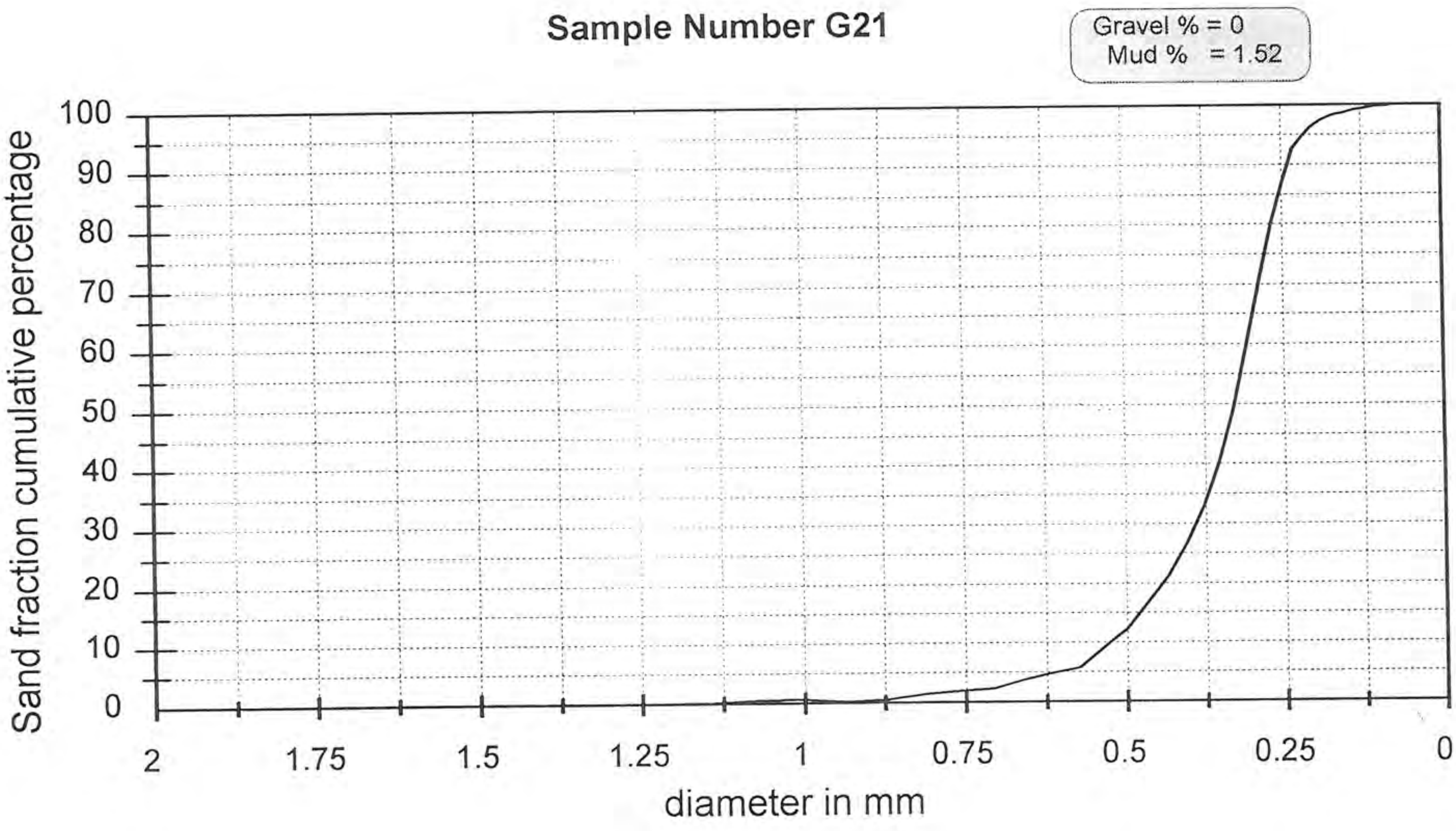
Sample Number G16
Gravel % = 0
Mud % = 1.75
Sand fraction cumulative percentage
100
90
80
70
60
50
40
30
20
10
0
2
1.75
1.5
1.25
1
0.75
0.5
0.25
0
diameter in mm


Sample Number G17
Gravel % = 0.56
Mud % = 1.09
Sand fraction cumulative percentage
100
90
80
70
60
50
40
30
20
10
0
2
1.75
1.5
1.25
1
0.75
0.5
0.25
0
diameter in mm

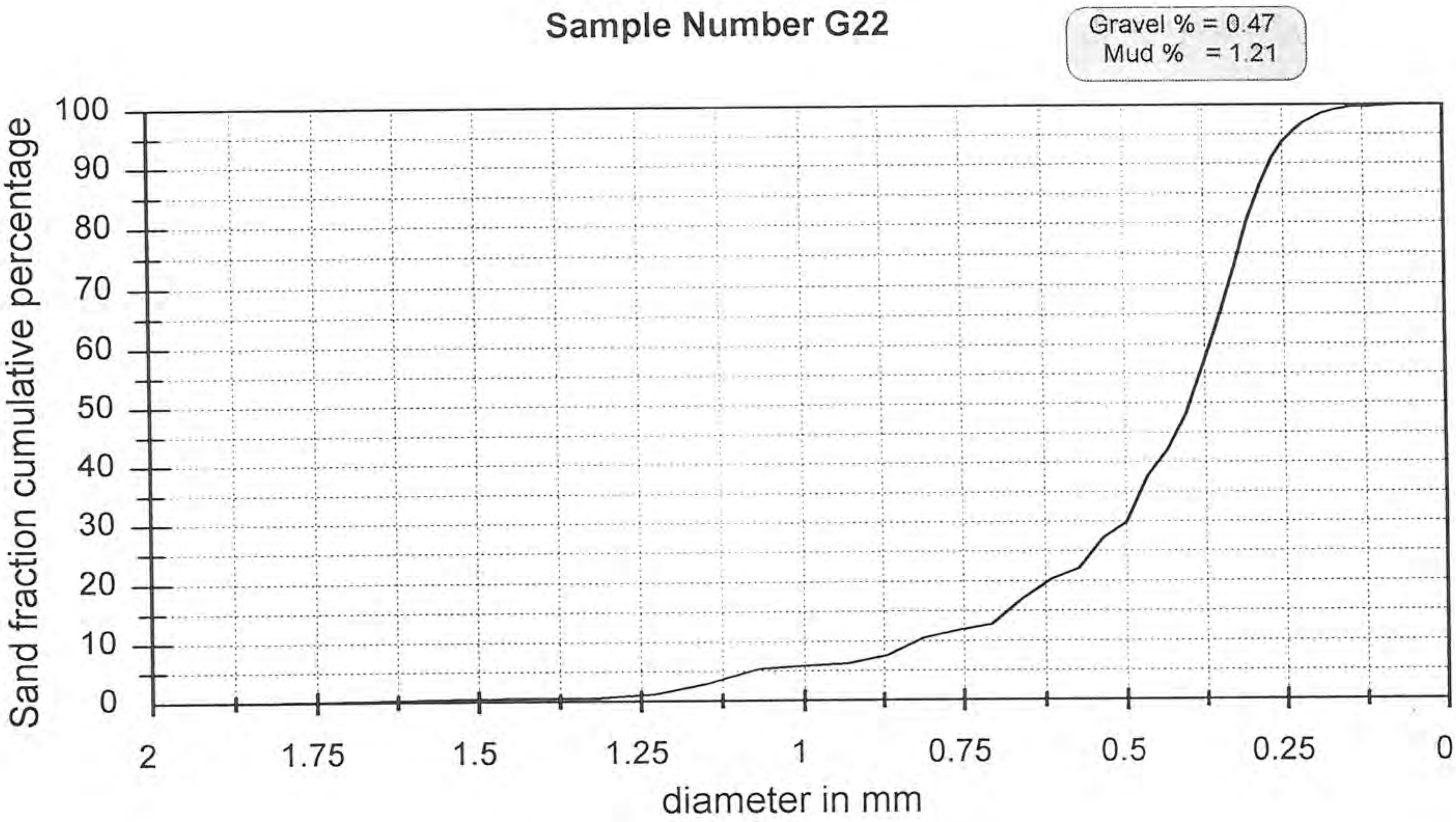

Sample Number G18
Gravel % = 0.35
Mud % = 1.27
Sand fraction cumulative percentage
100
90
80
70
60
50
40
30
20
10
0
2
1.75
1.5
1.25
1
0.75
0.5
0.25
0
diameter in mm

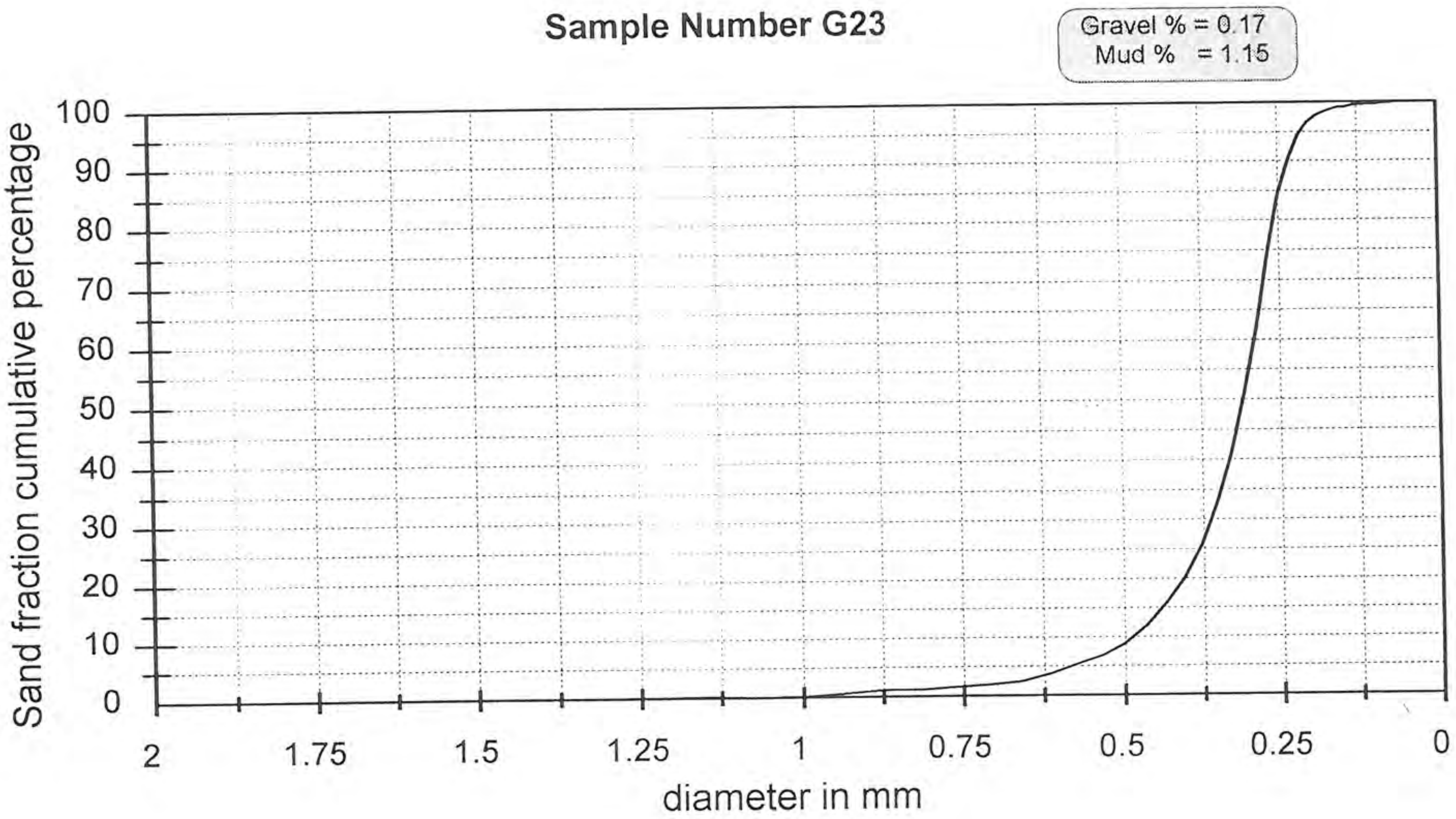

Sample Number G19
Gravel % = 0.13
Mud % = 1.43
Sand fraction cumulative percentage
100
90
80
70
60
50
40
30
20
10
0
2
1.75
1.5
1.25
1
0.75
0.5
0.25
0
diameter in mm


Sample Number G20
Gravel % = 0.66
Mud % = 1.34
Sand fraction cumulative percentage
100
90
80
70
60
50
40
30
20
10
0
2
1.75
1.5
1.25
1
0.75
0.5
0.25
0
diameter in mm

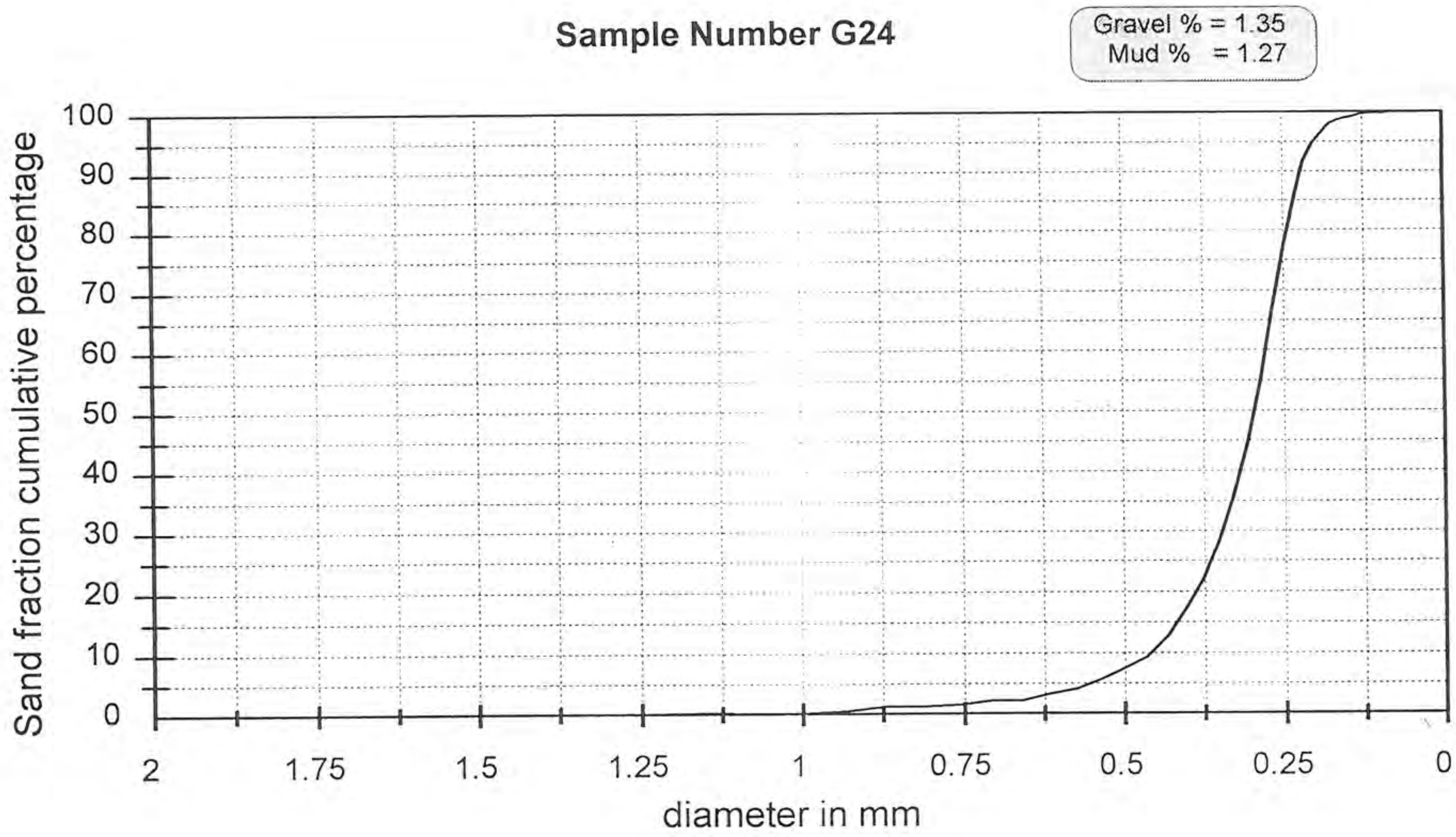


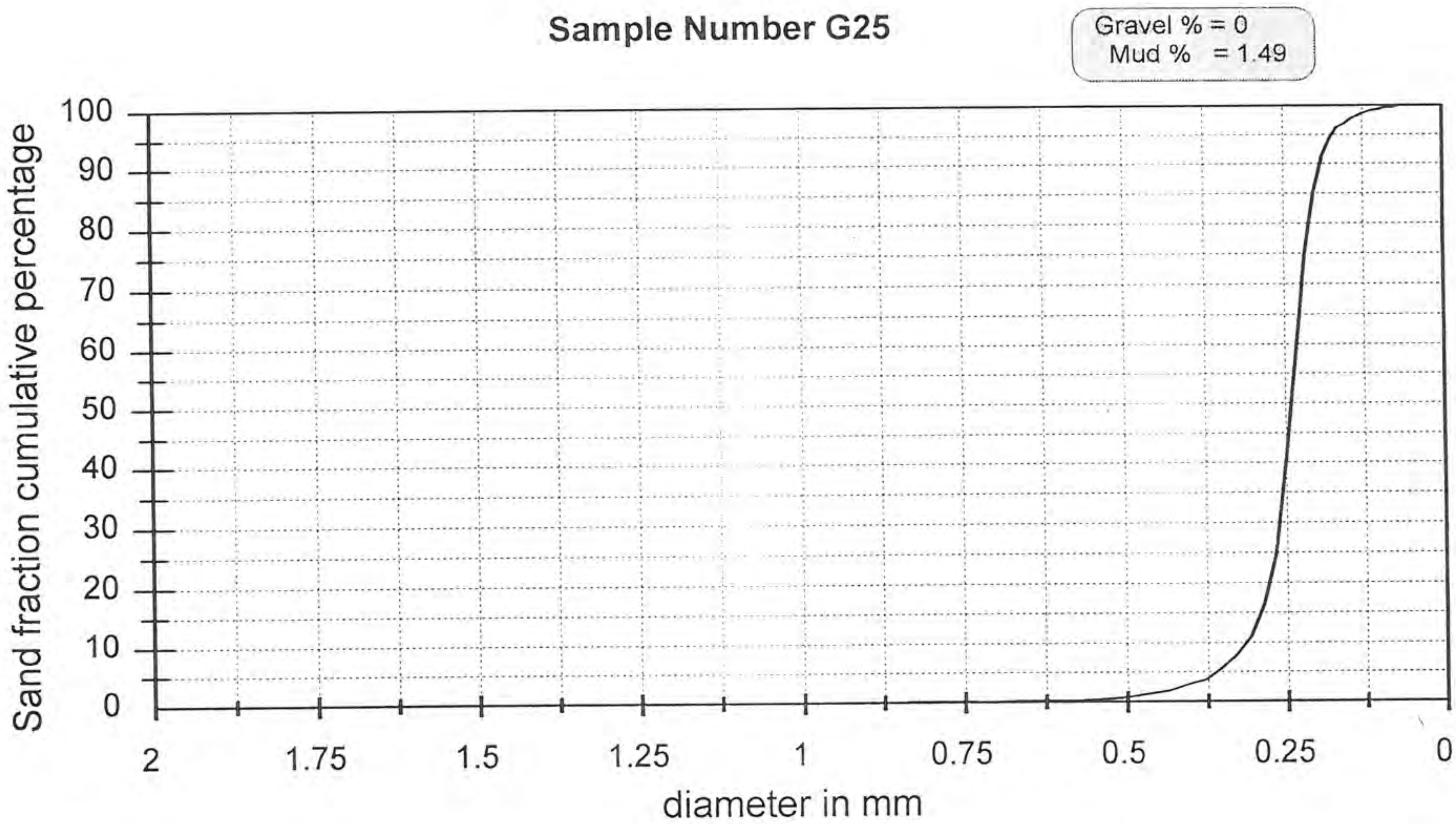
Sample Number G21
Gravel % = 0
Mud % = 1.52
Sand fraction cumulative percentage
100
90
80
70
60
50
40
30
20
10
0
2
1.75
1.5
1.25
1
0.75
0.5
0.25
0
diameter in mm

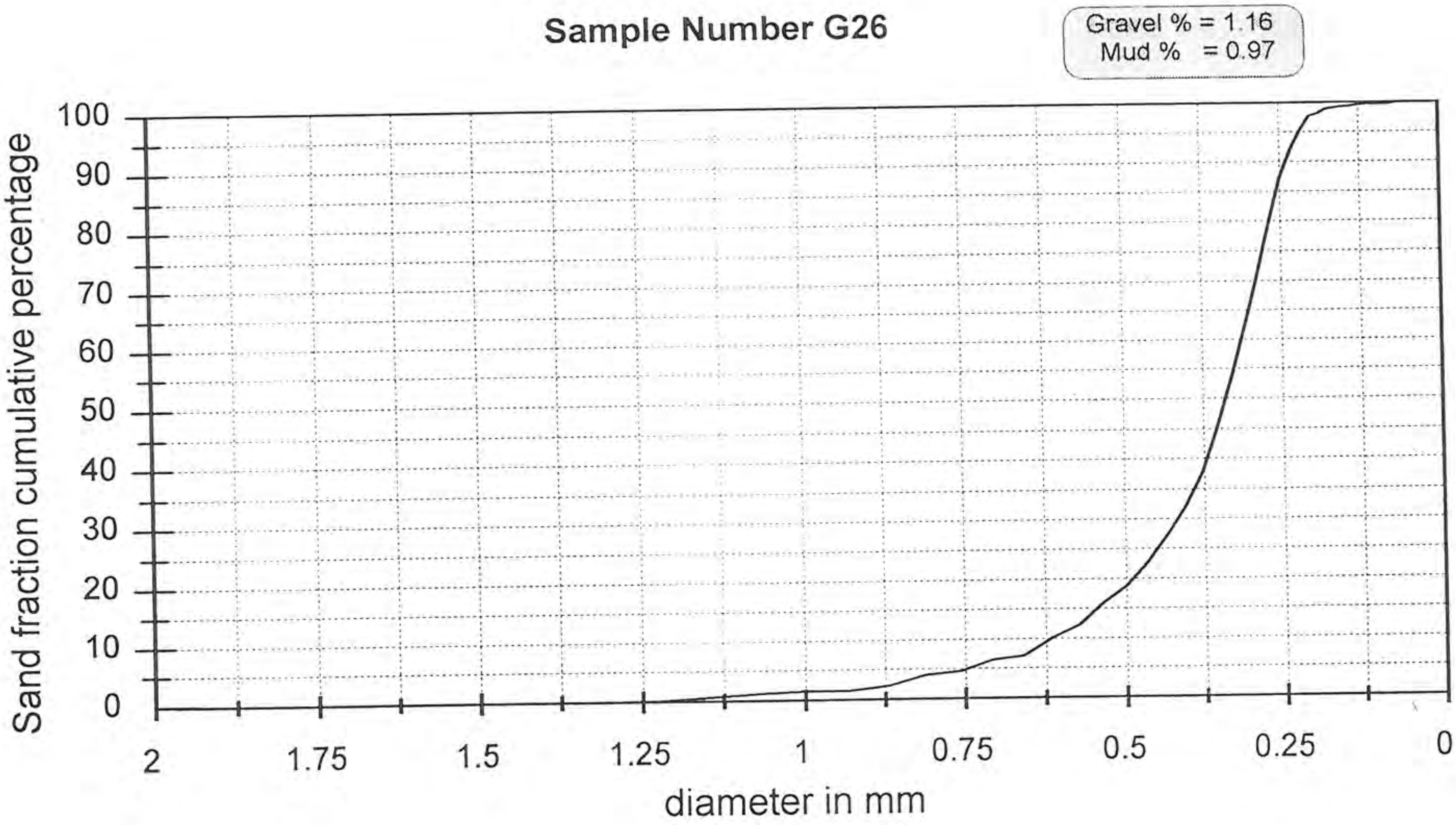

Sample Number G22
Gravel % = 0.47
Mud % = 1.21
Sand fraction cumulative percentage
100
90
80
70
60
50
40
30
20
10
0
2
1.75
1.5
1.25
1
0.75
0.5
0.25
0
diameter in mm

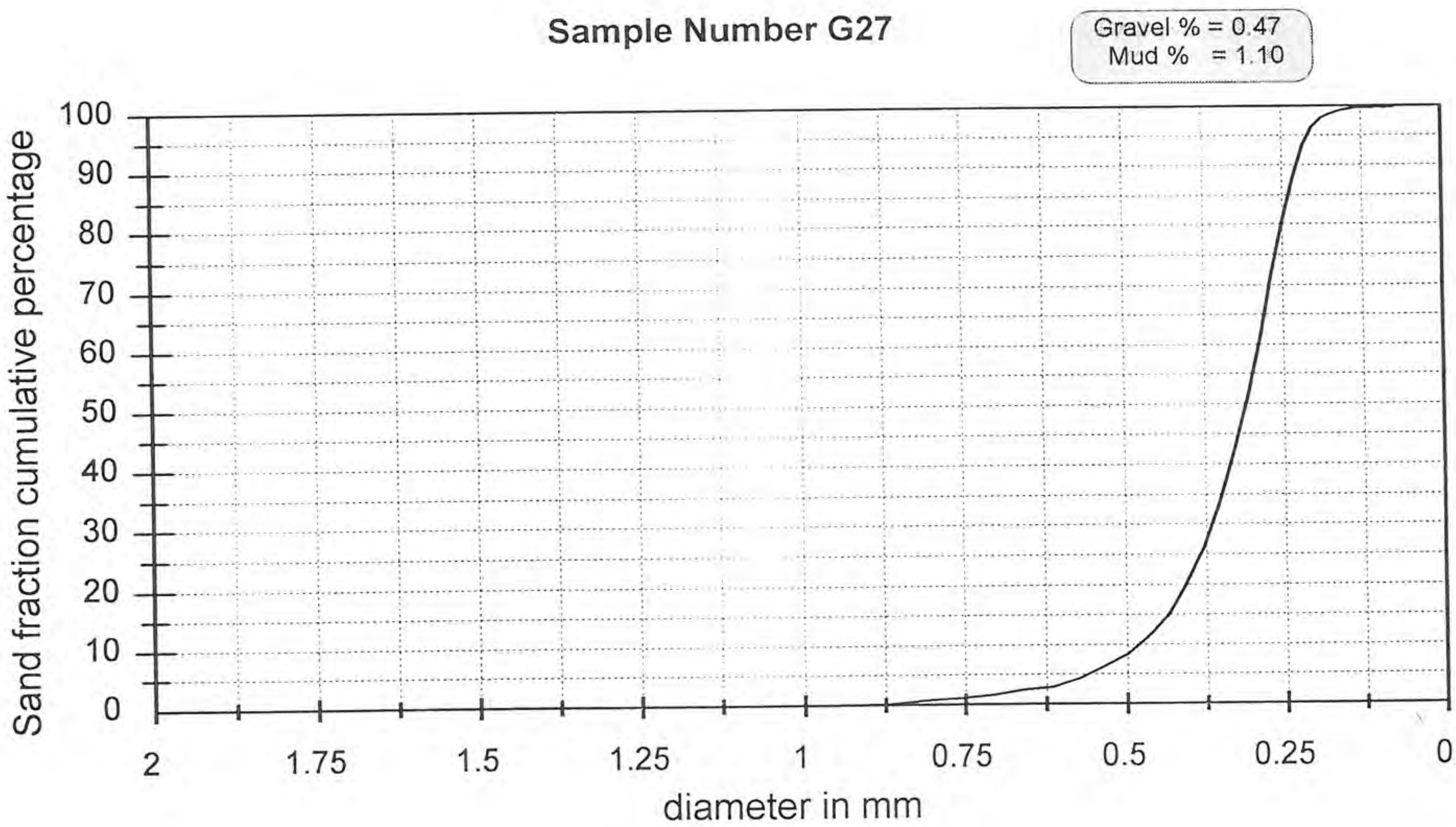


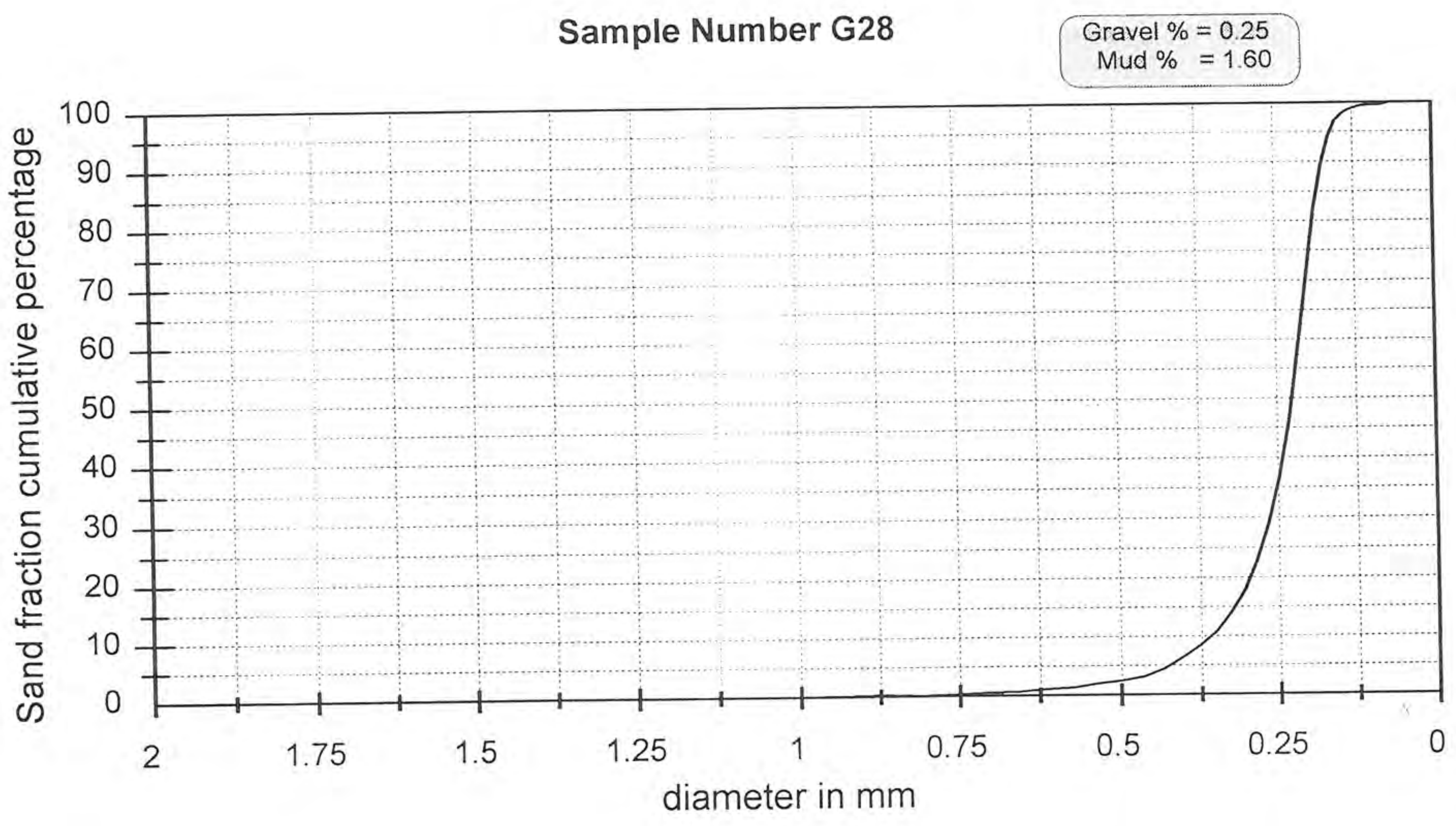
Sample Number G23
Gravel % = 0.17
Mud % = 1.15
Sand fraction cumulative percentage
100
90
80
70
60
50
40
30
20
10
0
2
1.75
1.5
1.25
1
0.75
0.5
0.25
0
diameter in mm

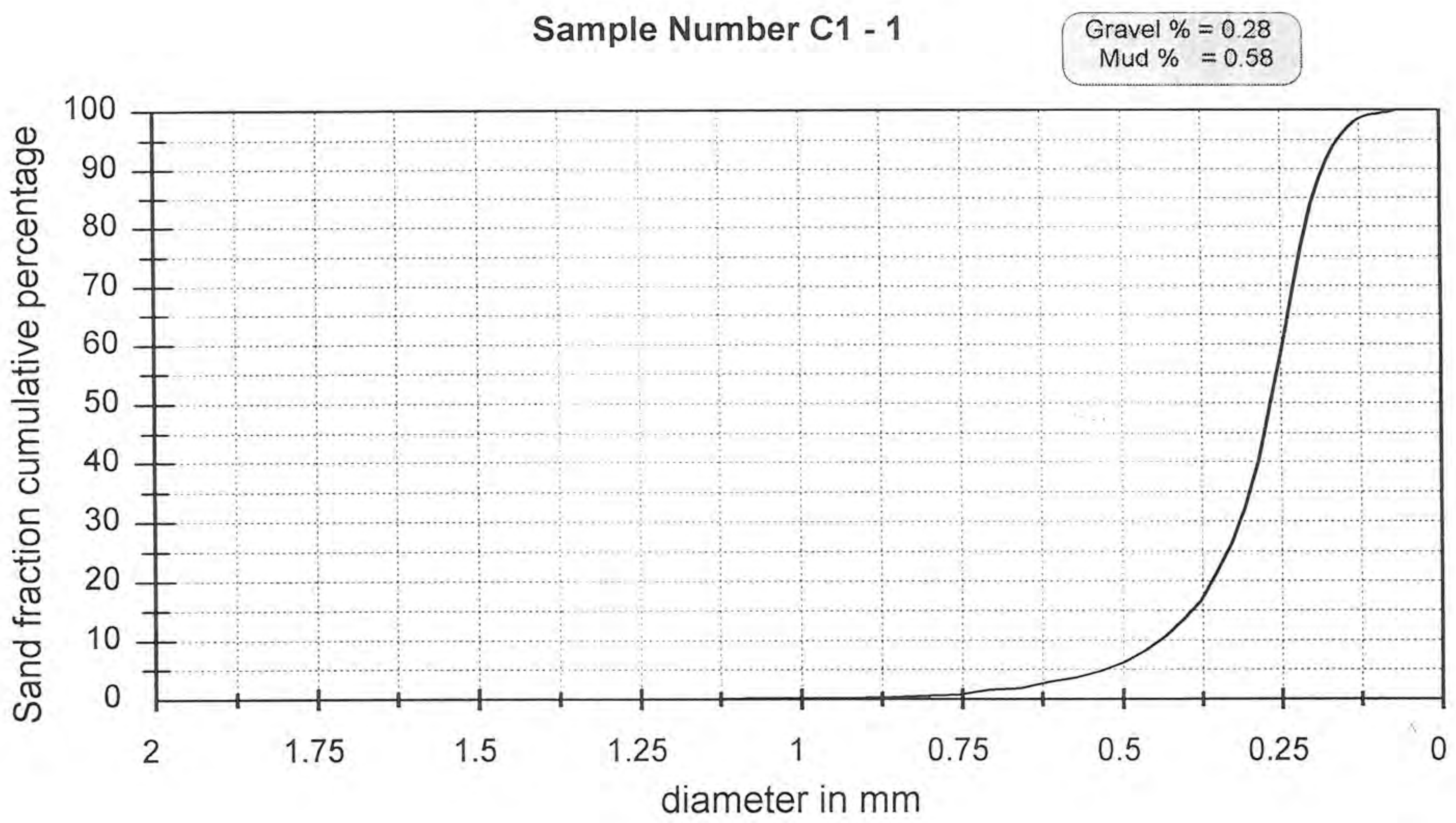

Sample Number G24
Gravel % = 1.35
Mud % = 1.27
Sand fraction cumulative percentage
100
90
80
70
60
50
40
30
20
10
0
2
1.75
1.5
1.25
1
0.75
0.5
0.25
0
diameter in mm

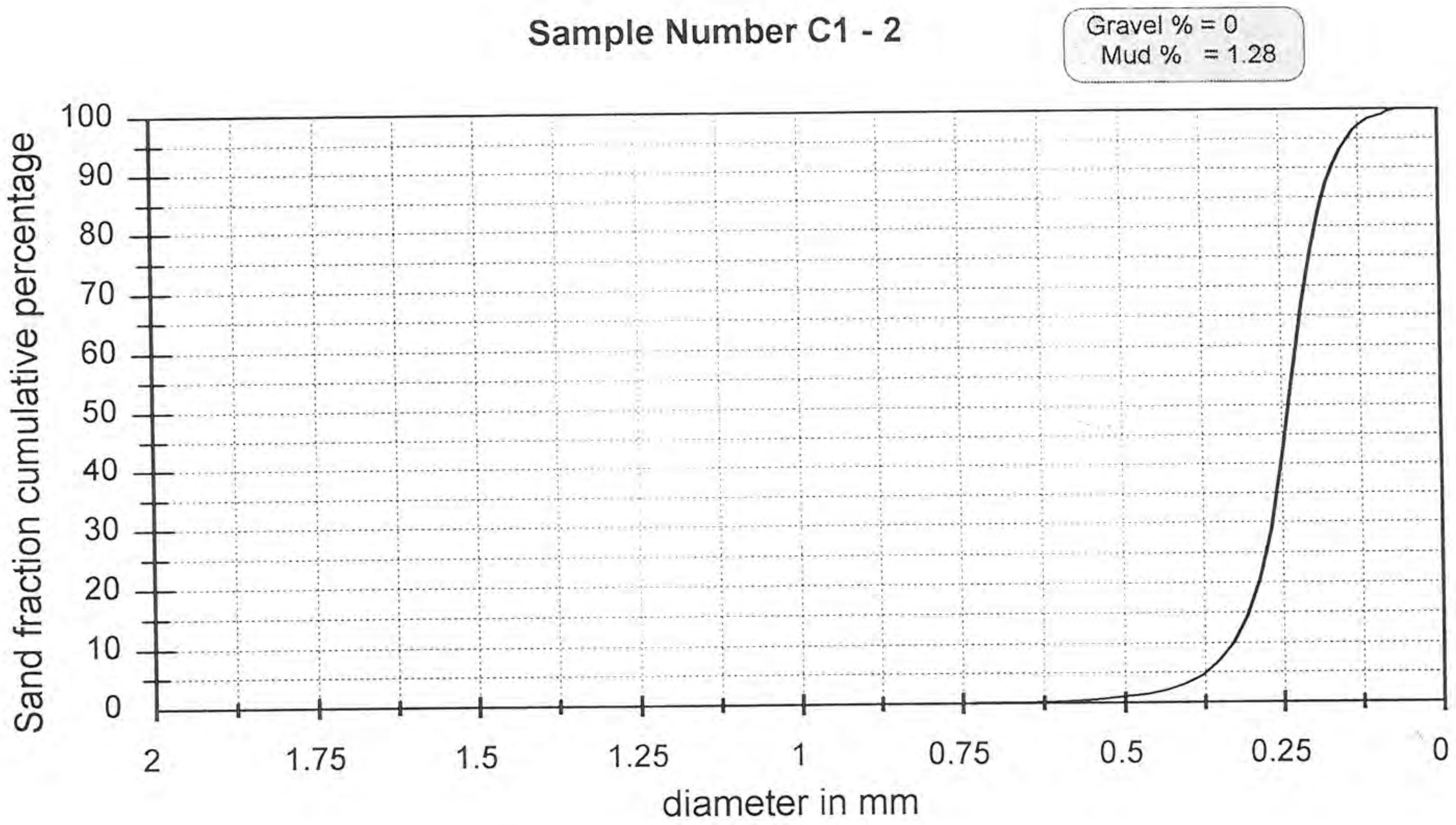

Sample Number G25
Gravel % = 0
Mud % = 1.49
Sand fraction cumulative percentage
100
90
80
70
60
50
40
30
20
10
0
2
1.75
1.5
1.25
1
0.75
0.5
0.25
0
diameter in mm

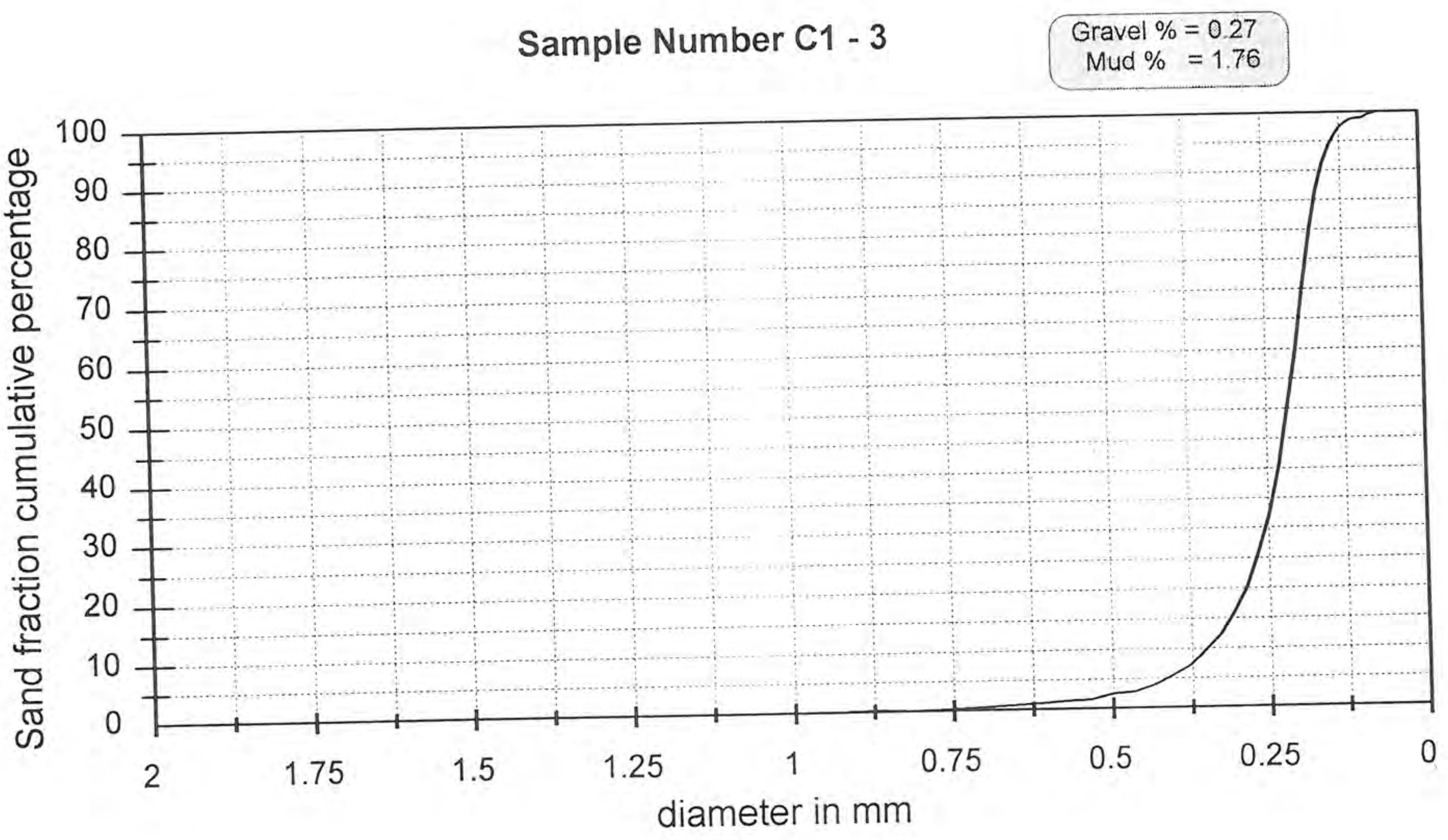

Sample Number G26
Gravel % = 1.16
Mud % = 0.97
Sand fraction cumulative percentage
100
90
80
70
60
50
40
30
20
10
0
2
1.75
1.5
1.25
1
0.75
0.5
0.25
0
diameter in mm


Sample Number G27
Gravel % = 0.47
Mud % = 1.10
Sand fraction cumulative percentage
100
90
80
70
60
50
40
30
20
10
0
2
1.75
1.5
1.25
1
0.75
0.5
0.25
0
diameter in mm

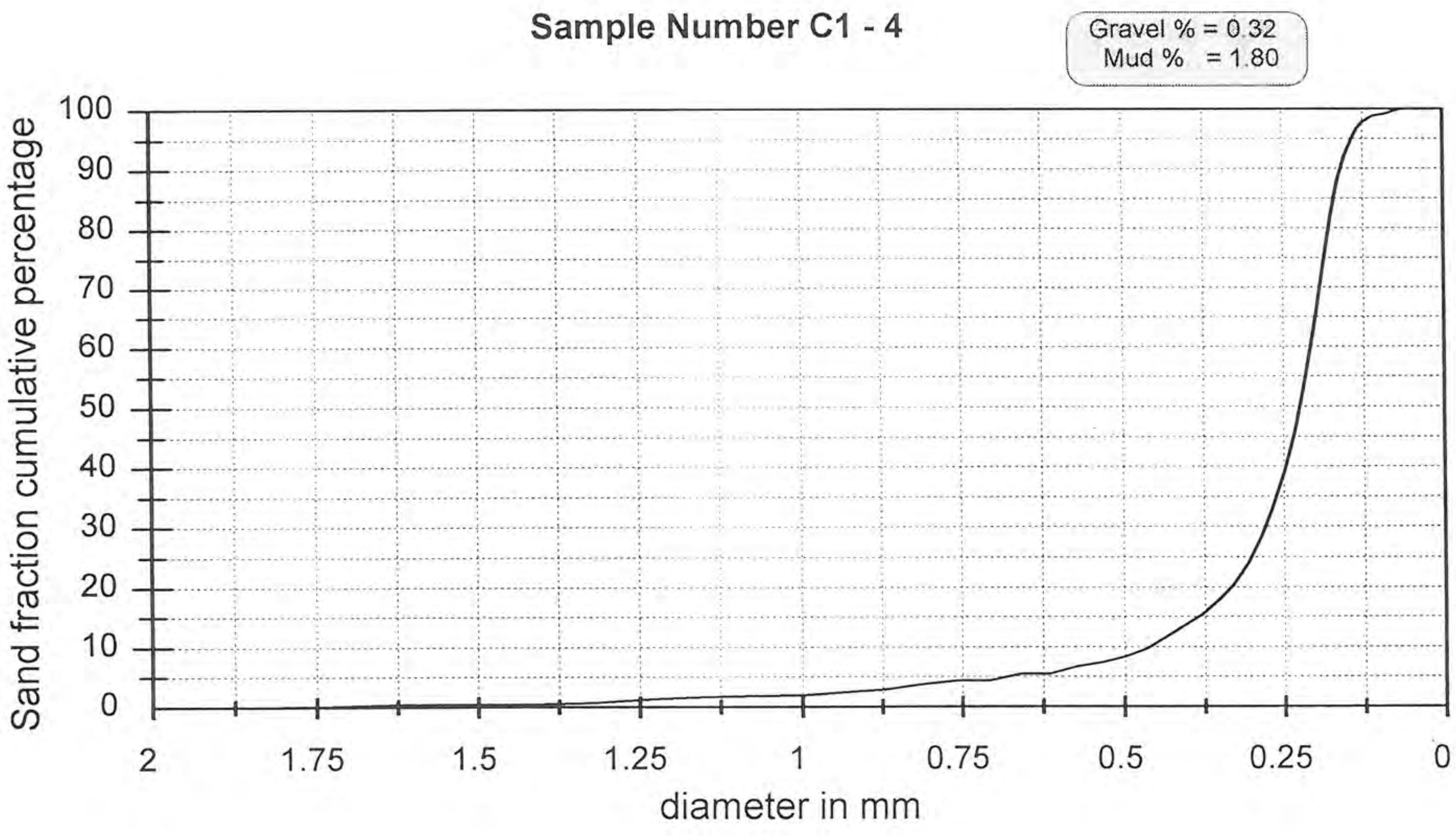

Sample Number G28
Gravel % = 0.25
Mud % = 1.60
Sand fraction cumulative percentage
100
90
80
70
60
50
40
30
20
10
0
2
1.75
1.5
1.25
1
0.75
0.5
0.25
0
diameter in mm

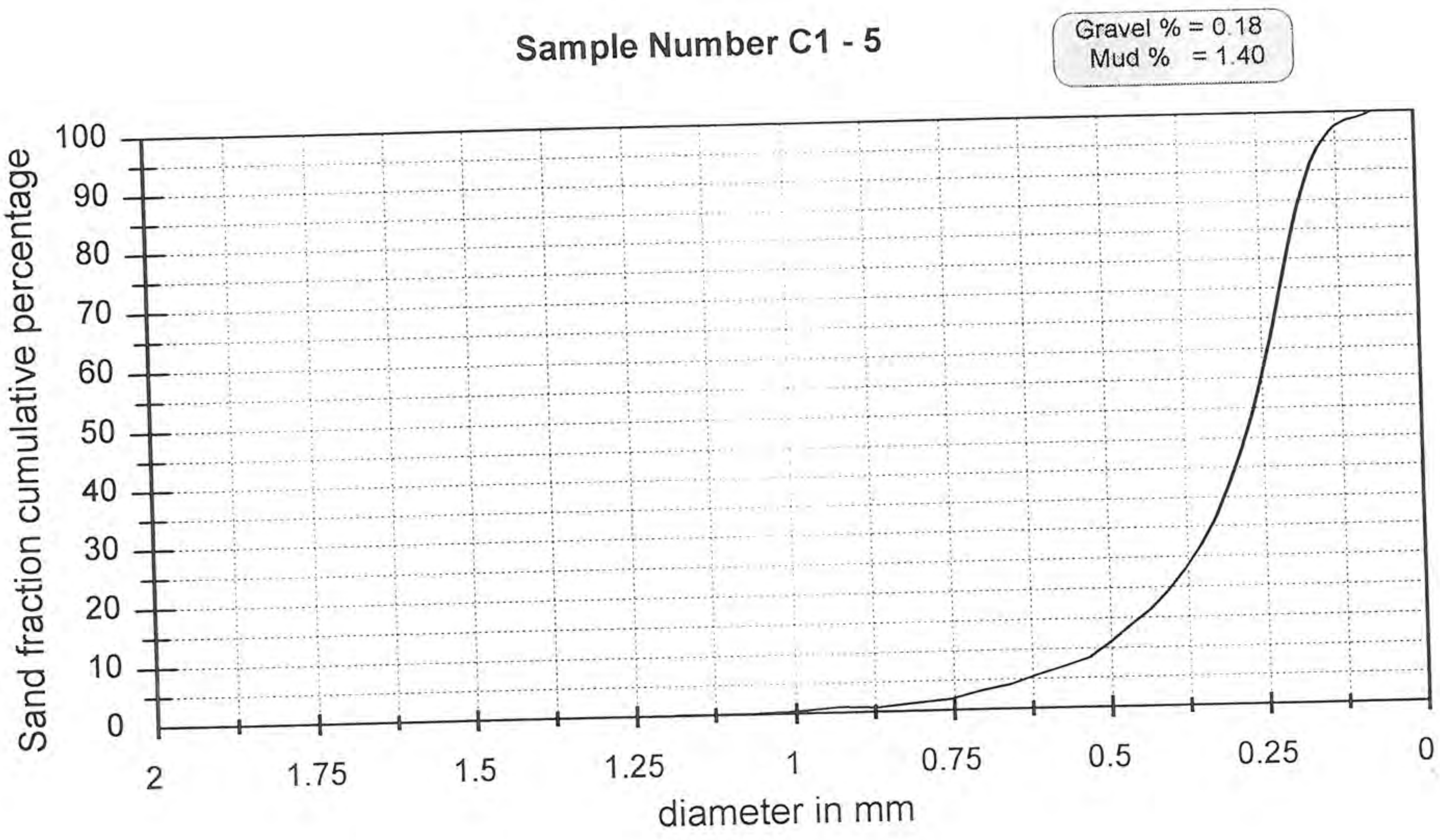

Sample Number C1 - 1
Gravel % = 0.28
Mud % = 0.58
Sand fraction cumulative percentage
100
90
80
70
60
50
40
30
20
10
0
2
1.75
1.5
1.25
1
0.75
0.5
0.25
0
diameter in mm

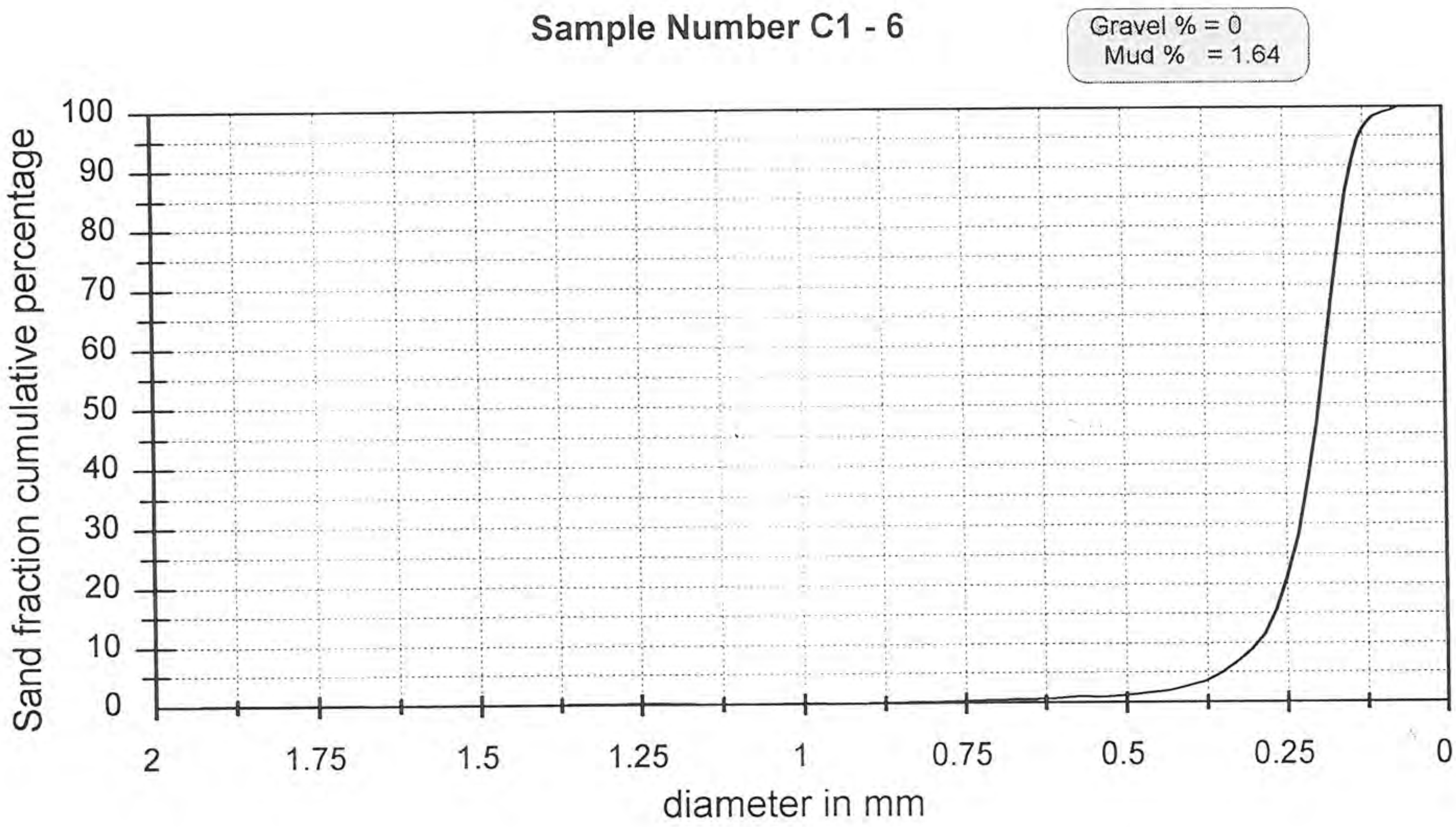

Sample Number C1 - 2
Gravel % = 0
Mud % = 1.28
Sand fraction cumulative percentage
100
90
80
70
60
50
40
30
20
10
0
2
1.75
1.5
1.25
1
0.75
0.5
0.25
0
diameter in mm



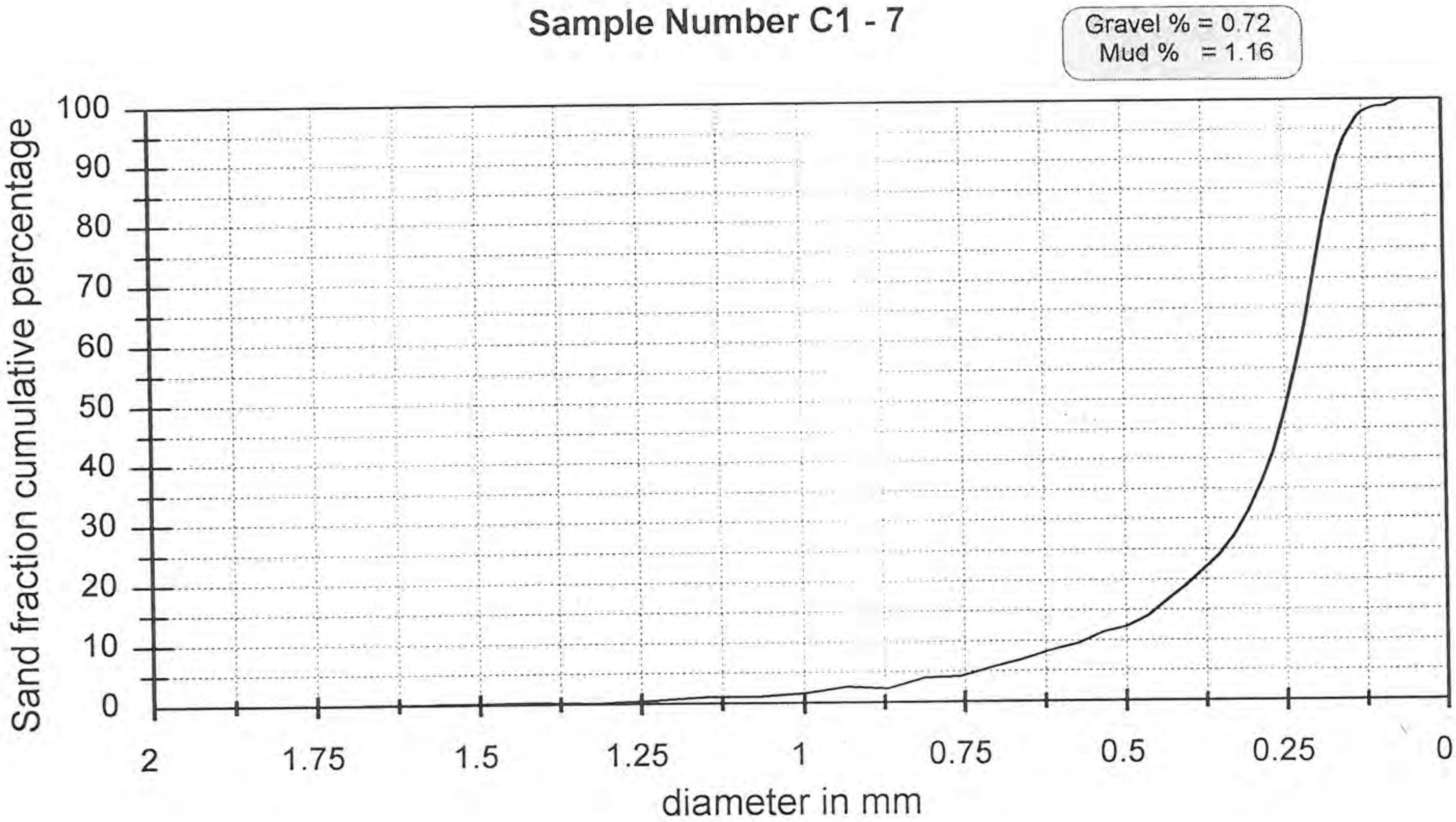
Sample Number C1 - 3
Gravel % = 0.27
Mud % = 1.76
Sand fraction cumulative percentage
100
90
80
70
60
50
40
30
20
10
0
2
1.75
1.5
1.25
1
0.75
0.5
0.25
0
diameter in mm


Sample Number C1 - 4
Gravel % = 0.32
Mud % = 1.80
Sand fraction cumulative percentage
100
90
80
70
60
50
40
30
20
10
0
2
1.75
1.5
1.25
1
0.75
0.5
0.25
0
diameter in mm

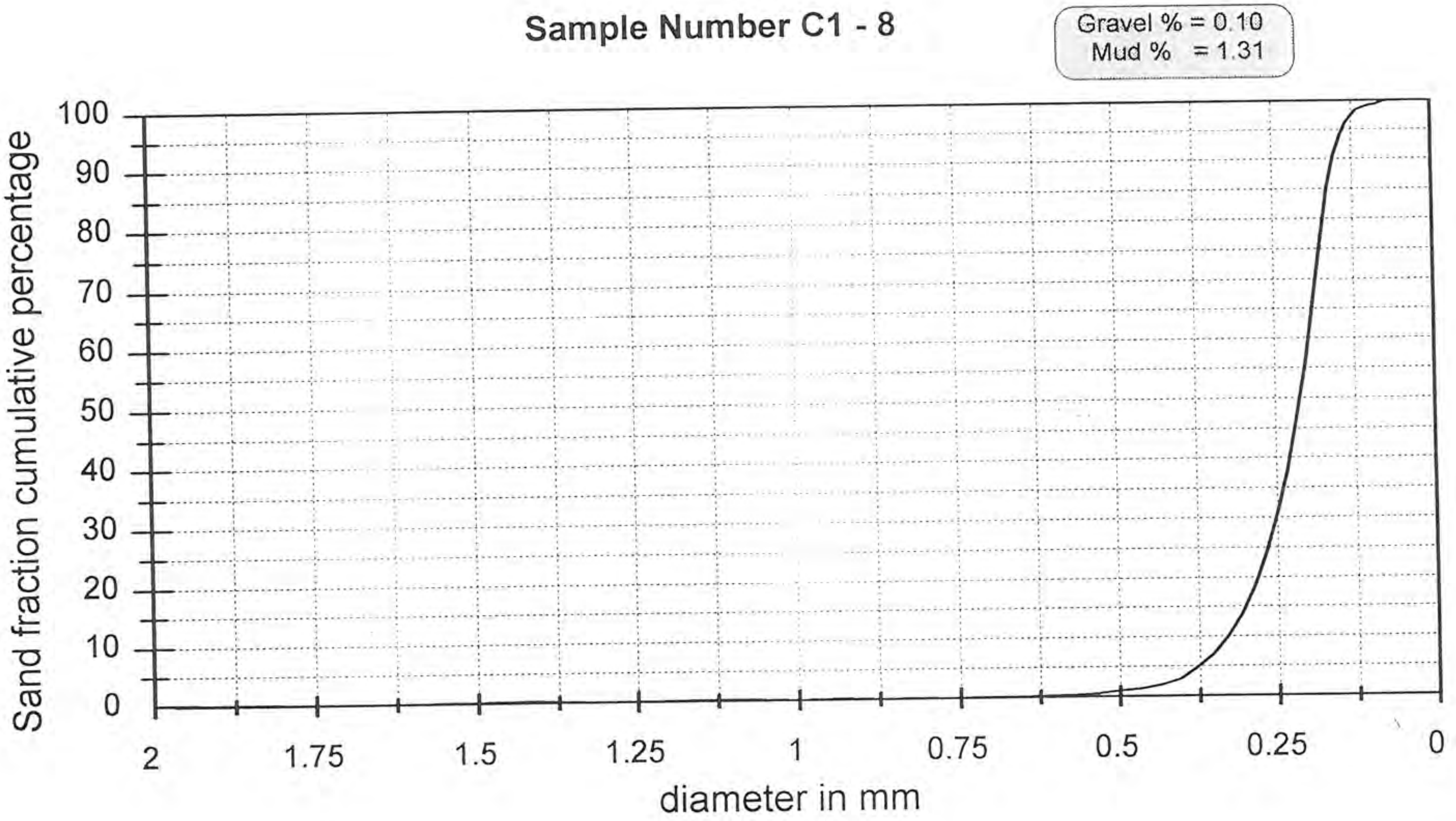

Sample Number C1 - 5
Gravel % = 0.18
Mud % = 1.40
Sand fraction cumulative percentage
100
90
80
70
60
50
40
30
20
10
0
2
1.75
1.5
1.25
1
0.75
0.5
0.25
0
diameter in mm



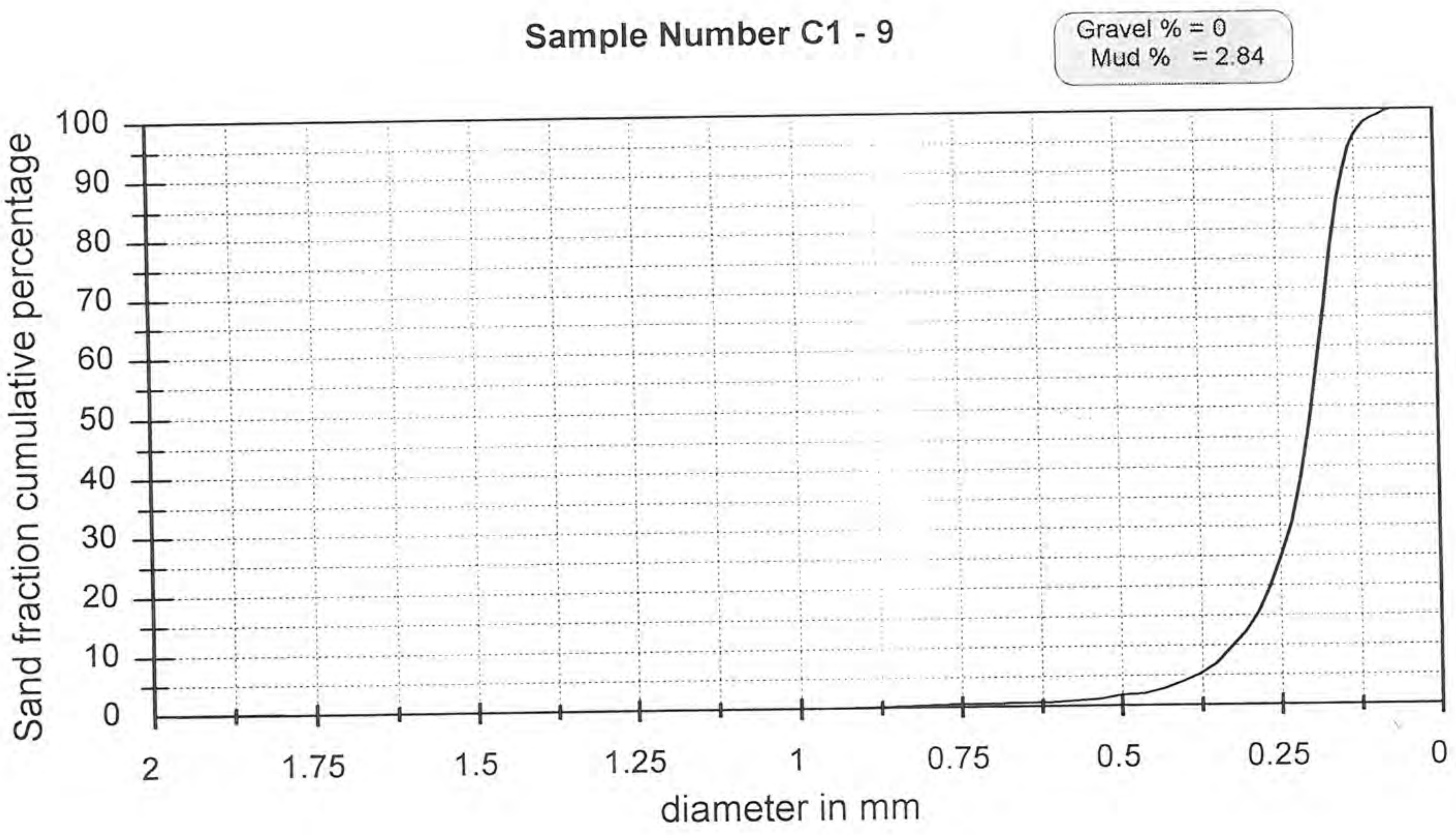
Sample Number C1 - 6
Gravel % = 0
Mud % = 1.64
100
90
80
70
60
50
40
30
20
10
0
Sand fraction cumulative percentage
2
1.75
1.5
1.25
1
0.75
0.5
0.25
0
diameter in mm

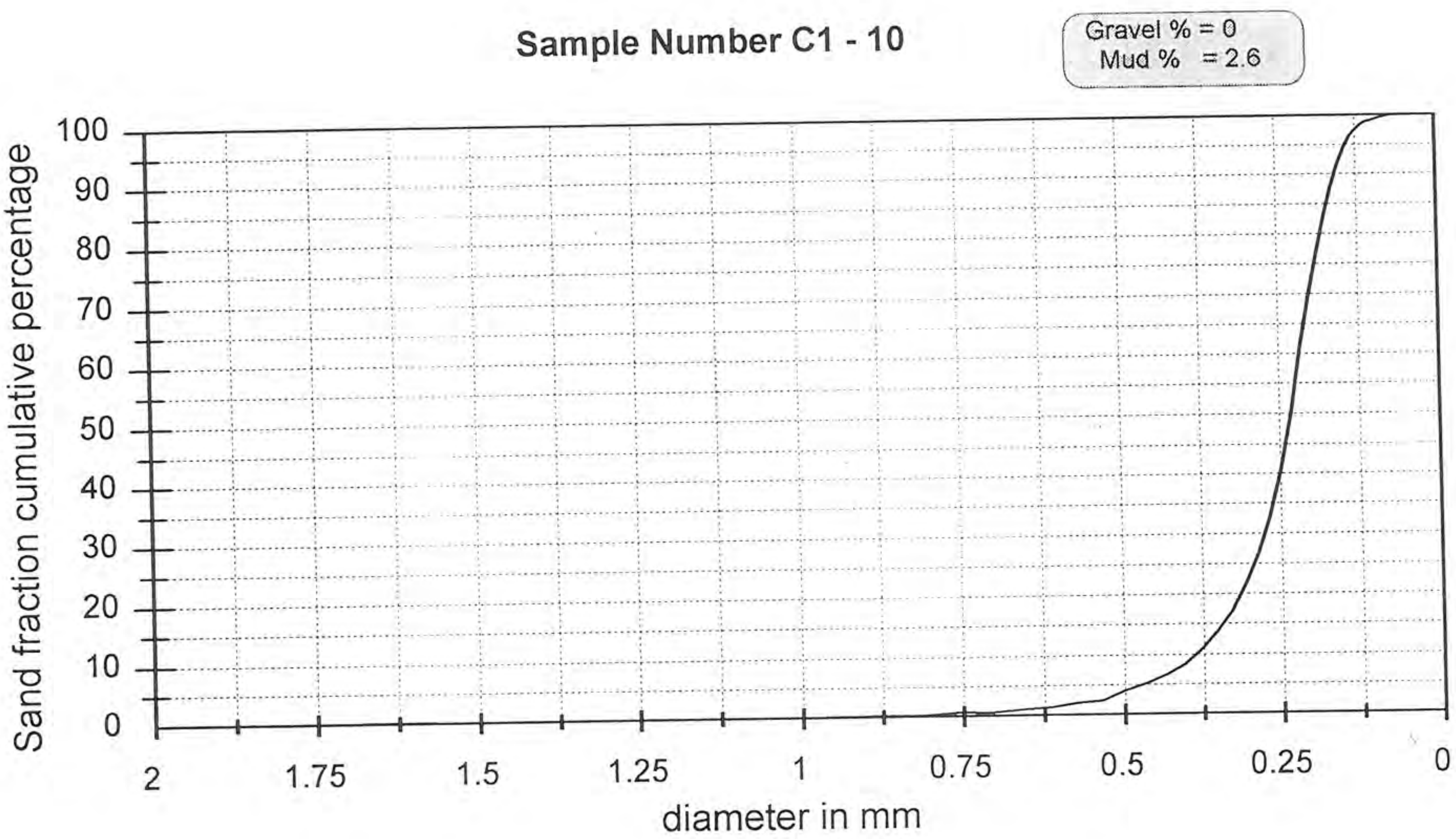


Sample Number C1 - 7
Gravel % = 0.72
Mud % = 1.16
Sand fraction cumulative percentage
100
90
80
70
60
50
40
30
20
10
0
2
1.75
1.5
1.25
1
0.75
0.5
0.25
0
diameter in mm

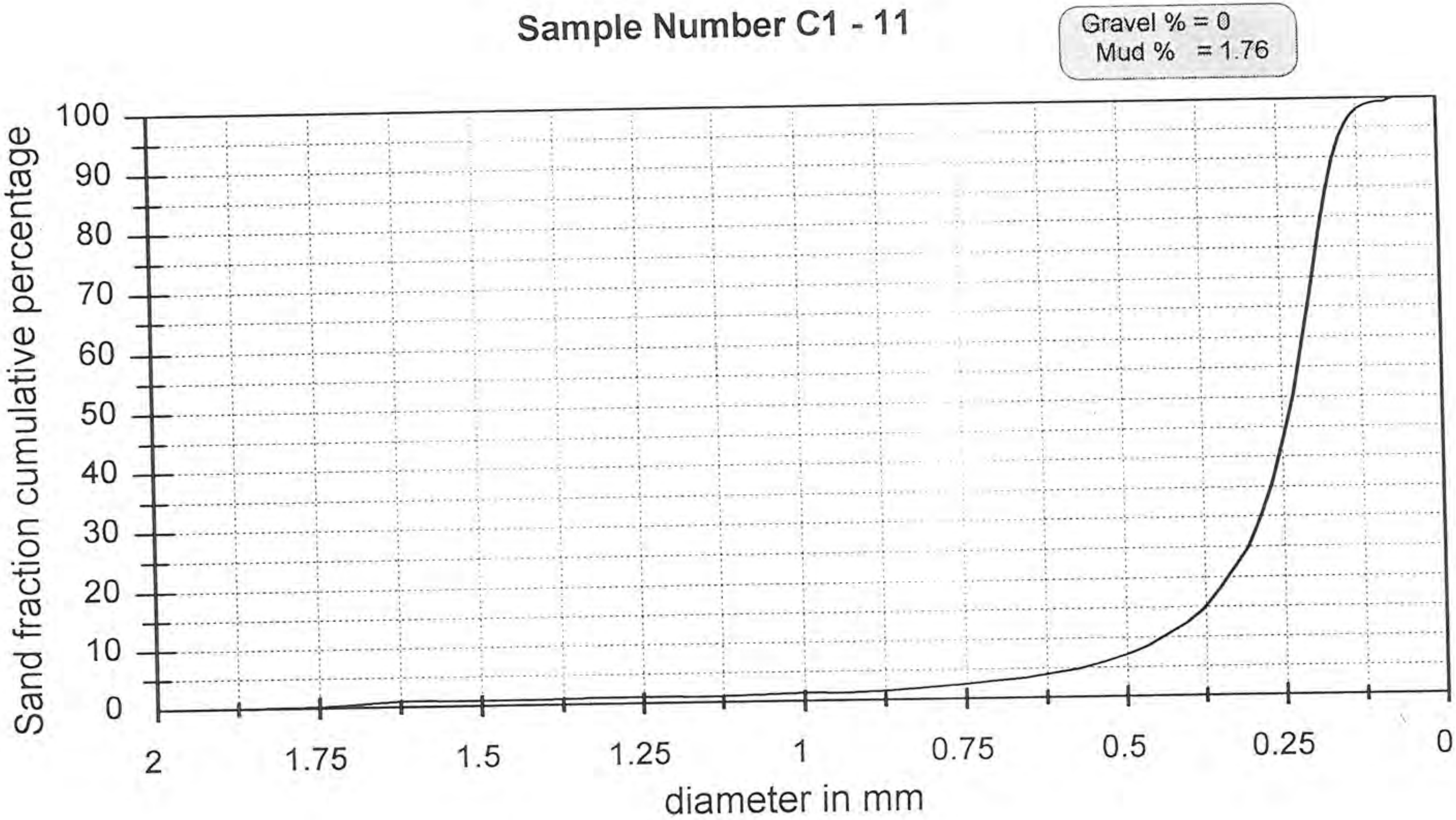


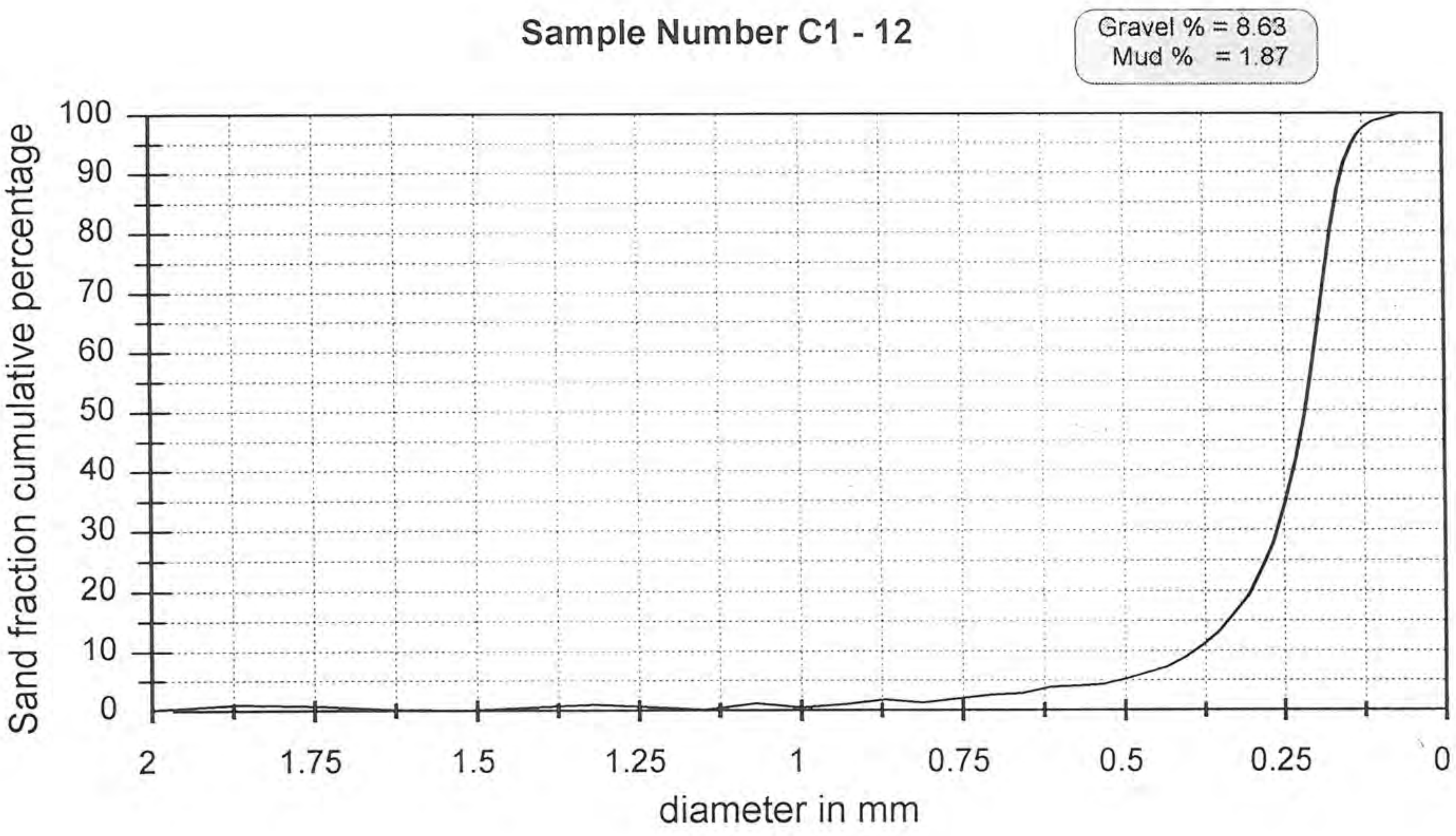
Sample Number C1 - 8
Gravel % = 0.10
Mud % = 1.31
Sand fraction cumulative percentage
100
90
80
70
60
50
40
30
20
10
0
2
1.75
1.5
1.25
1
0.75
0.5
0.25
0
diameter in mm


Sample Number C1 - 9
Gravel % = 0
Mud % = 2.84
Sand fraction cumulative percentage
100
90
80
70
60
50
40
30
20
10
0
2
1.75
1.5
1.25
1
0.75
0.5
0.25
0
diameter in mm

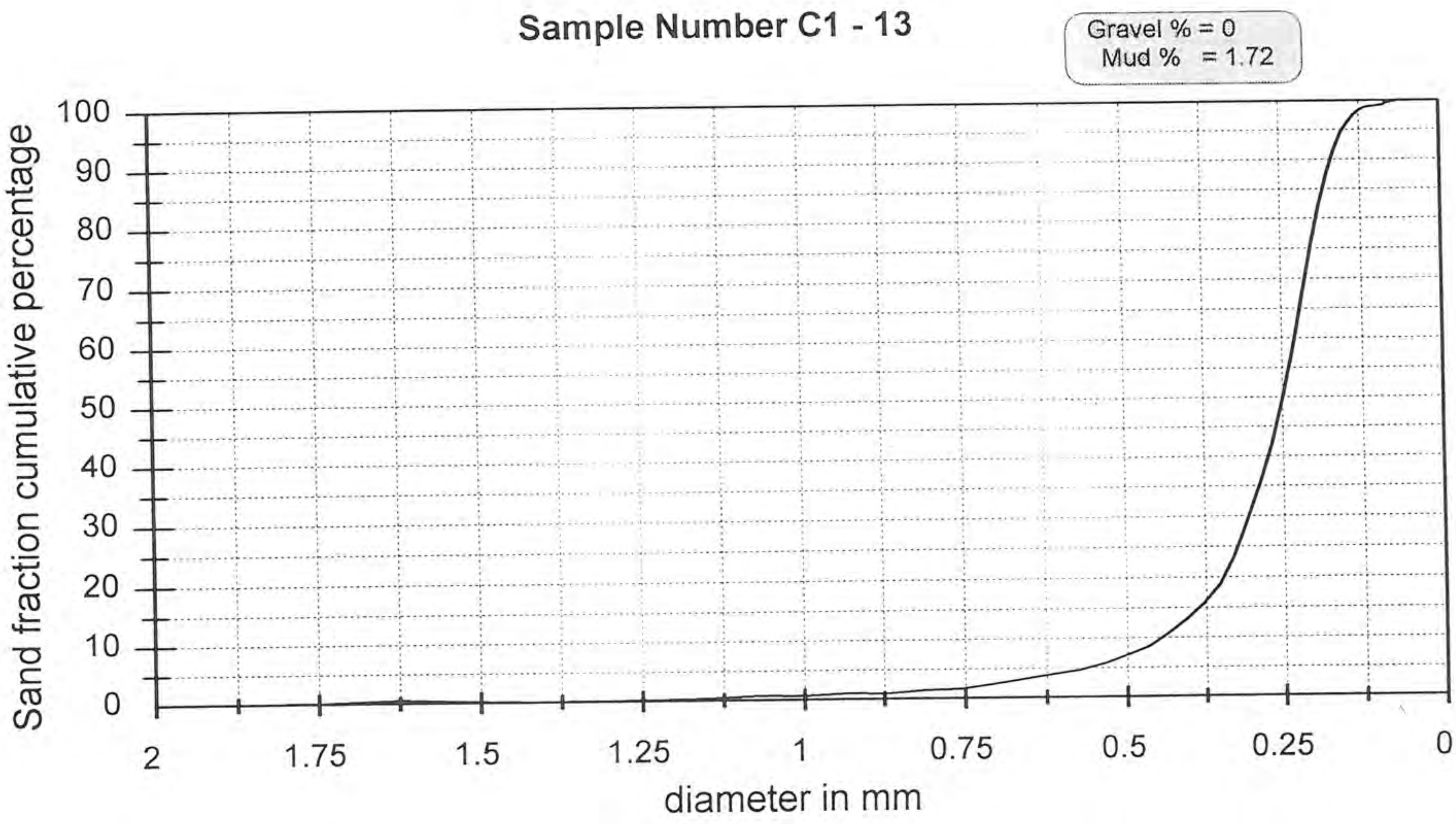

Sample Number C1 - 10
Gravel % = 0
Mud % = 2.6
100
90
80
70
60
50
40
30
20
10
0
Sand fraction cumulative percentage
2
1.75
1.5
1.25
1
0.75
0.5
0.25
0
diameter in mm

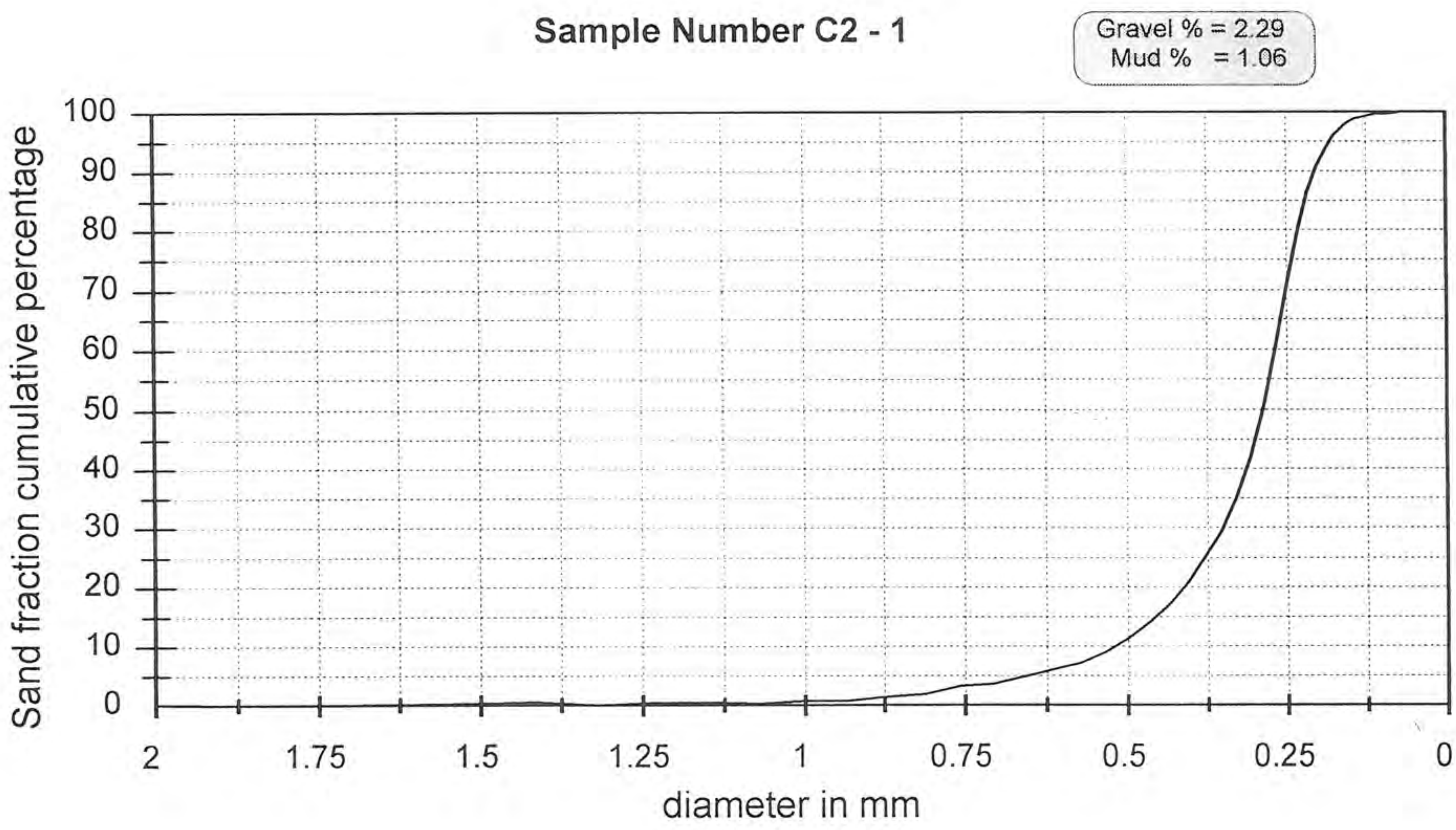
Sample Number C1 - 11

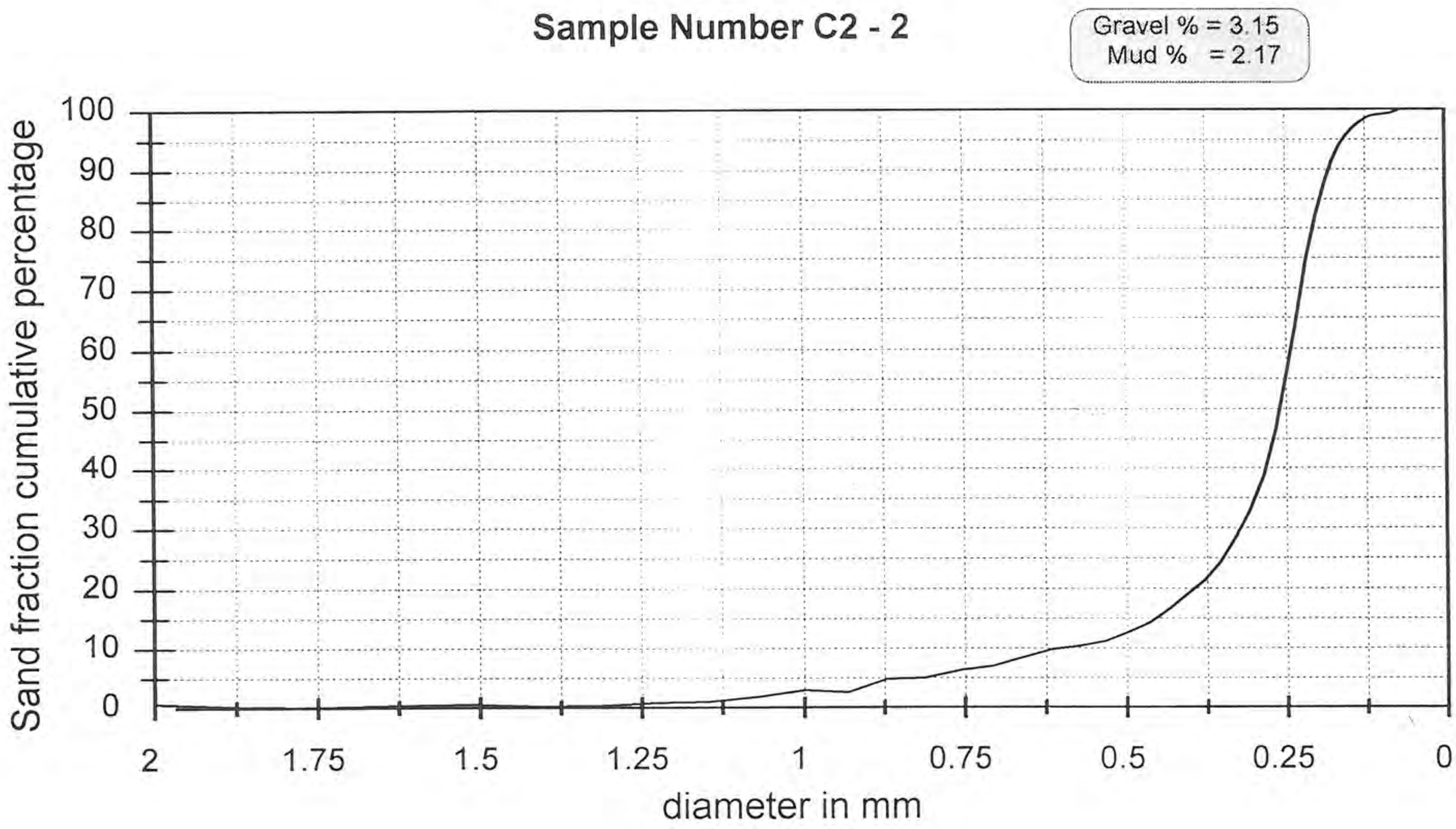




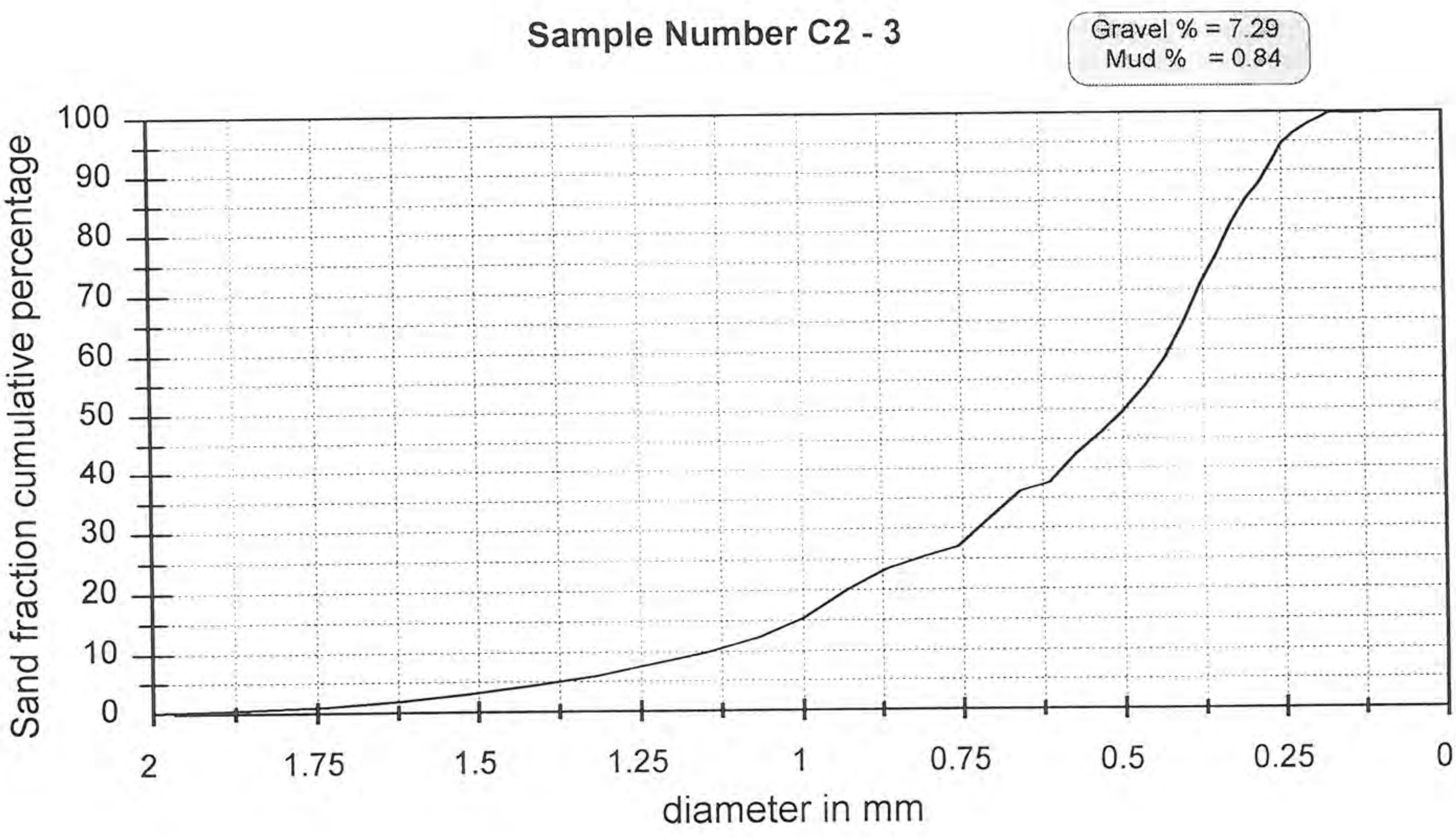
Sample Number C1 - 12
Gravel % = 8.63
Mud % = 1.87
Sand fraction cumulative percentage
100
90
80
70
60
50
40
30
20
10
0
2
1.75
1.5
1.25
1
0.75
0.5
0.25
0
diameter in mm


Sample Number C1 - 13
Gravel % = 0
Mud % = 1.72
Sand fraction cumulative percentage
100
90
80
70
60
50
40
30
20
10
0
2
1.75
1.5
1.25
1
0.75
0.5
0.25
0
diameter in mm

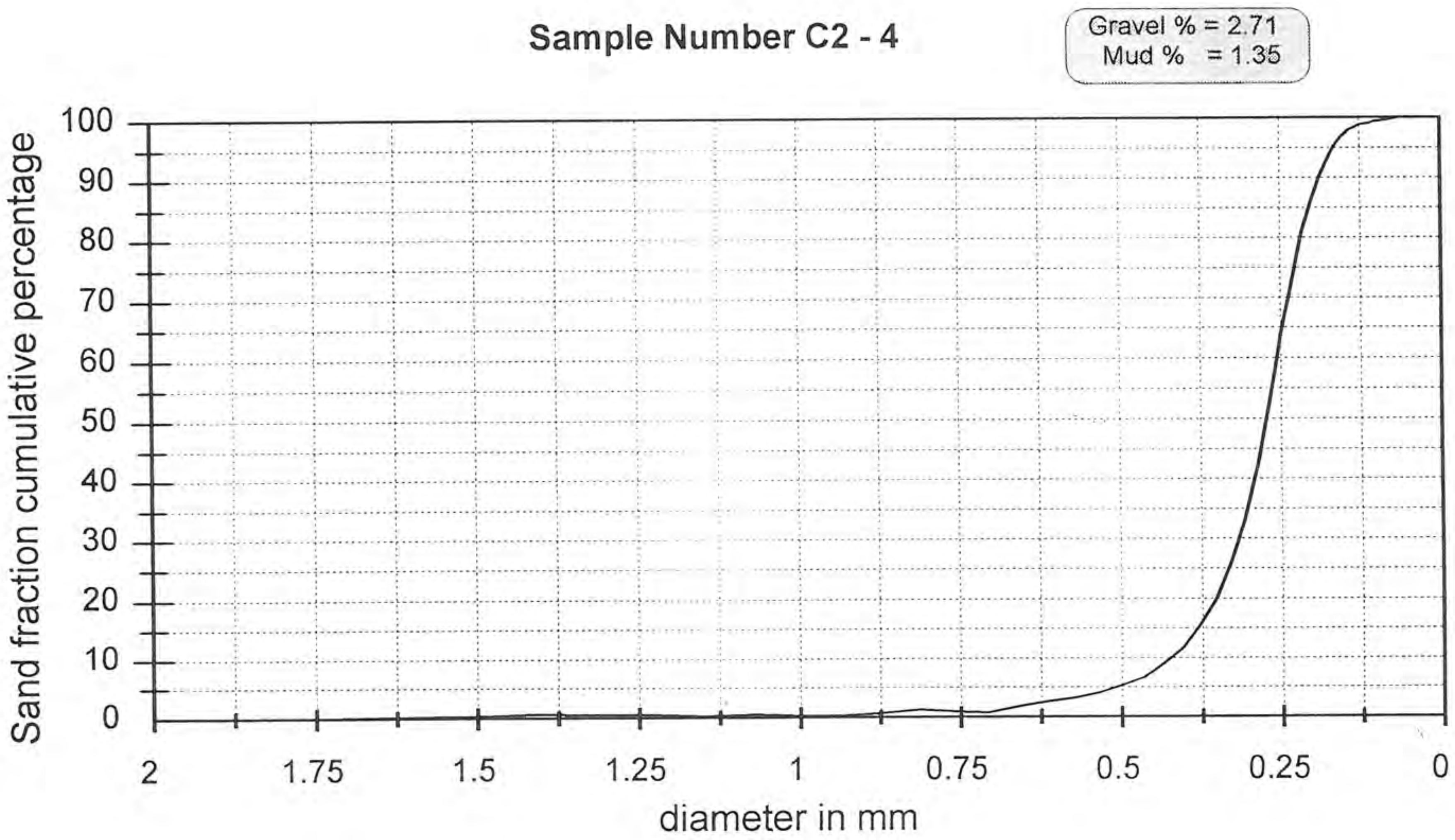

Sample Number C2 - 1
Gravel % = 2.29
Mud % = 1.06
Sand fraction cumulative percentage
100
90
80
70
60
50
40
30
20
10
0
2
1.75
1.5
1.25
1
0.75
0.5
0.25
0
diameter in mm

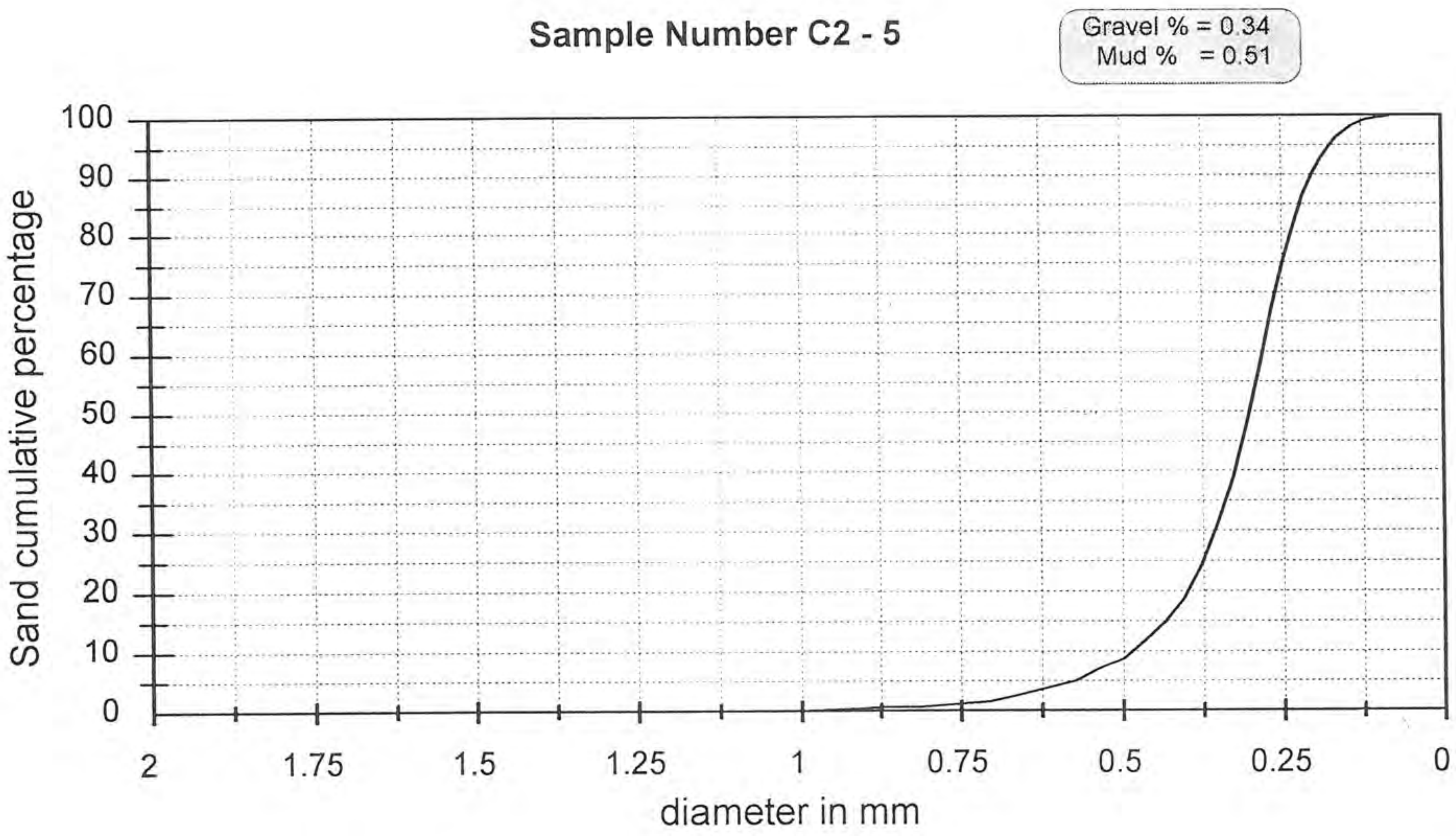


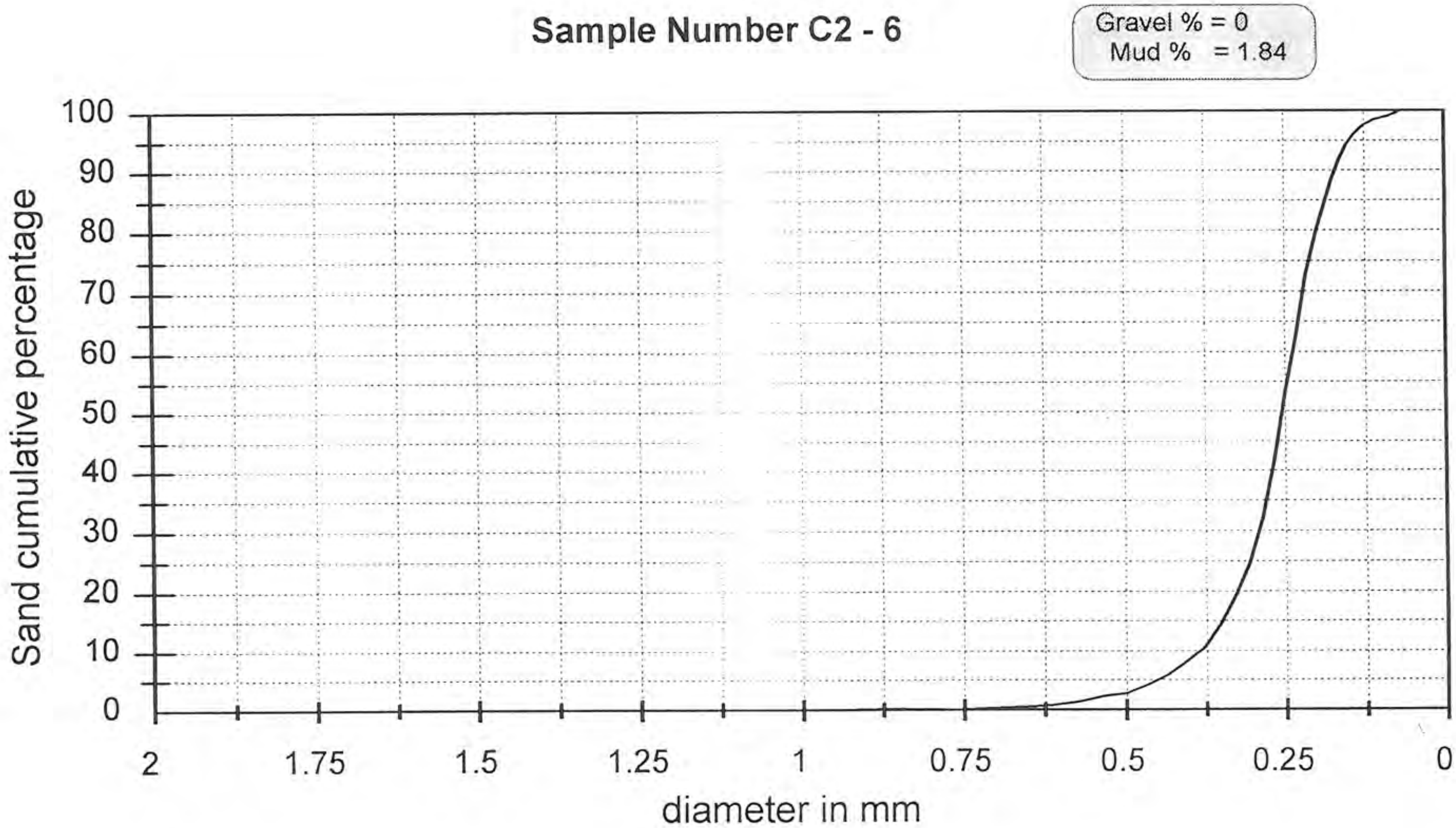
Sample Number C2 - 2
Gravel % = 3.15
Mud % = 2.17
Sand fraction cumulative percentage
100
90
80
70
60
50
40
30
20
10
0
2
1.75
1.5
1.25
1
0.75
0.5
0.25
0
diameter in mm

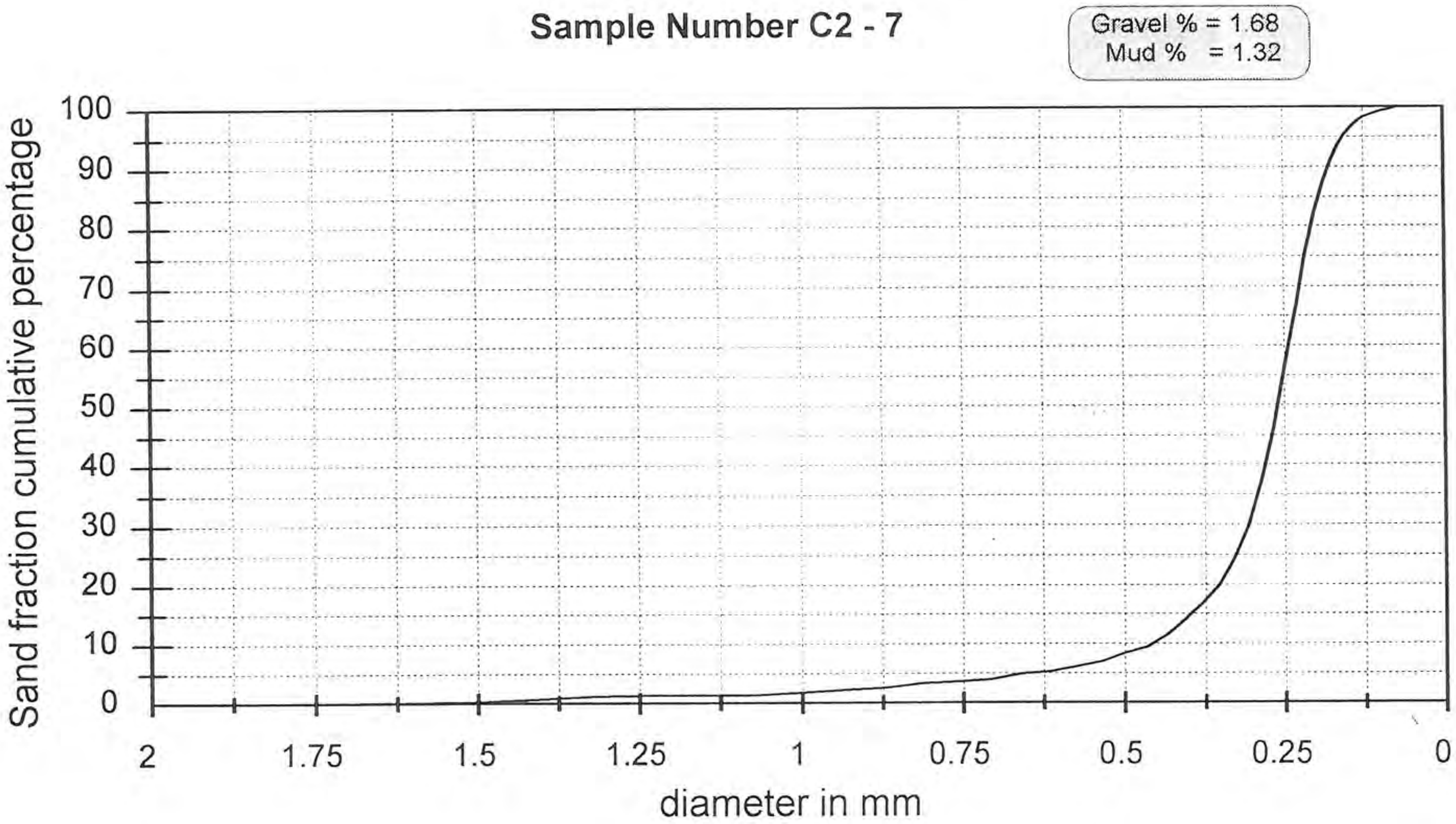


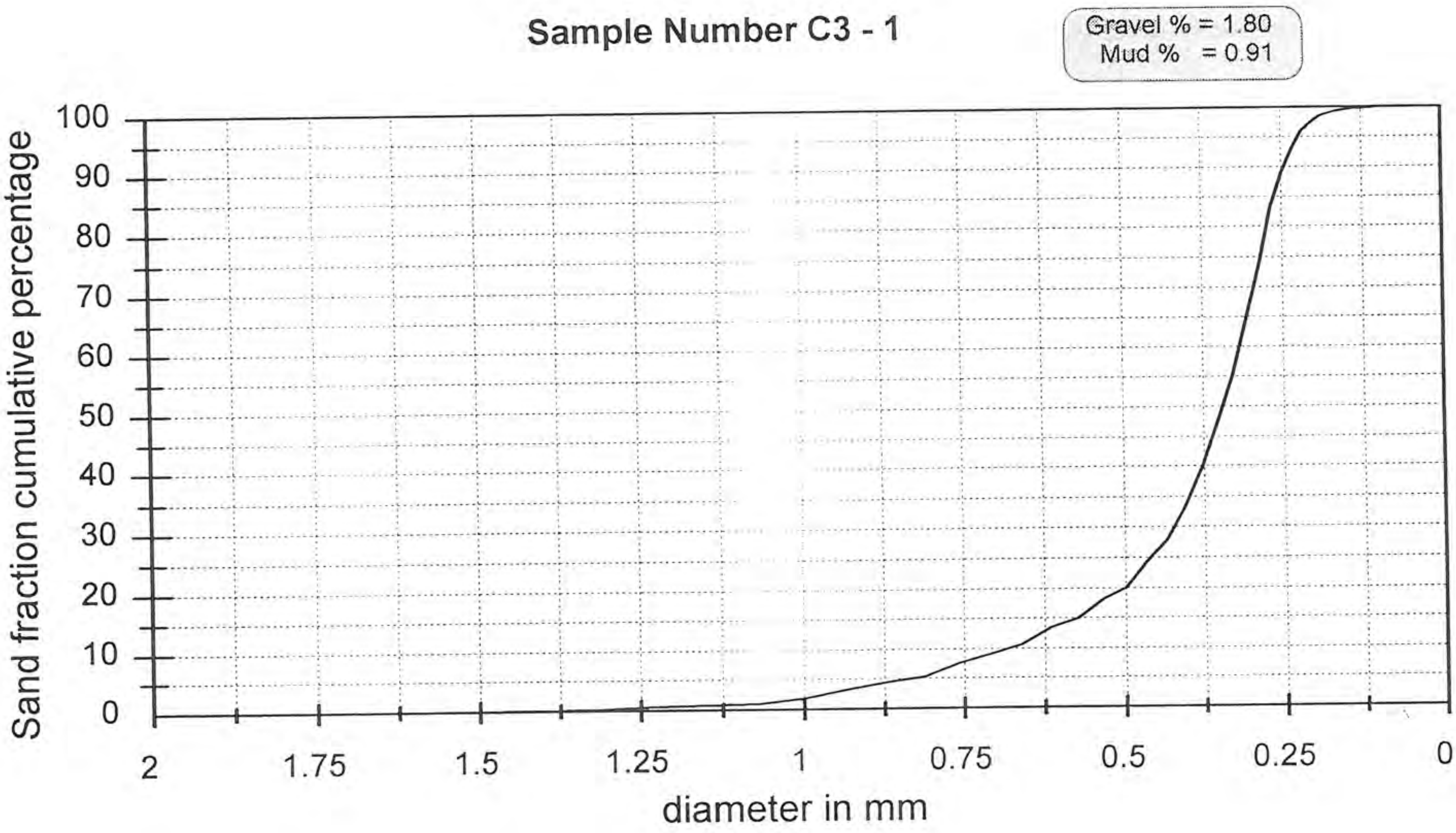
Sample Number C2 - 3
Gravel % = 7.29
Mud % = 0.84
Sand fraction cumulative percentage
100
90
80
70
60
50
40
30
20
10
0
2
1.75
1.5
1.25
1
0.75
0.5
0.25
0
diameter in mm

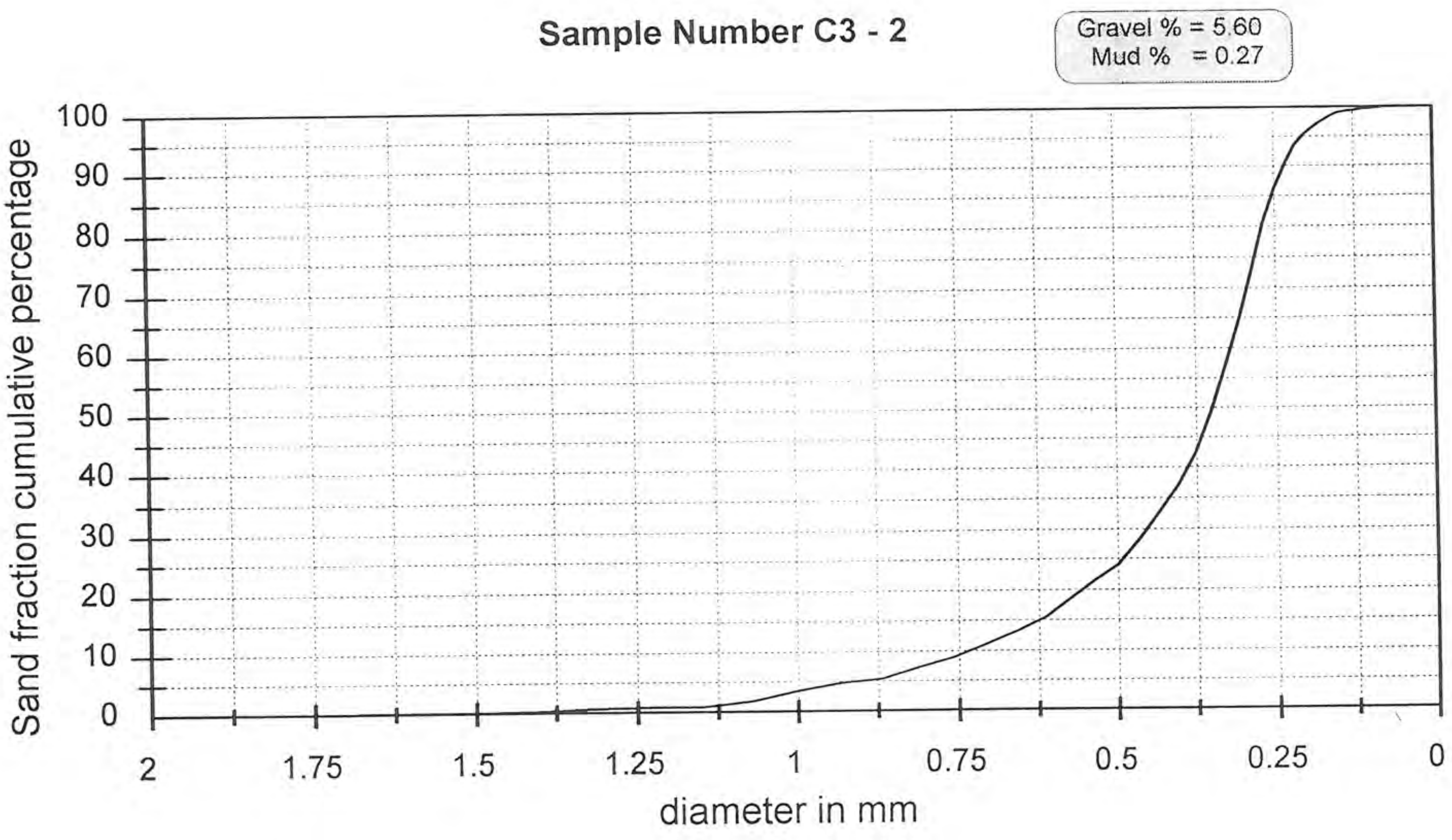

Sample Number C2 - 4
Gravel % = 2.71
Mud % = 1.35
Sand fraction cumulative percentage
100
90
80
70
60
50
40
30
20
10
0
2
1.75
1.5
1.25
1
0.75
0.5
0.25
0
diameter in mm


Sample Number C2 - 5
Gravel % = 0.34
Mud % = 0.51
Sand cumulative percentage
100
90
80
70
60
50
40
30
20
10
0
2
1.75
1.5
1.25
1
0.75
0.5
0.25
0
diameter in mm

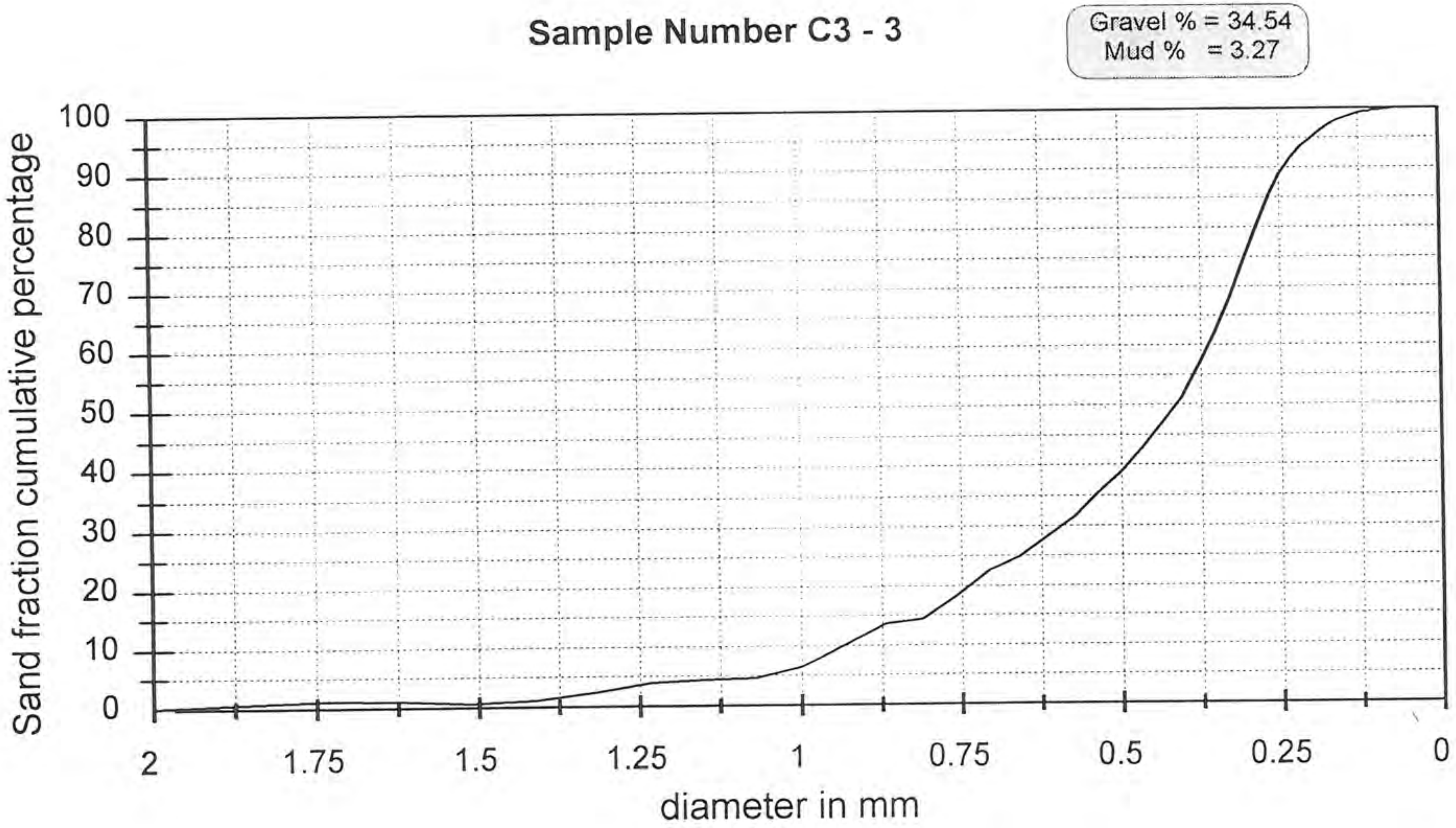

Sample Number C2 - 6
Gravel % = 0
Mud % = 1.84
100
90
80
70
60
50
40
30
20
10
0
Sand cumulative percentage
2
1.75
1.5
1.25
1
0.75
0.5
0.25
0
diameter in mm

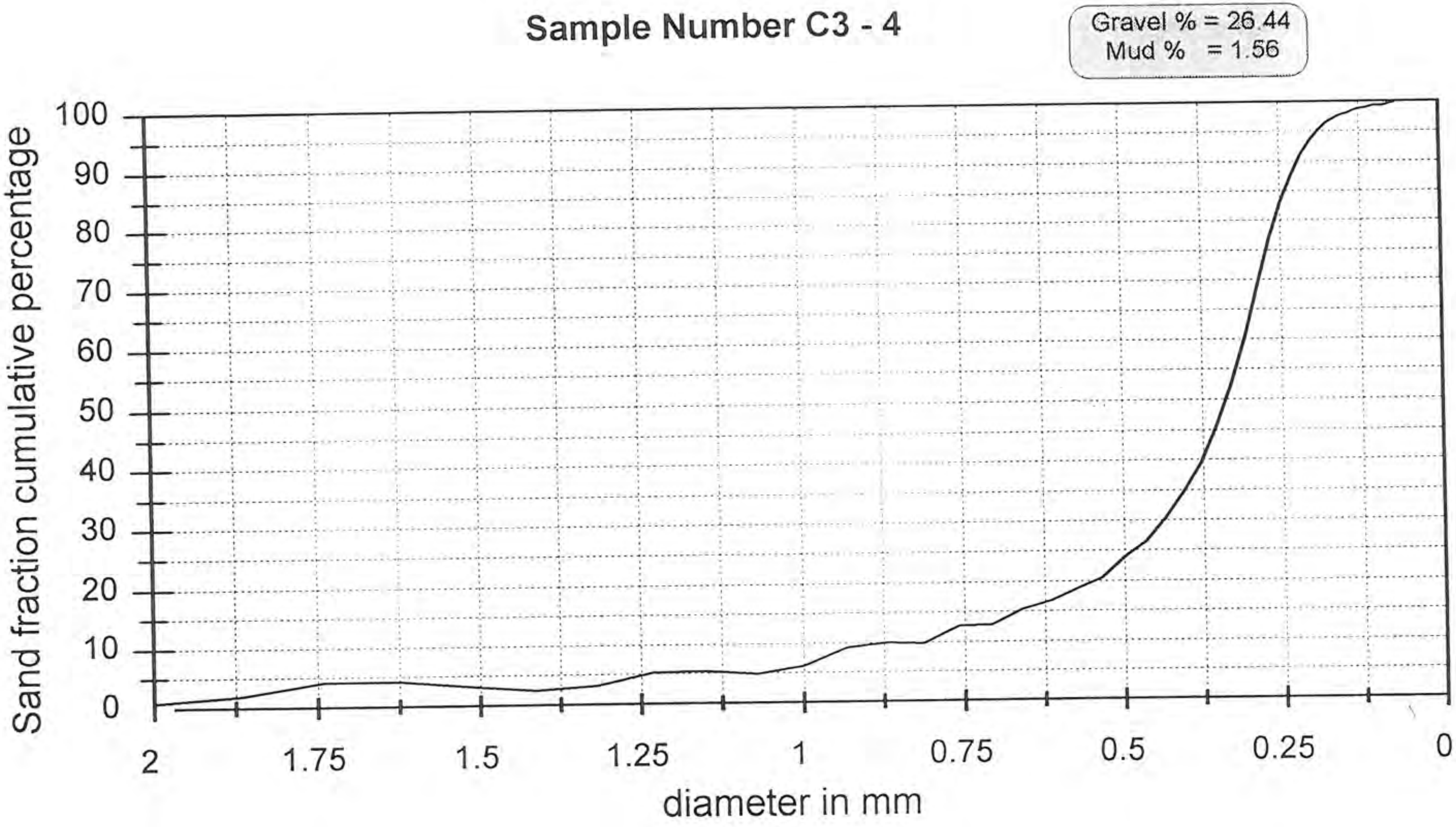

Sample Number C2 - 7
Gravel % = 1.68
Mud % = 1.32
Sand fraction cumulative percentage
100
90
80
70
60
50
40
30
20
10
0
2
1.75
1.5
1.25
1
0.75
0.5
0.25
0
diameter in mm


Sample Number C3 - 1
Gravel % = 1.80
Mud % = 0.91
Sand fraction cumulative percentage
100
90
80
70
60
50
40
30
20
10
0
2
1.75
1.5
1.25
1
0.75
0.5
0.25
0
diameter in mm

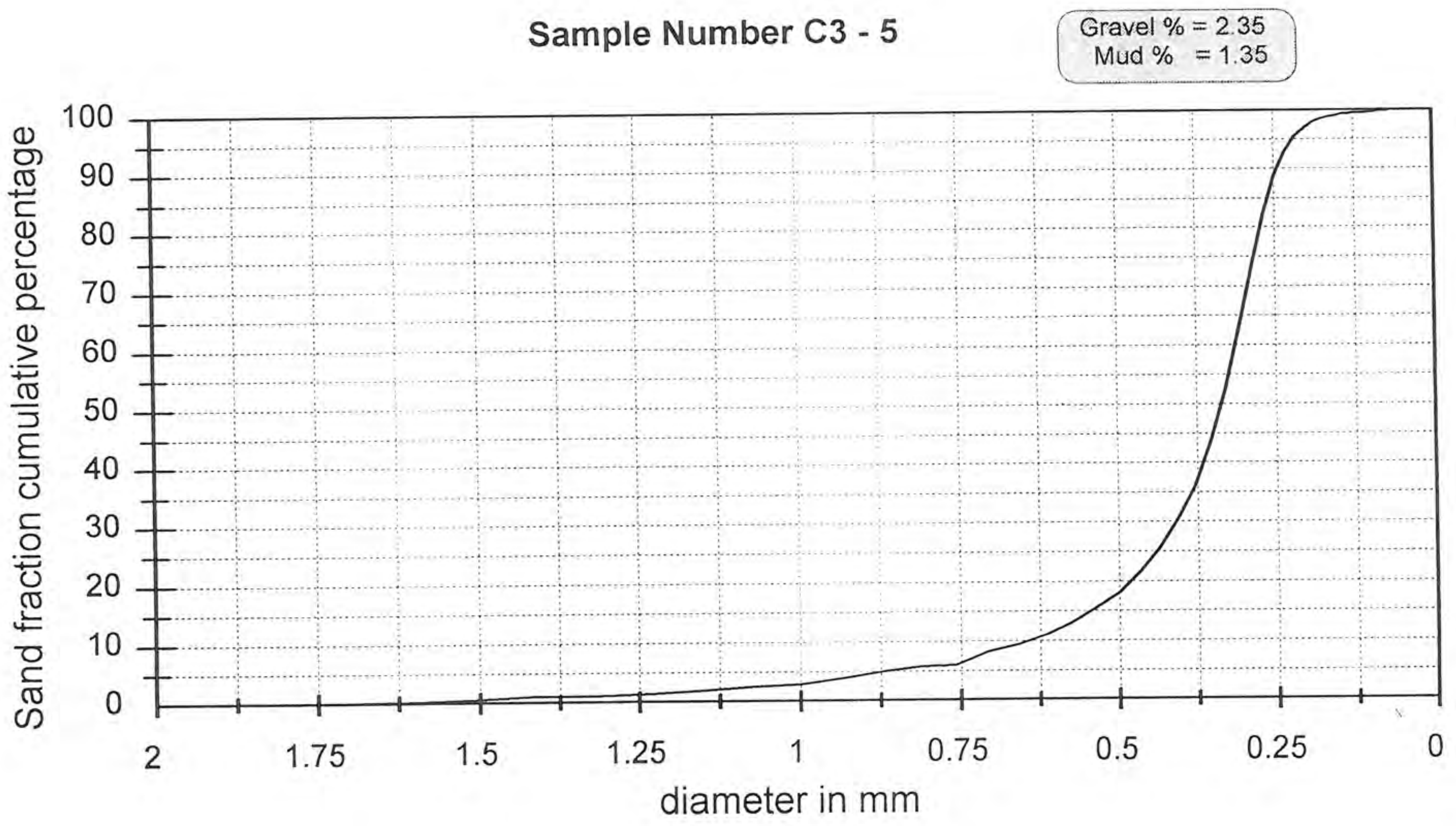


Sample Number C3 - 2
Gravel % = 5.60
Mud % = 0.27
Sand fraction cumulative percentage
100
90
80
70
60
50
40
30
20
10
0
2
1.75
1.5
1.25
1
0.75
0.5
0.25
0
diameter in mm

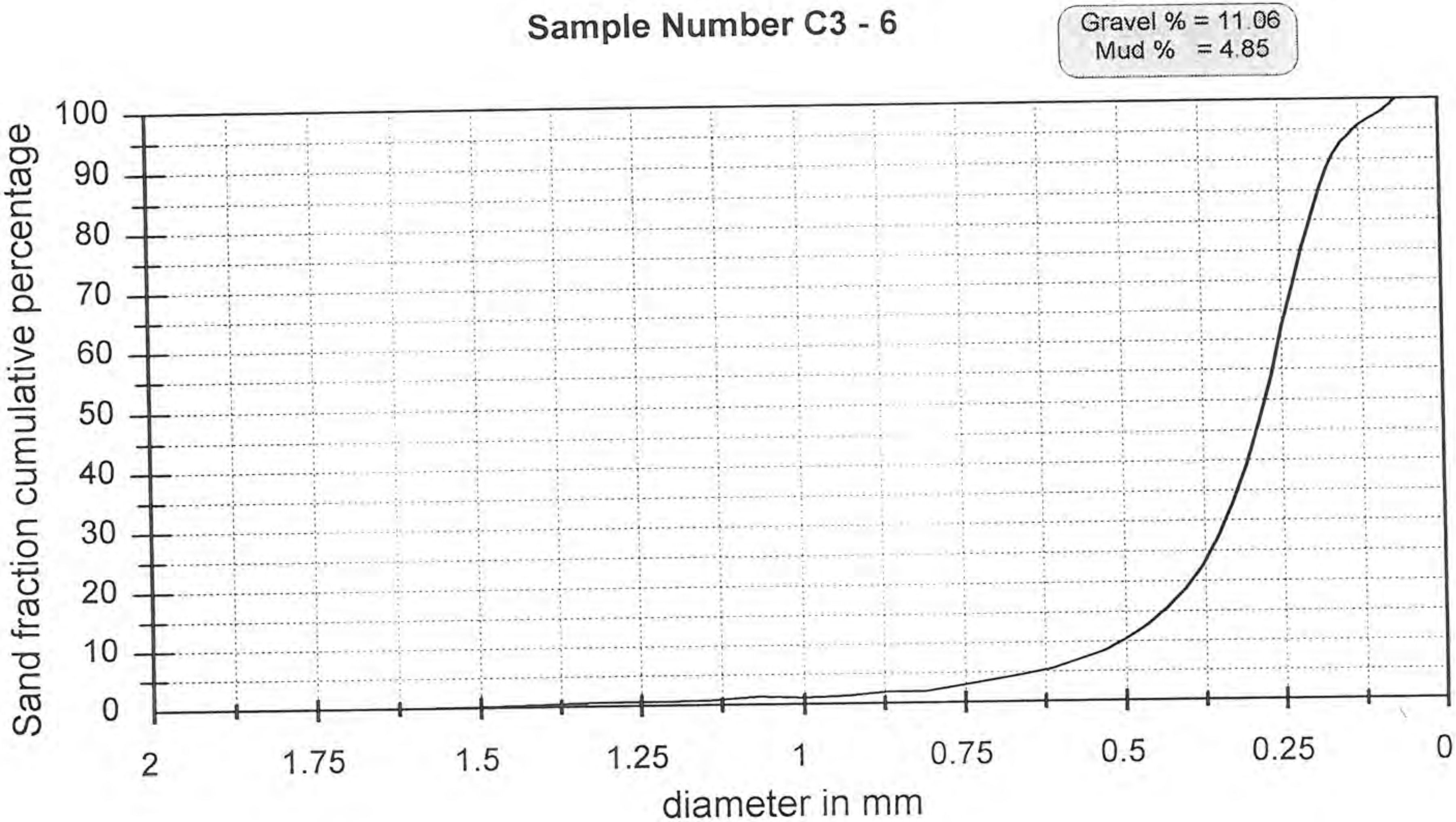

Sample Number C3 - 3
Gravel % = 34.54
Mud % = 3.27
Sand fraction cumulative percentage
100
90
80
70
60
50
40
30
20
10
0
2
1.75
1.5
1.25
1
0.75
0.5
0.25
0
diameter in mm

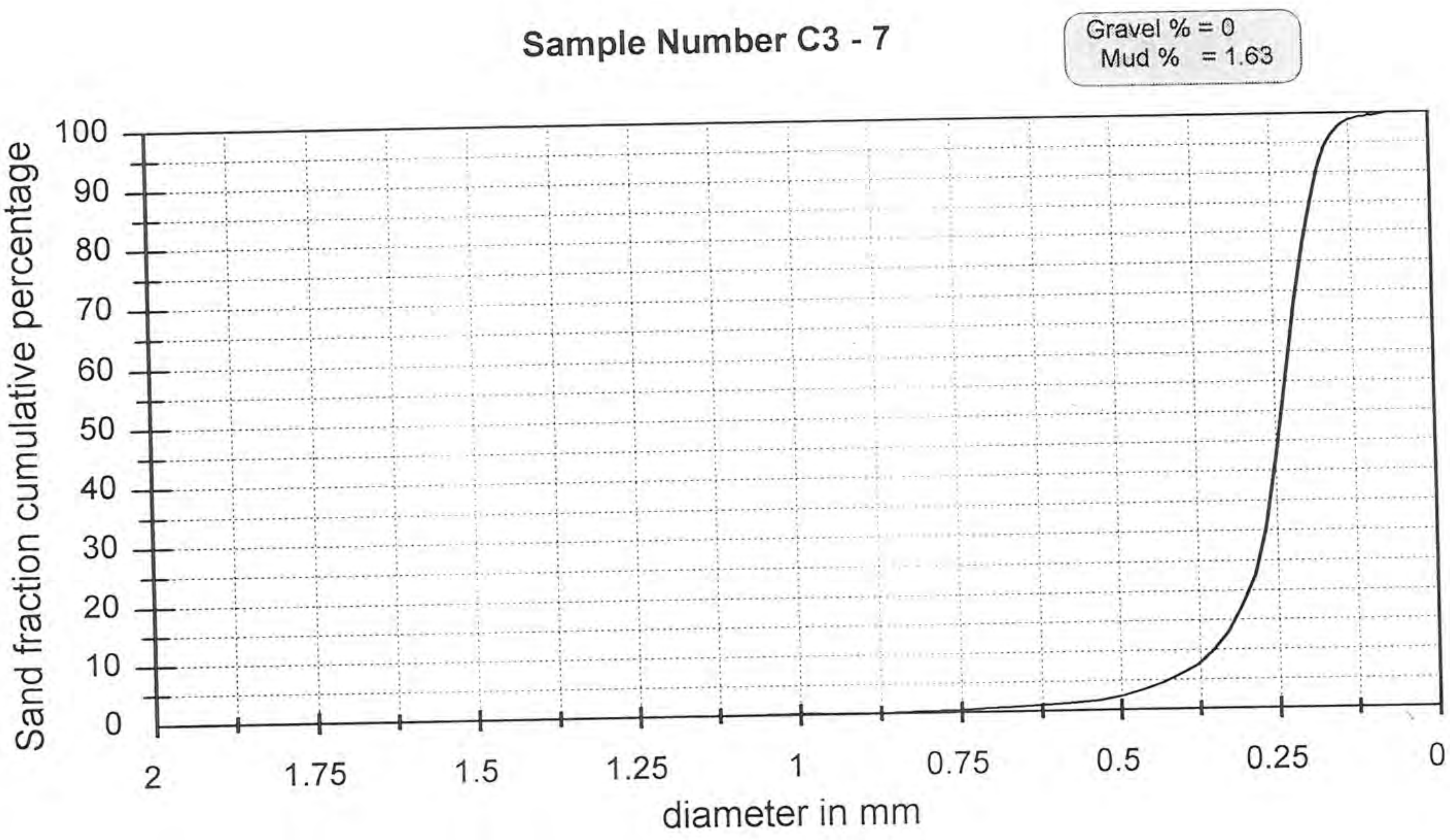


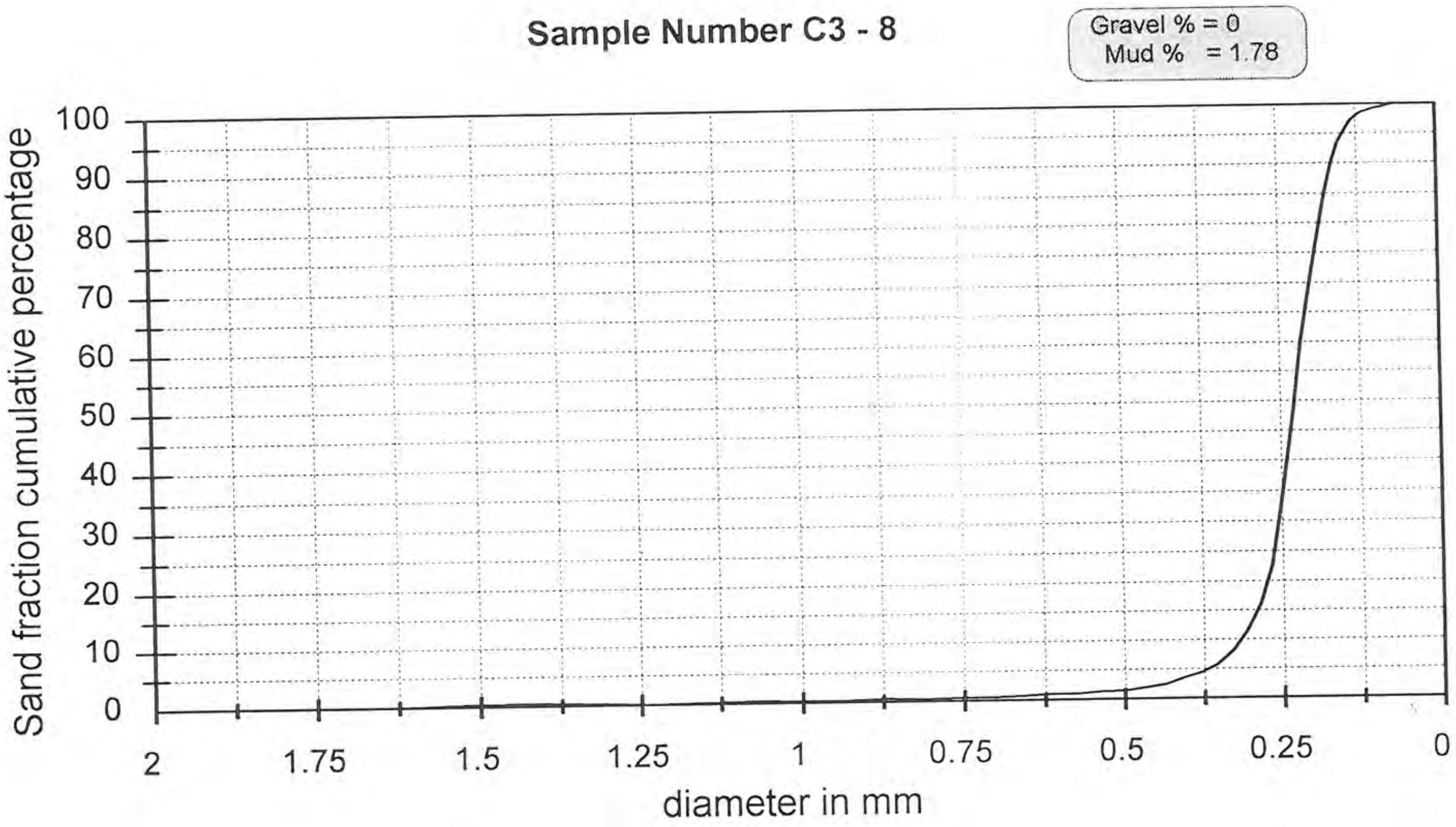
Sample Number C3 - 4
Gravel % = 26.44
Mud % = 1.56
Sand fraction cumulative percentage
100
90
80
70
60
50
40
30
20
10
0
2
1.75
1.5
1.25
1
0.75
0.5
0.25
0
diameter in mm



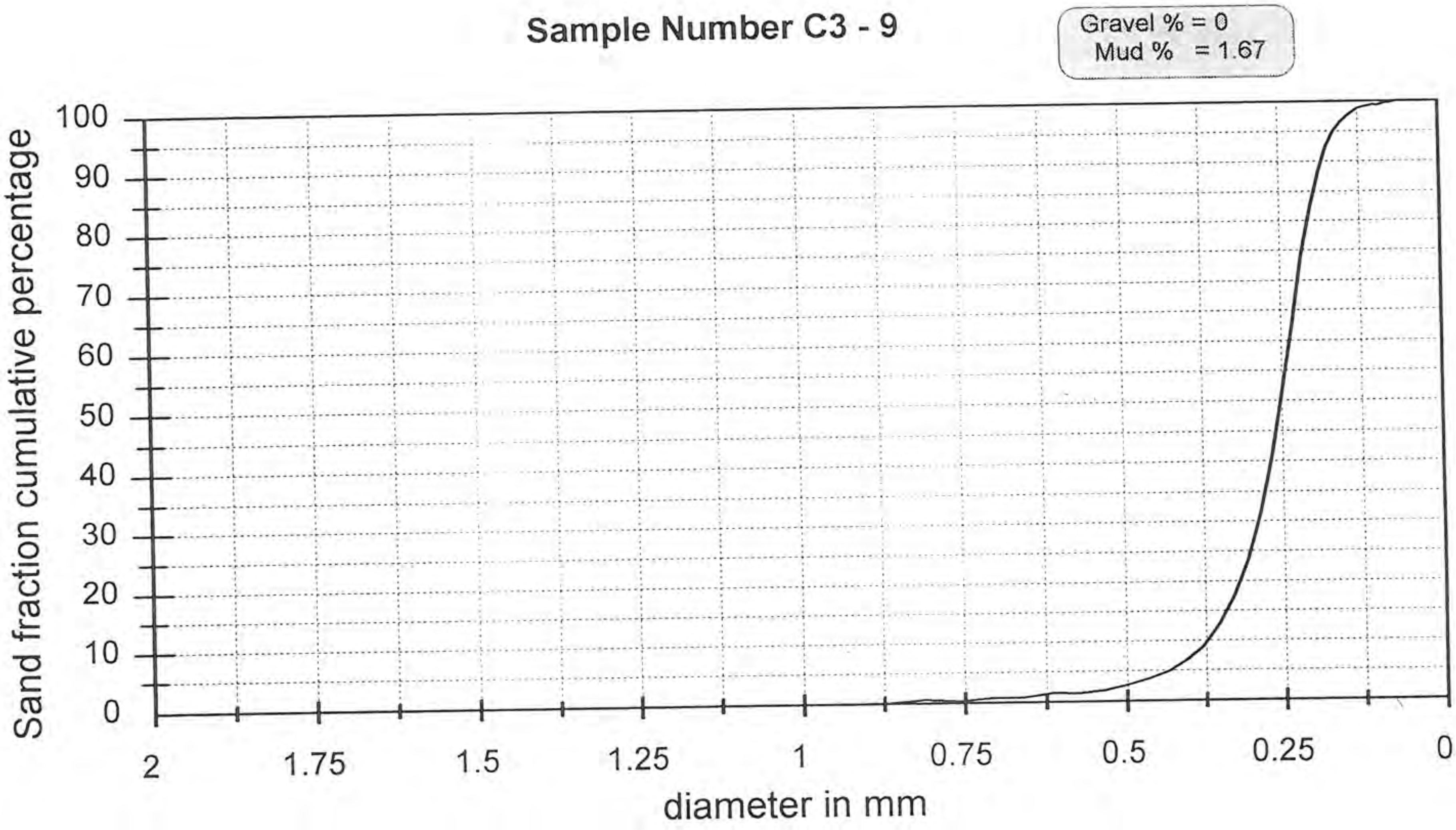
Sample Number C3 - 5
Gravel % = 2.35
Mud % = 1.35
Sand fraction cumulative percentage
100
90
80
70
60
50
40
30
20
10
0
2
1.75
1.5
1.25
1
0.75
0.5
0.25
0
diameter in mm


Sample Number C3 - 6
Gravel % = 11.06
Mud % = 4.85
Sand fraction cumulative percentage
100
90
80
70
60
50
40
30
20
10
0
2
1.75
1.5
1.25
1
0.75
0.5
0.25
0
diameter in mm

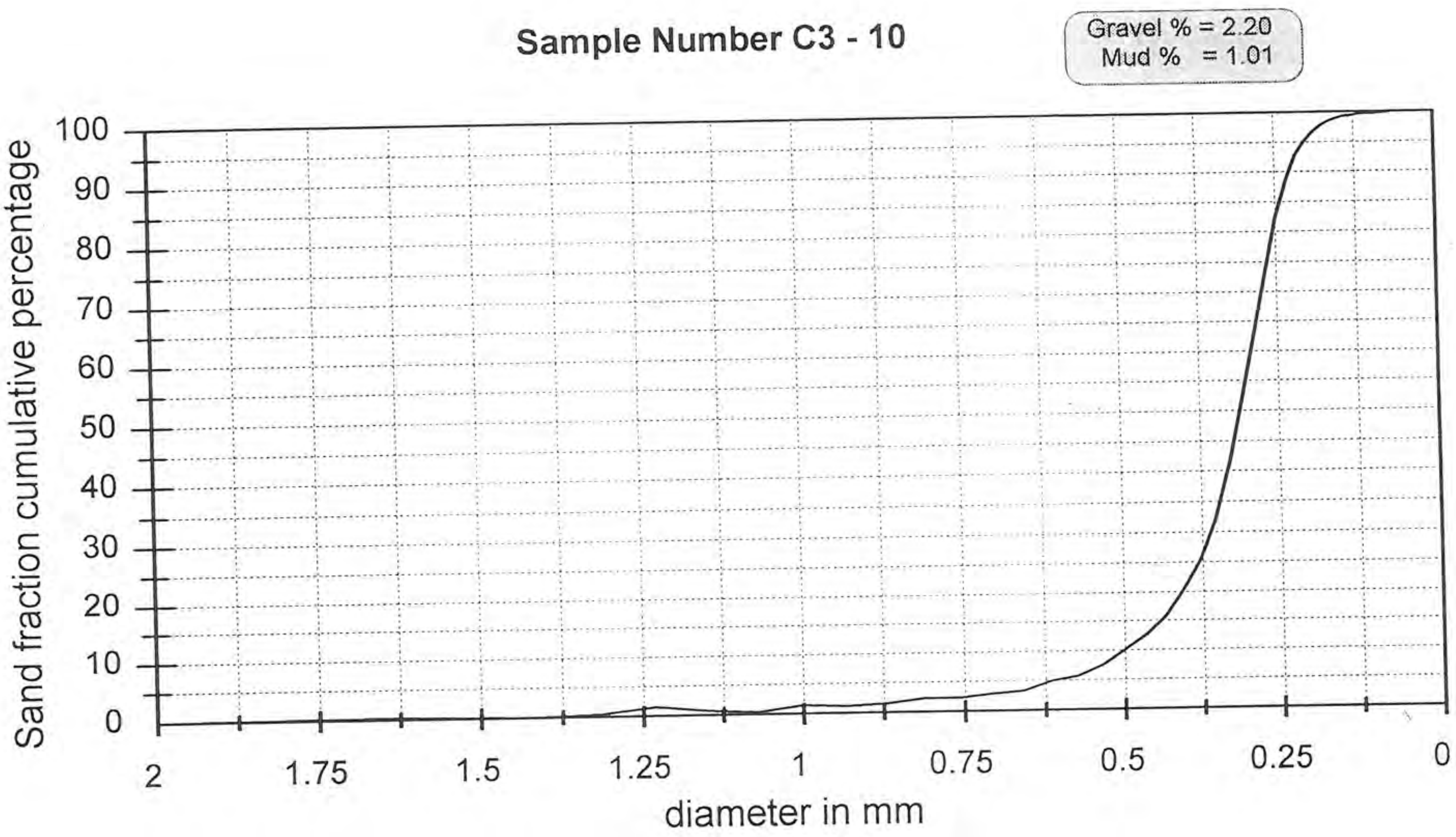

Sample Number C3 - 7
Gravel % = 0
Mud % = 1.63
Sand fraction cumulative percentage
100
90
80
70
60
50
40
30
20
10
0
2
1.75
1.5
1.25
1
0.75
0.5
0.25
0
diameter in mm

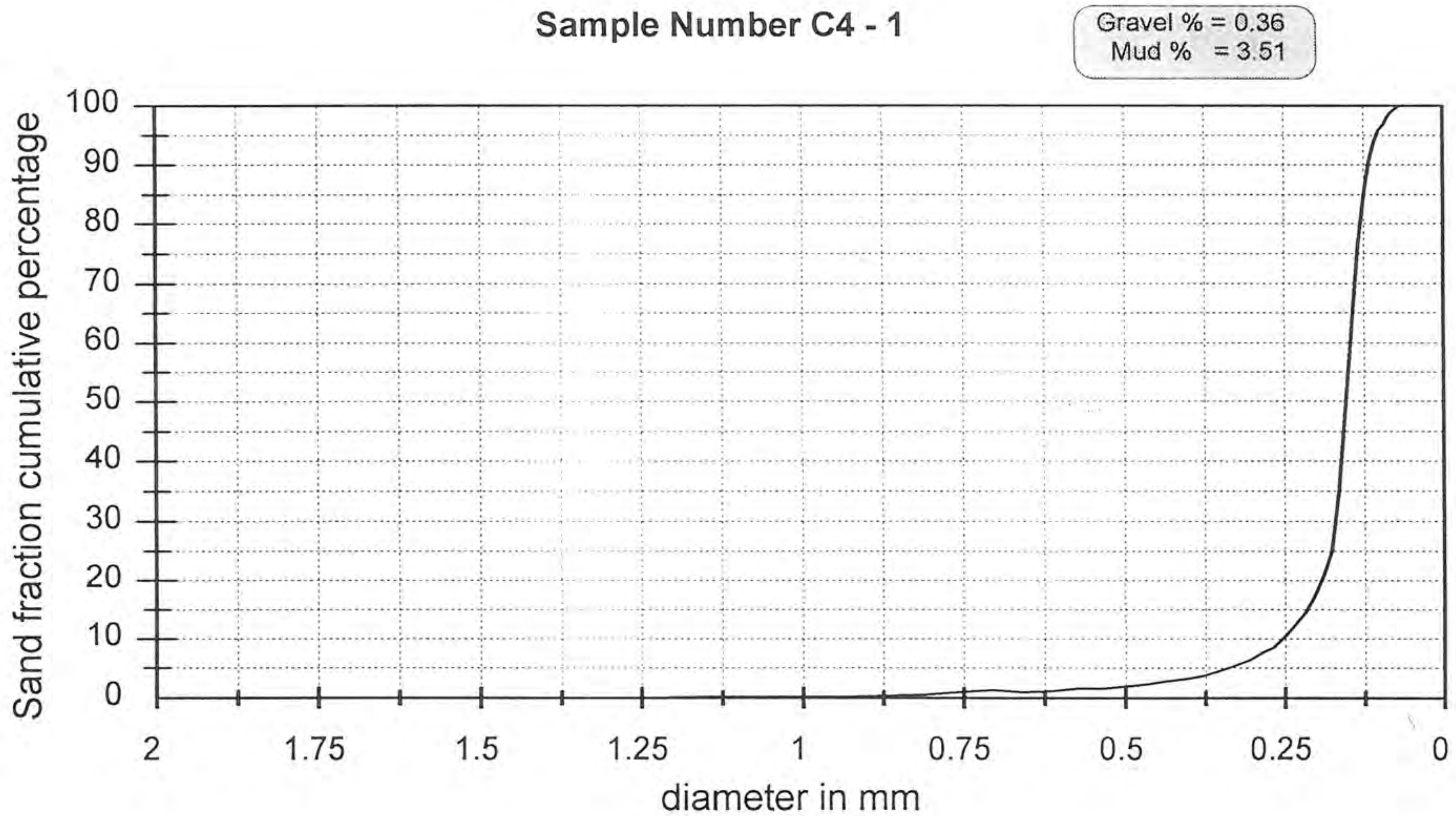


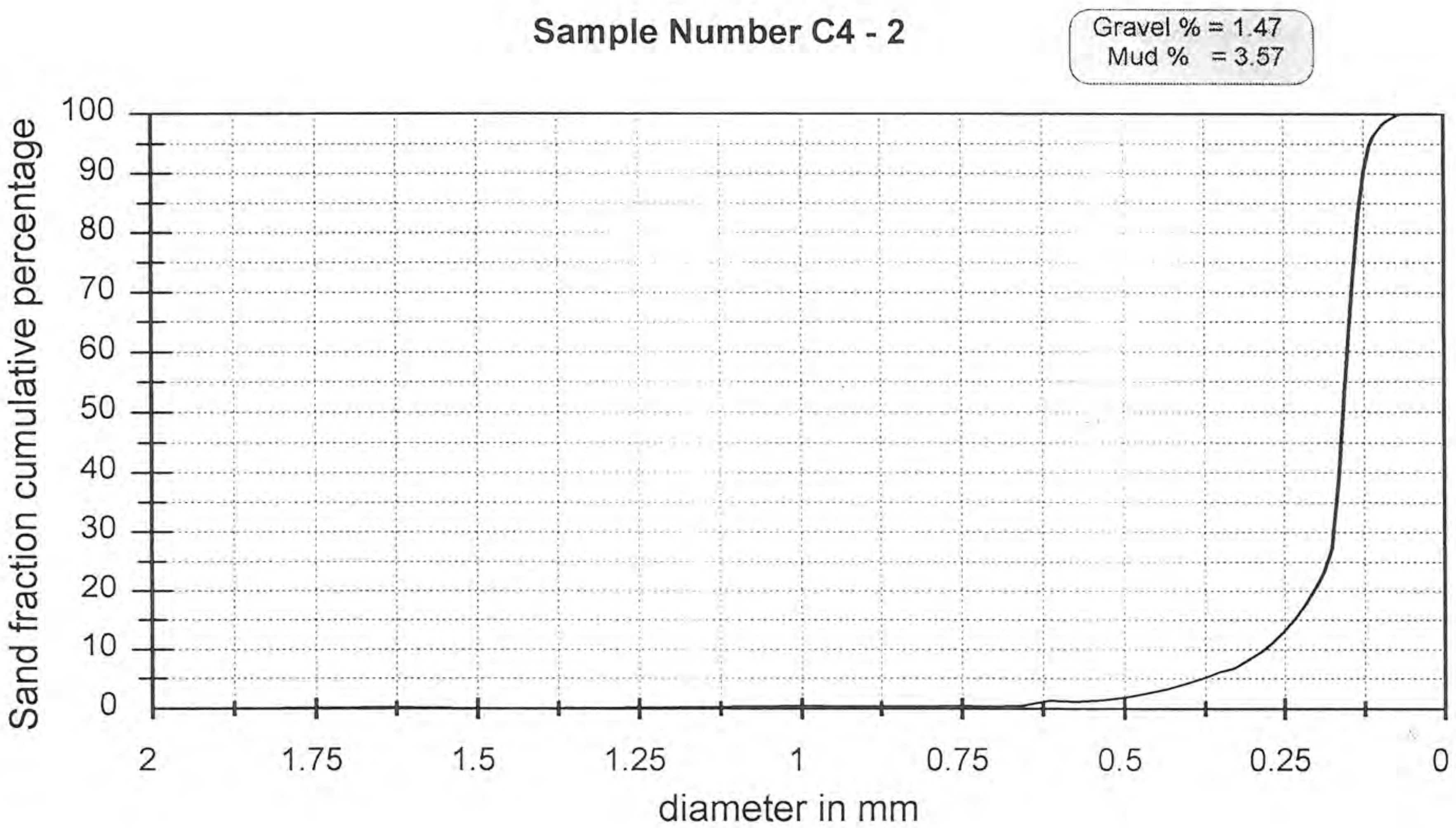
Sample Number C3 - 8
Gravel % = 0
Mud % = 1.78
Sand fraction cumulative percentage
100
90
80
70
60
50
40
30
20
10
0
2
1.75
1.5
1.25
1
0.75
0.5
0.25
0
diameter in mm



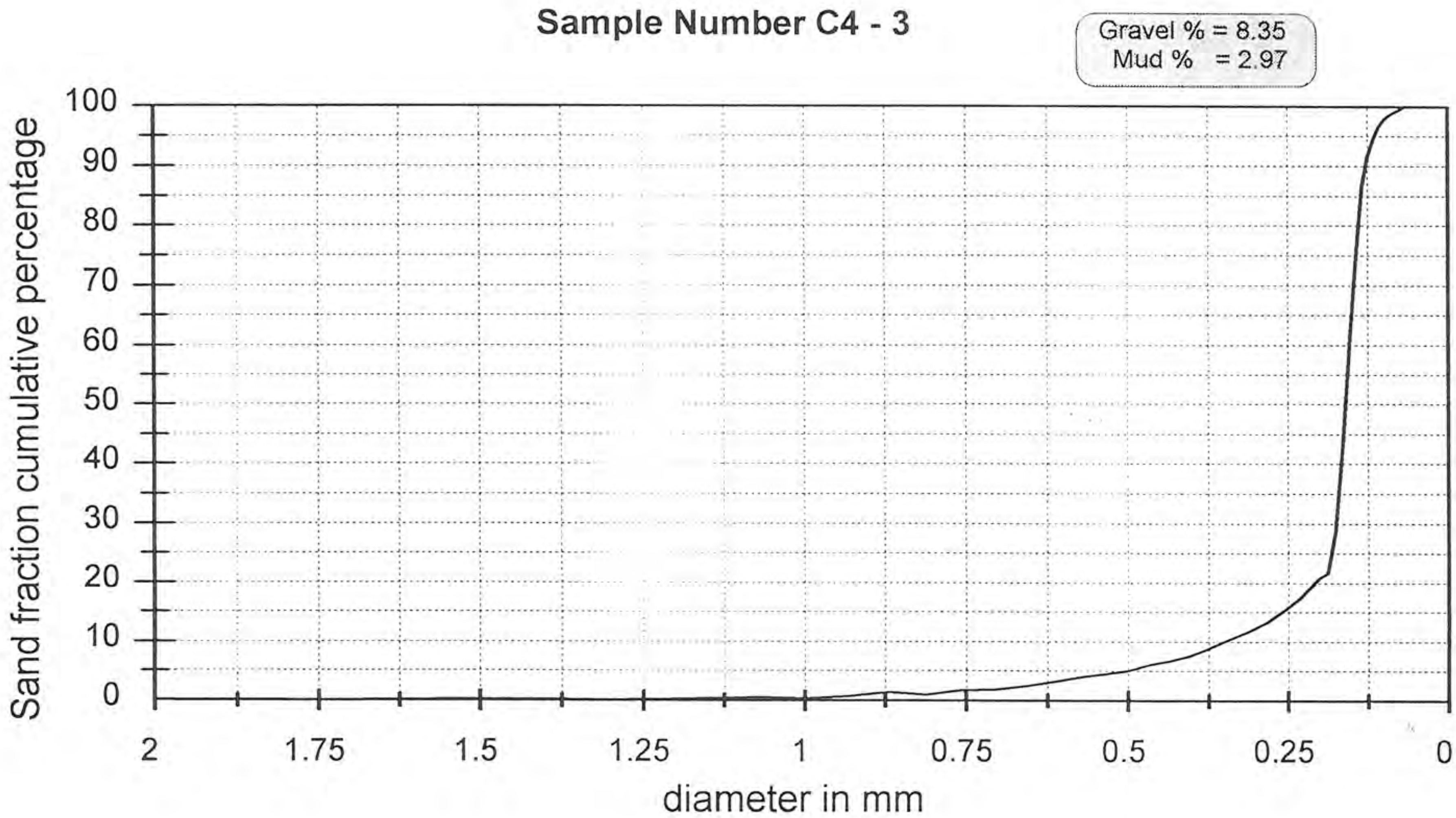
Sample Number C3 - 9
Gravel % = 0
Mud % = 1.67
Sand fraction cumulative percentage
100
90
80
70
60
50
40
30
20
10
0
2
1.75
1.5
1.25
1
0.75
0.5
0.25
0
diameter in mm

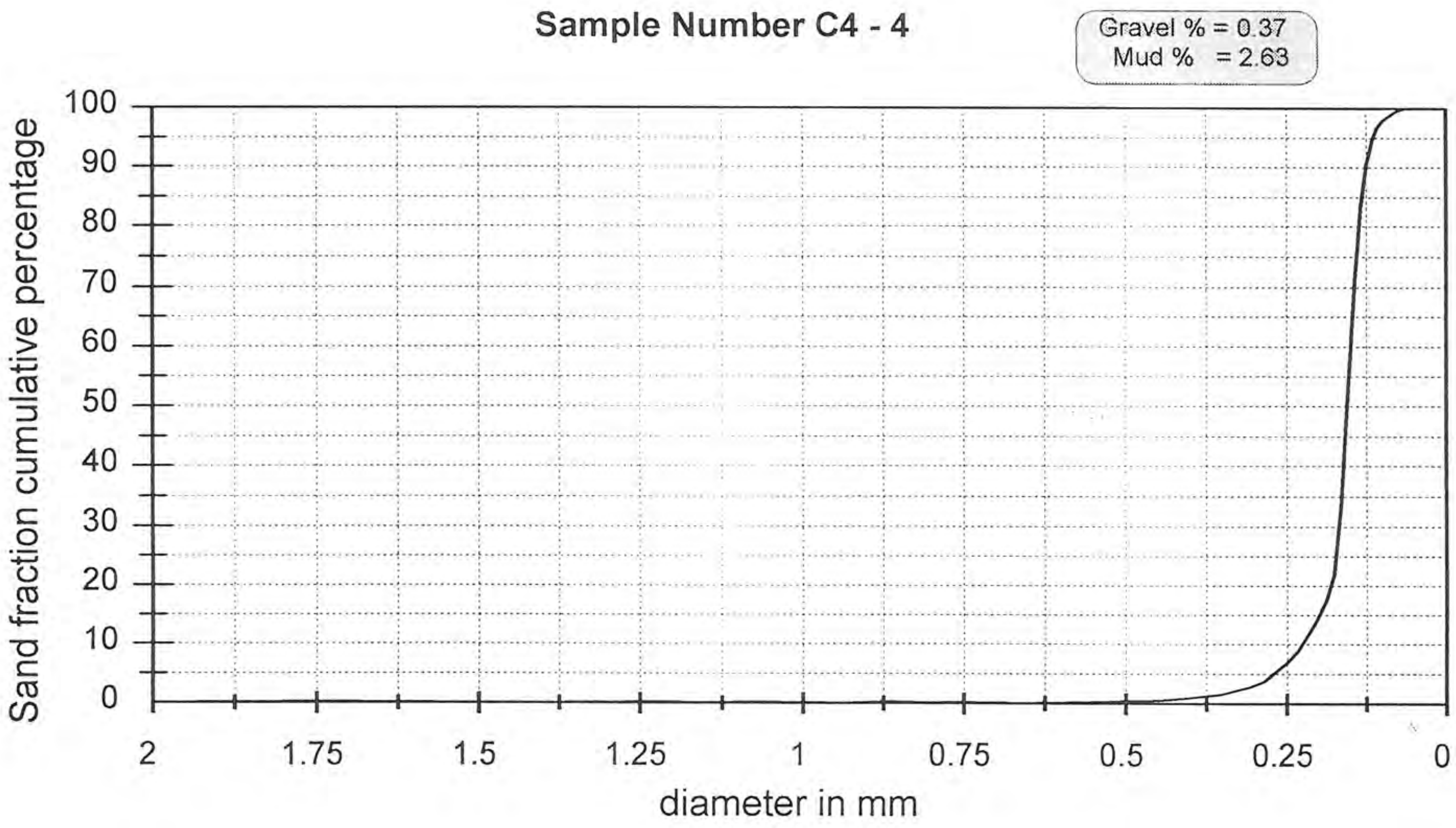

Sample Number C3 - 10
Gravel % = 2.20
Mud % = 1.01
Sand fraction cumulative percentage
100
90
80
70
60
50
40
30
20
10
0
2
1.75
1.5
1.25
1
0.75
0.5
0.25
0
diameter in mm


Sample Number C4 - 1
Gravel % = 0.36
Mud % = 3.51
Sand fraction cumulative percentage
100
90
80
70
60
50
40
30
20
10
0
2
1.75
1.5
1.25
1
0.75
0.5
0.25
0
diameter in mm

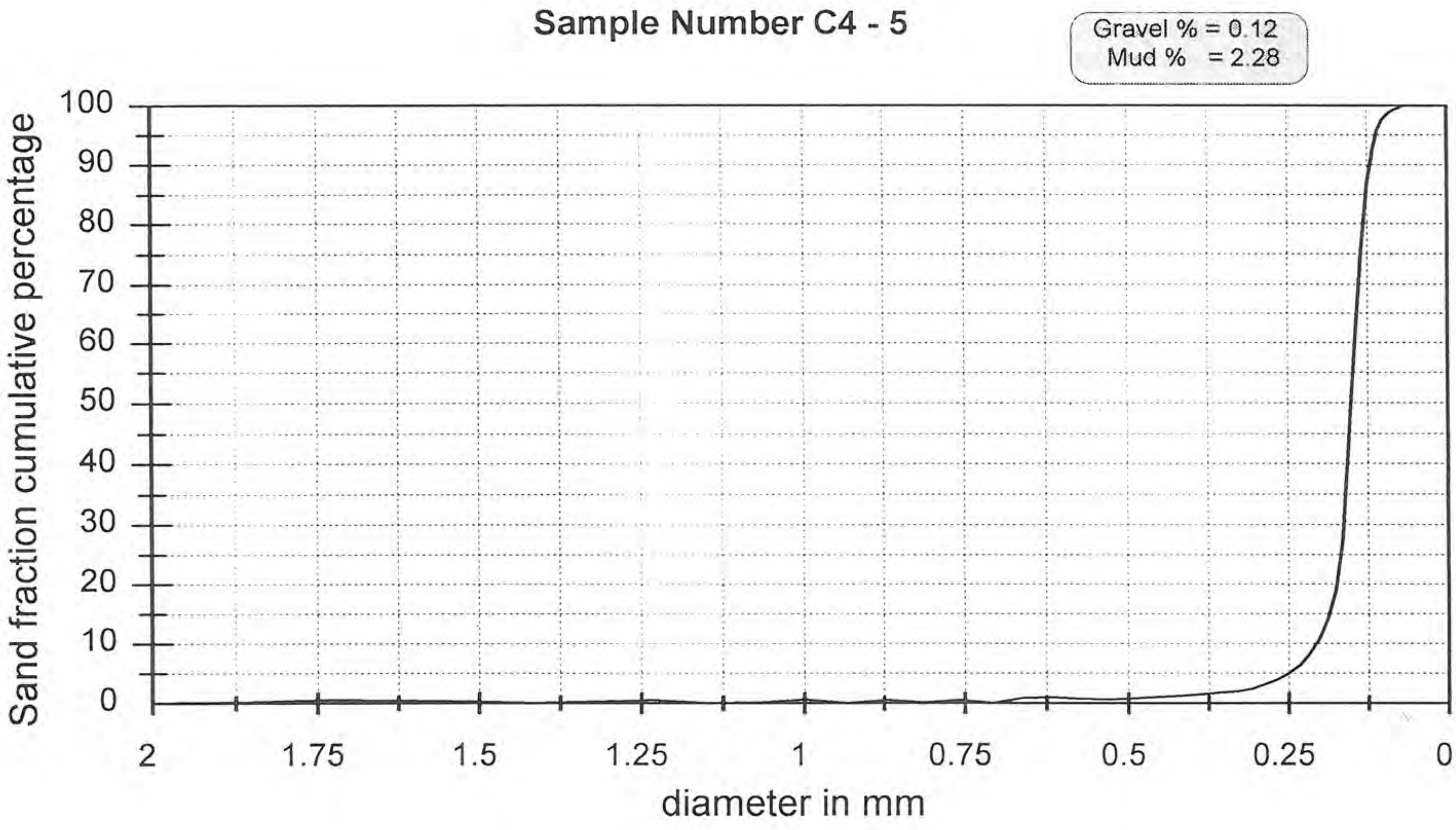


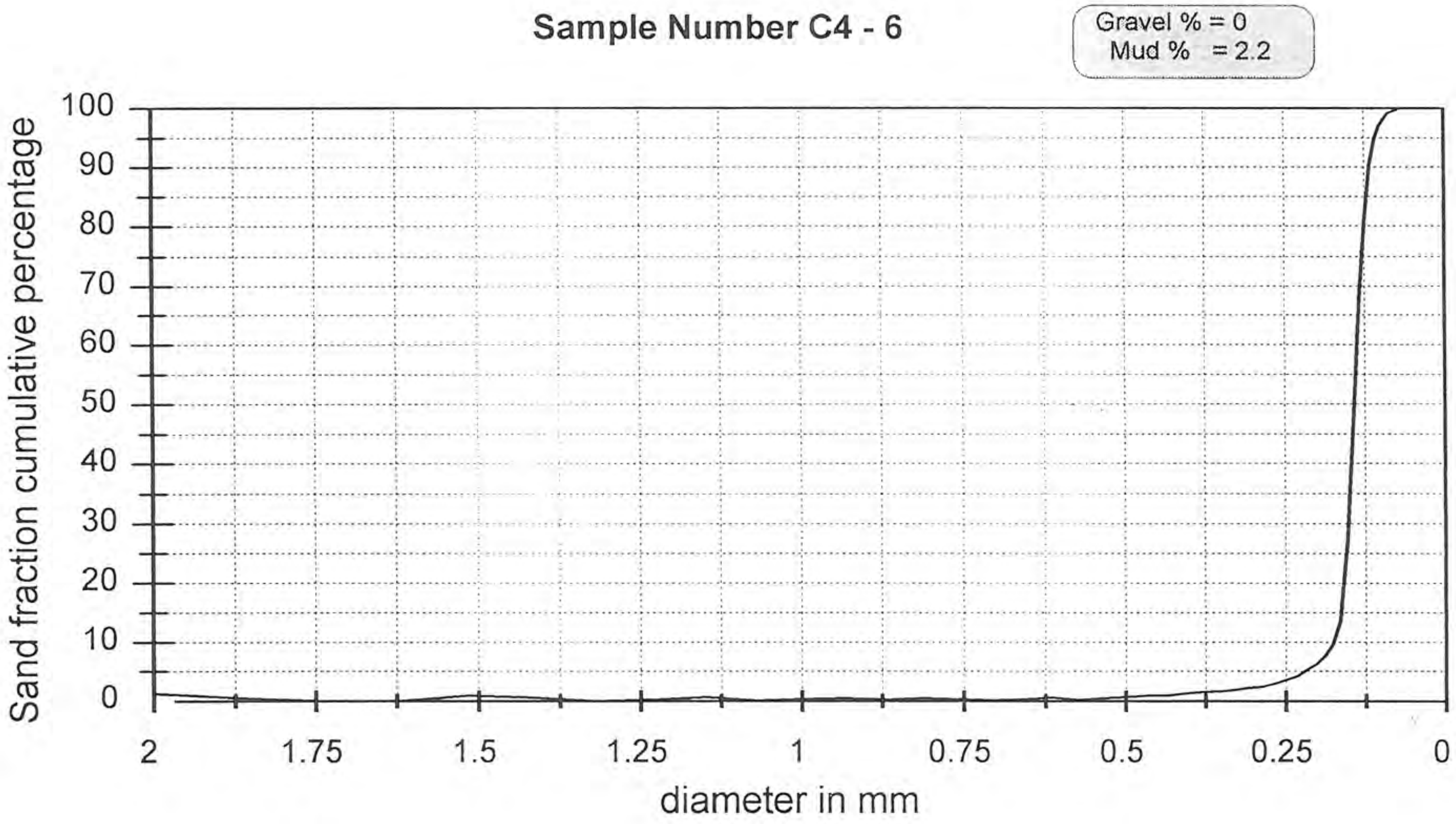
Sample Number C4 - 2
Gravel % = 1.47
Mud % = 3.57
Sand fraction cumulative percentage
100
90
80
70
60
50
40
30
20
10
0
2
1.75
1.5
1.25
1
0.75
0.5
0.25
0
diameter in mm

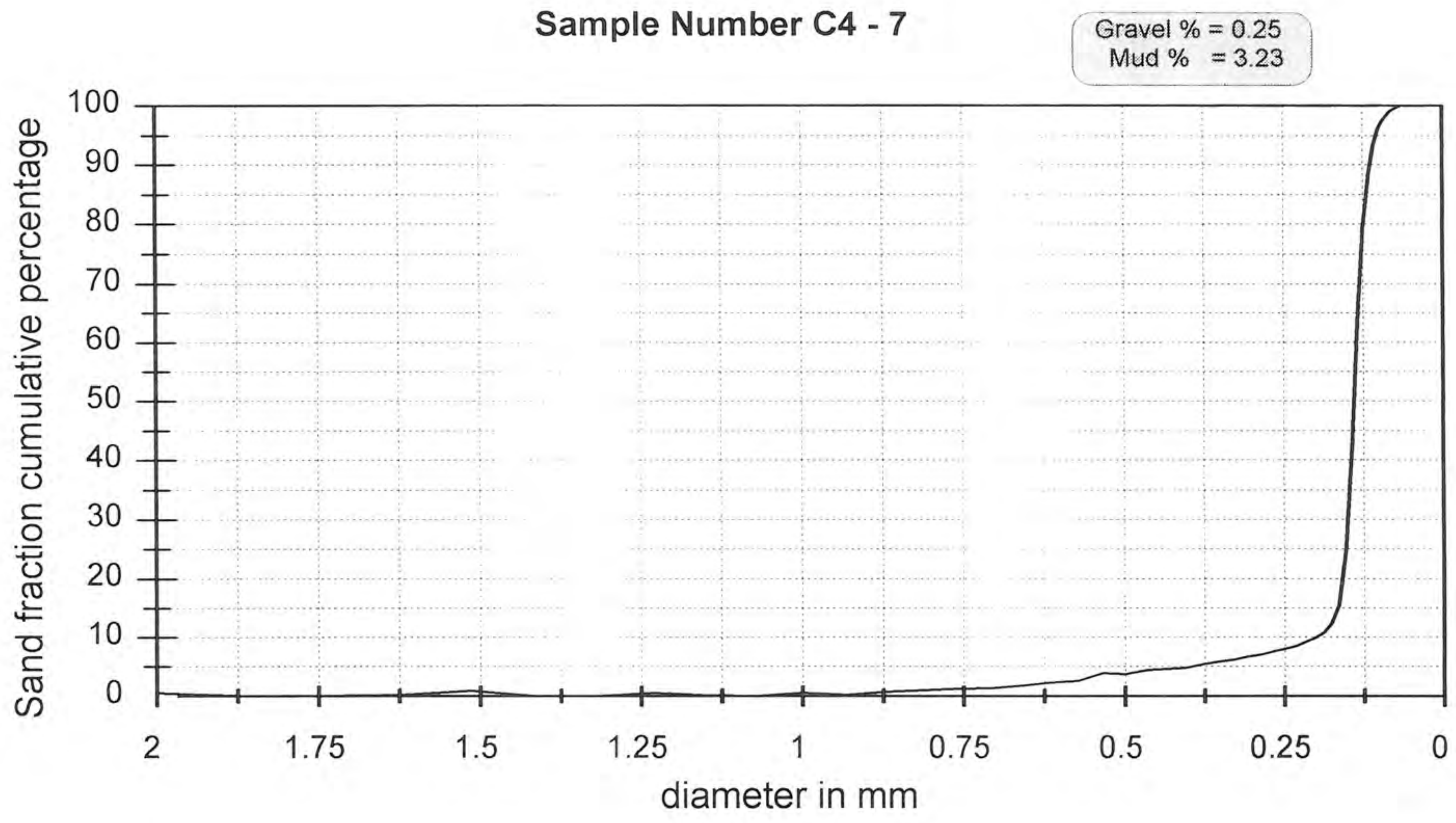

Sample Number C4 - 3
Gravel % = 8.35
Mud % = 2.97
100
90
80
70
60
50
40
30
20
10
0
Sand fraction cumulative percentage
2
1.75
1.5
1.25
1
0.75
0.5
0.25
0
diameter in mm



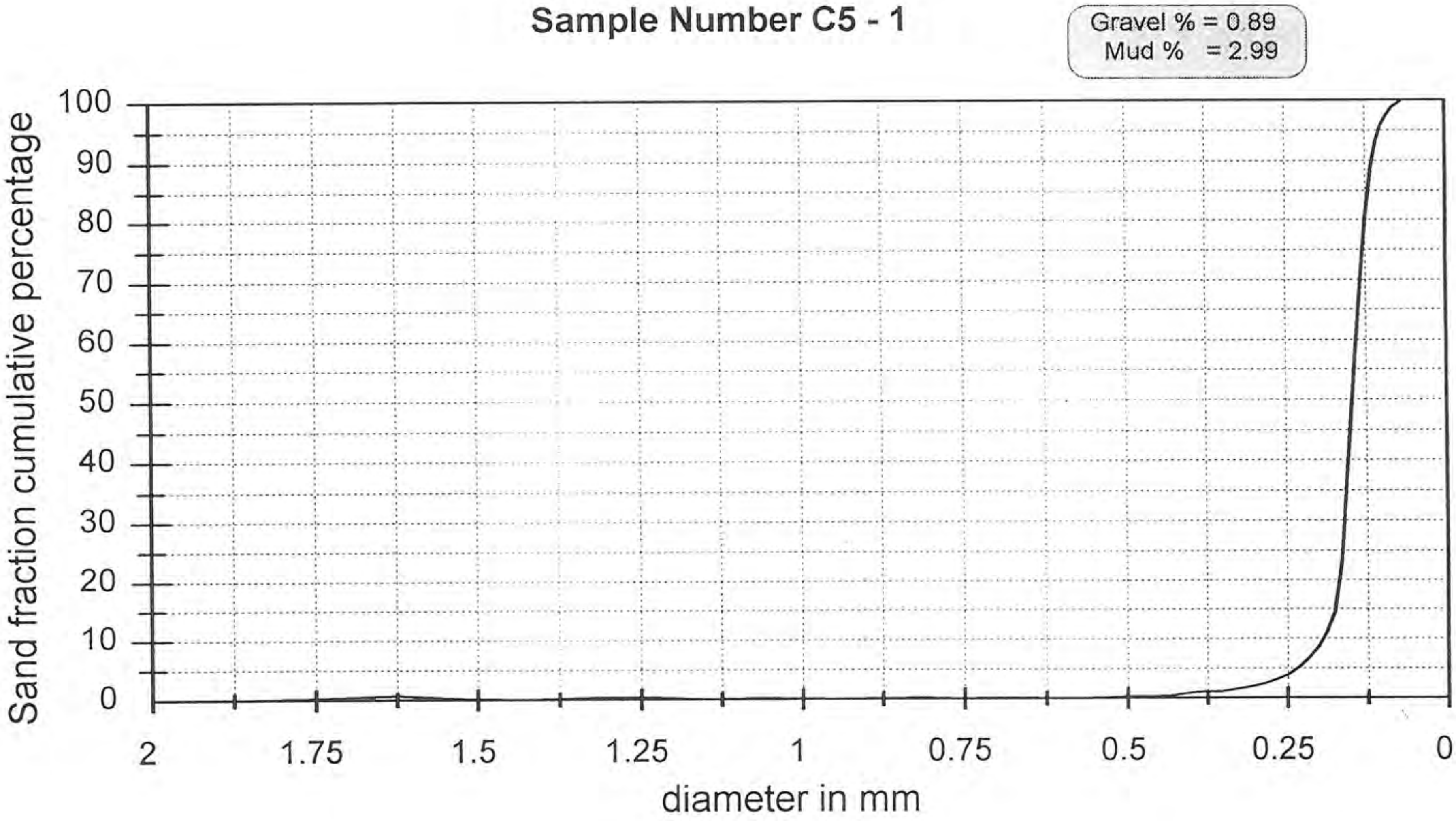
Sample Number C4 - 4
Gravel % = 0.37
Mud % = 2.63
Sand fraction cumulative percentage
100
90
80
70
60
50
40
30
20
10
0
2
1.75
1.5
1.25
1
0.75
0.5
0.25
0
diameter in mm

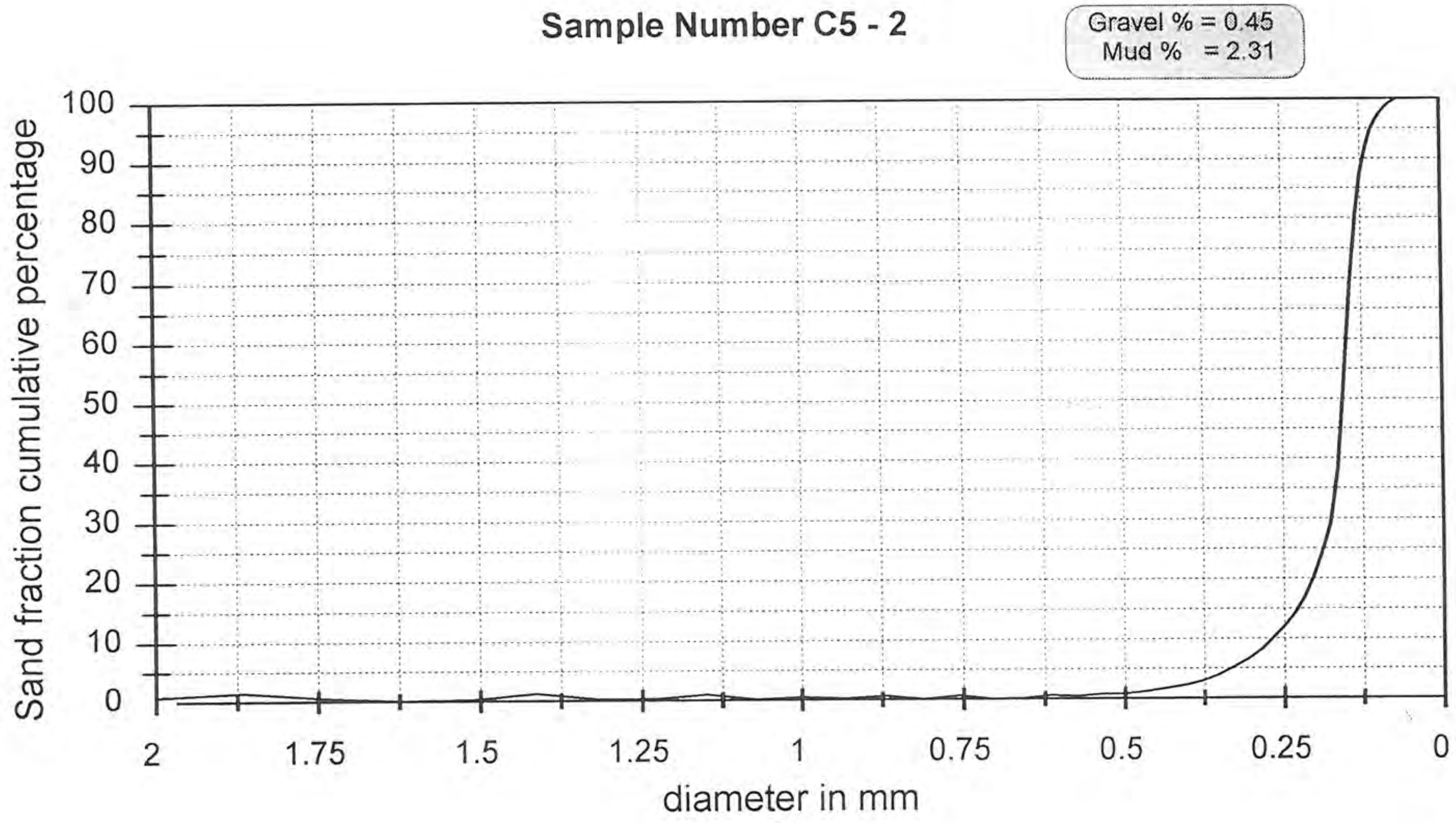

Sample Number C4 - 5
Gravel % = 0.12
Mud % = 2.28
Sand fraction cumulative percentage
100
90
80
70
60
50
40
30
20
10
0
2
1.75
1.5
1.25
1
0.75
0.5
0.25
0
diameter in mm


Sample Number C4 - 6
Gravel % = 0
Mud % = 2.2
100
90
80
70
60
50
40
30
20
10
0
Sand fraction cumulative percentage
2
1.75
1.5
1.25
1
0.75
0.5
0.25
0
diameter in mm

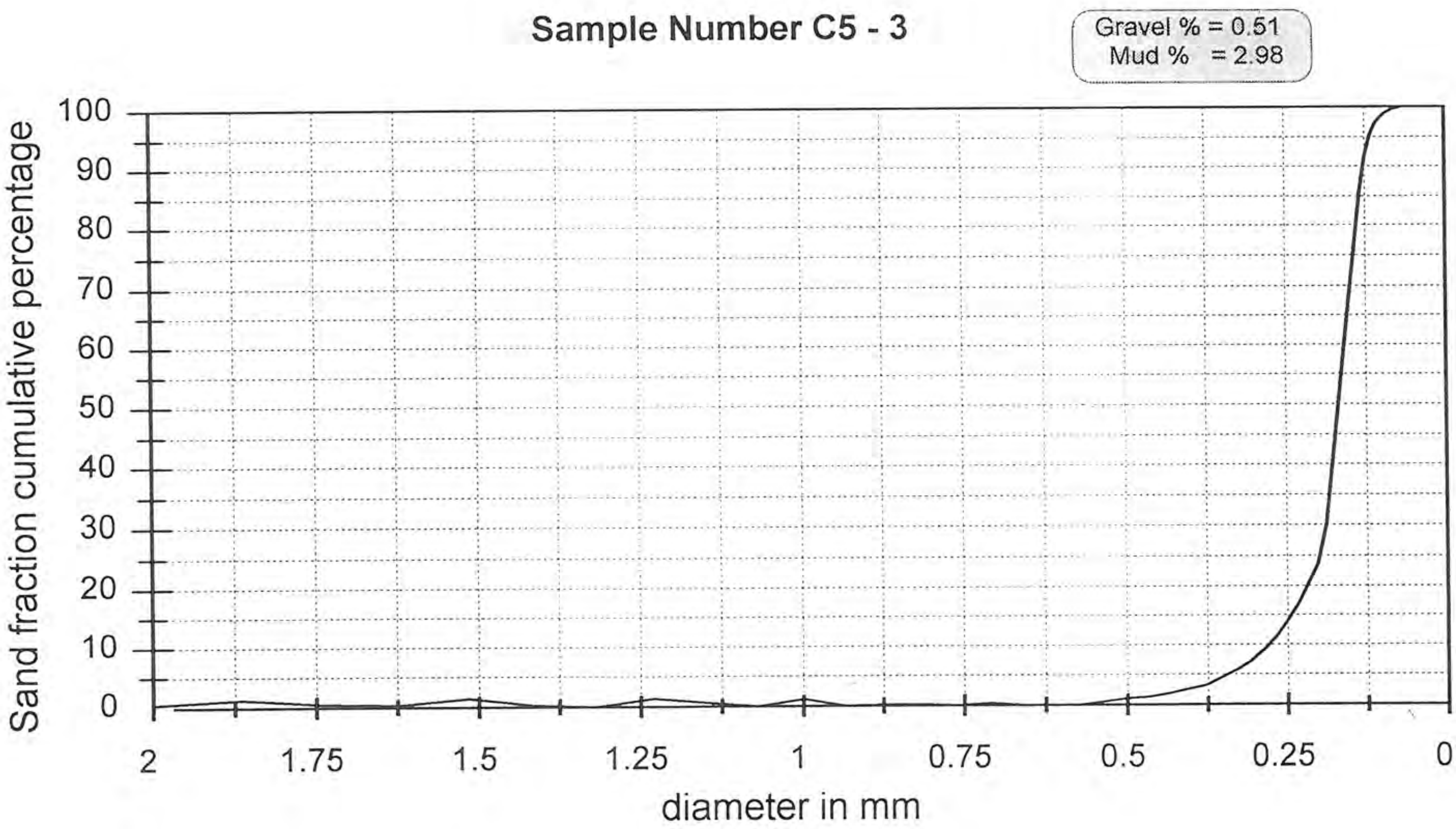


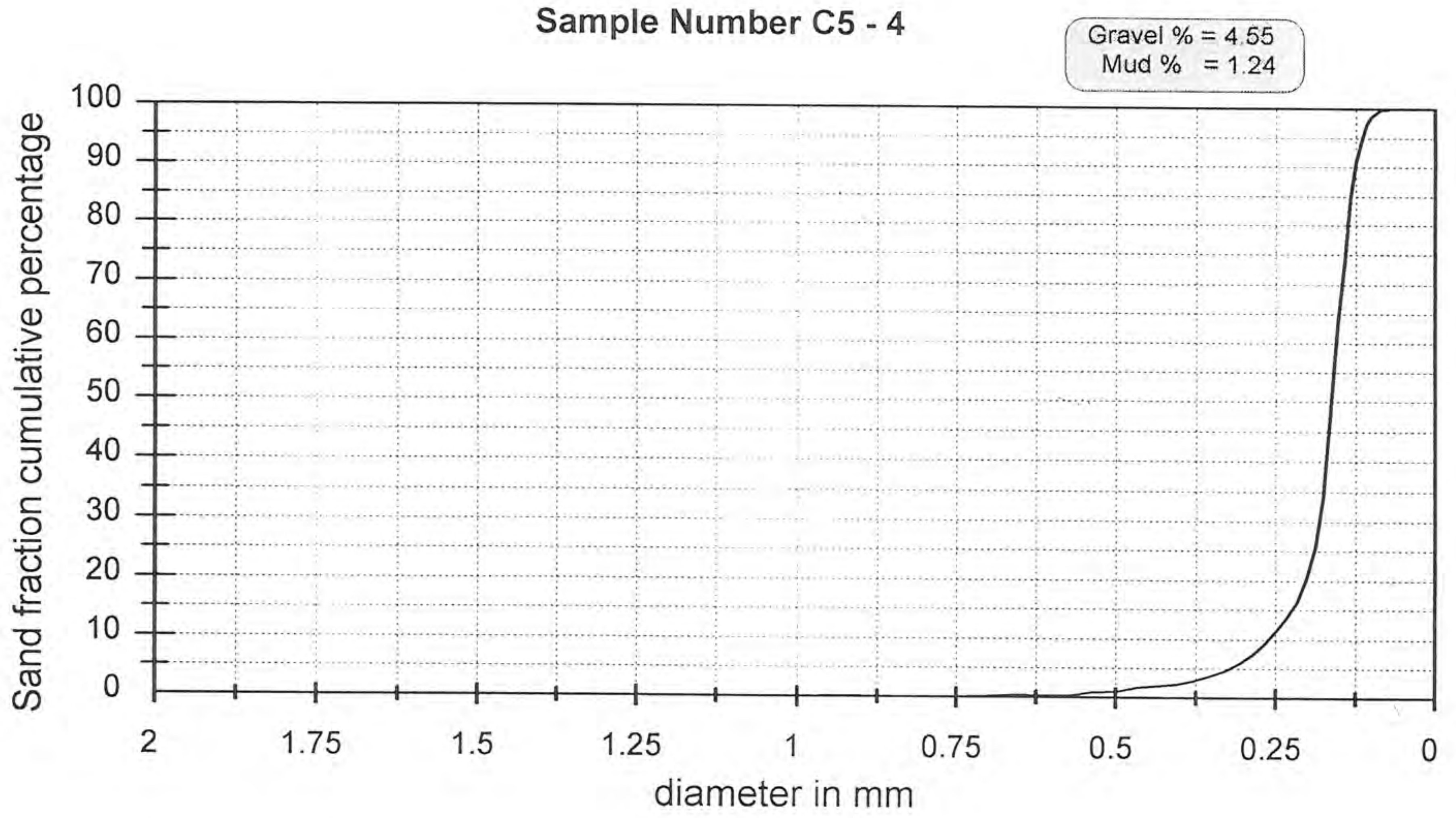
Sample Number C4 - 7
Gravel % = 0.25
Mud % = 3.23
Sand fraction cumulative percentage
100
90
80
70
60
50
40
30
20
10
0
2
1.75
1.5
1.25
1
0.75
0.5
0.25
0
diameter in mm

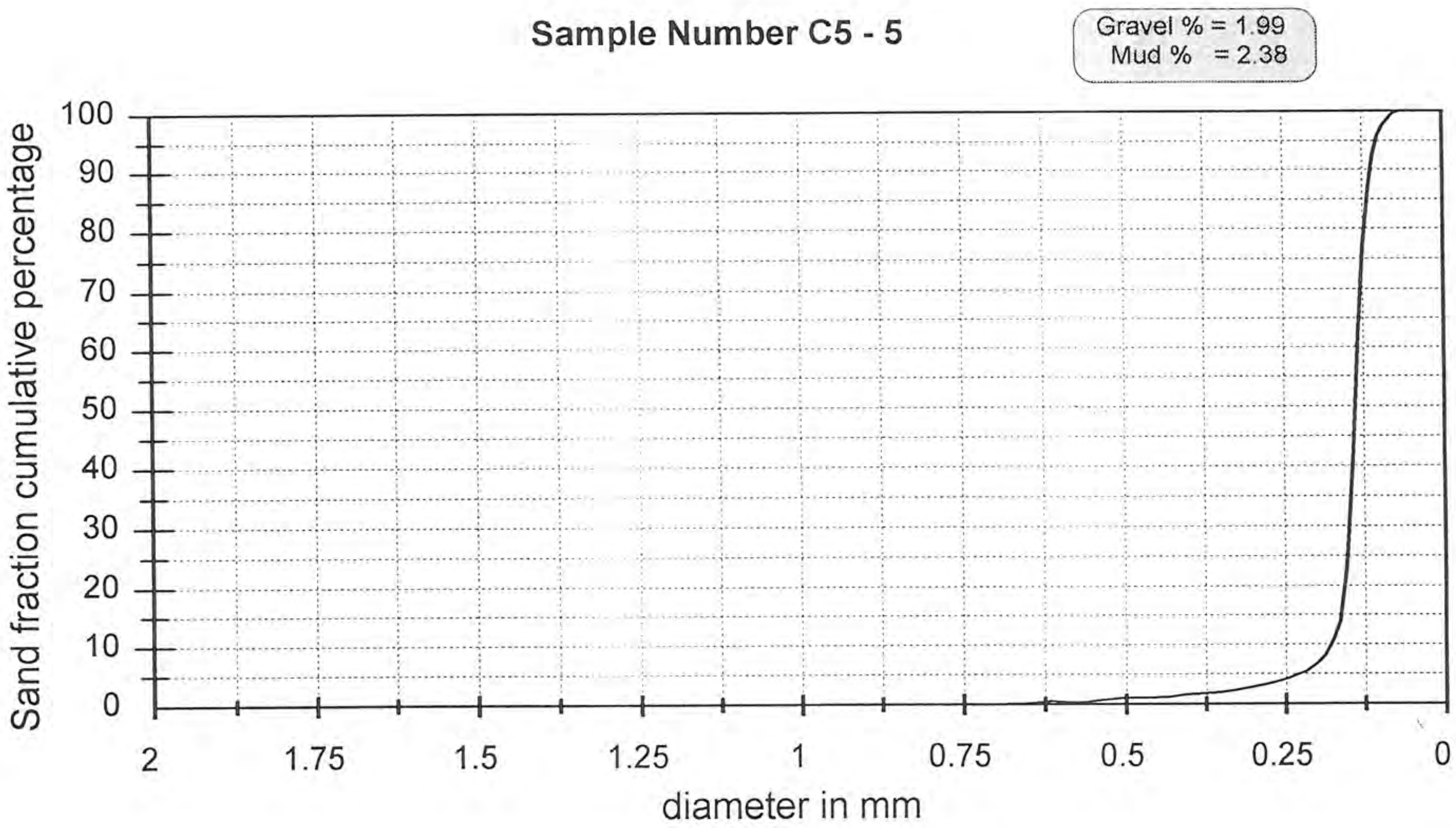

Sample Number C5 - 1
Gravel % = 0.89
Mud % = 2.99
Sand fraction cumulative percentage
100
90
80
70
60
50
40
30
20
10
0
2
1.75
1.5
1.25
1
0.75
0.5
0.25
0
diameter in mm

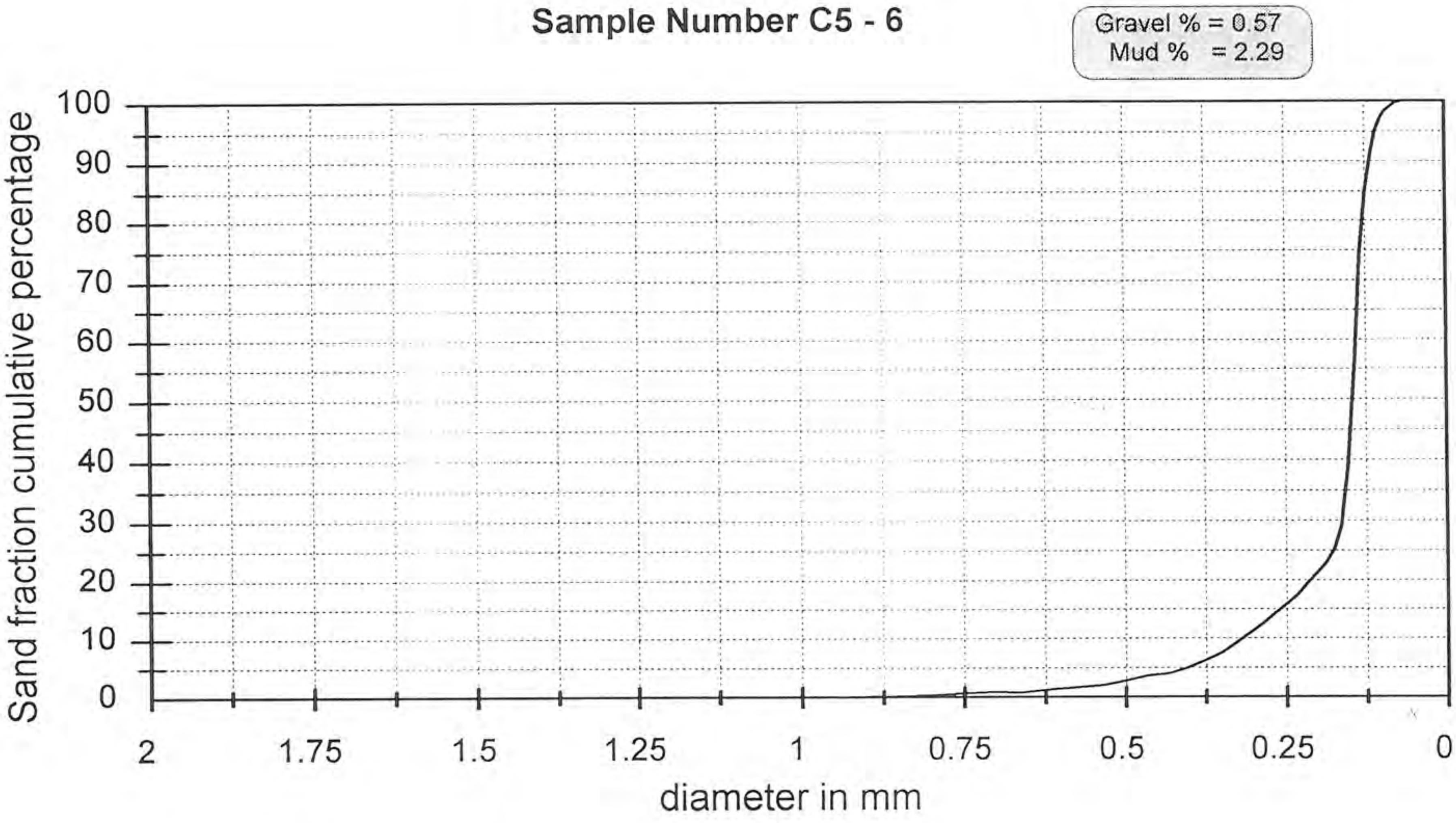


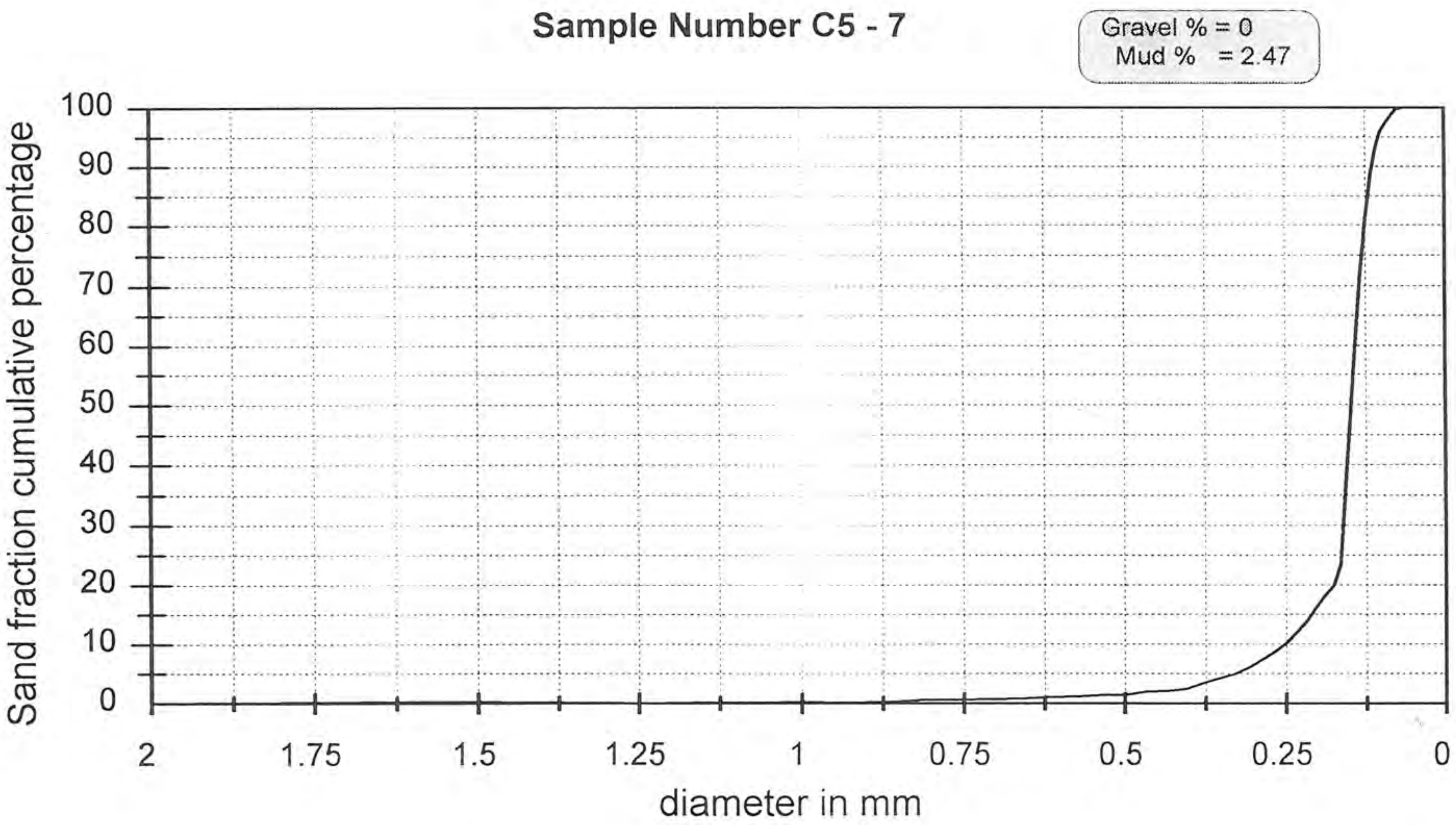
Sample Number C5 - 2
Gravel % = 0.45
Mud % = 2.31
Sand fraction cumulative percentage
100
90
80
70
60
50
40
30
20
10
0
2
1.75
1.5
1.25
1
0.75
0.5
0.25
0
diameter in mm

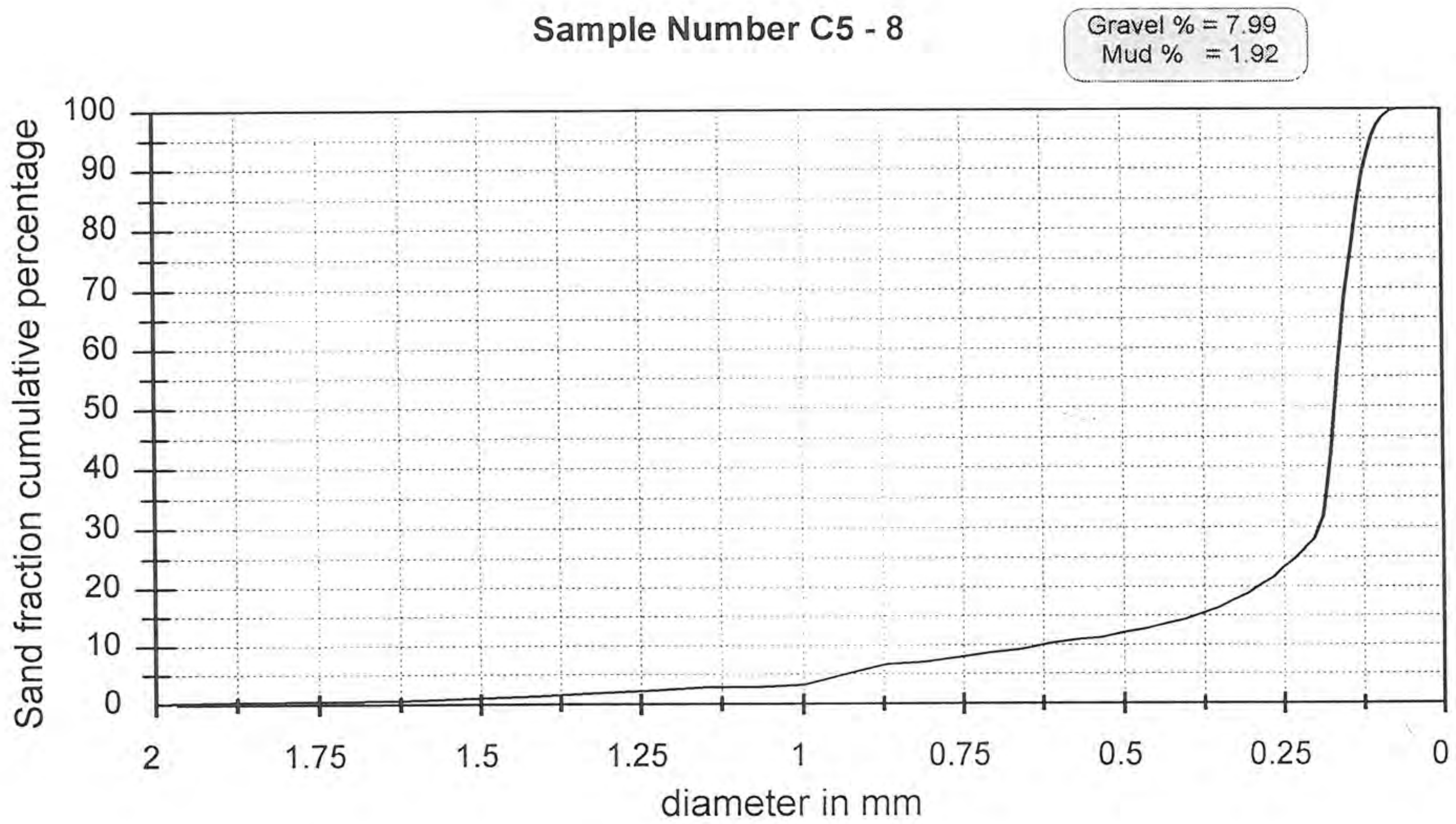

Sample Number C5 - 3
Gravel % = 0.51
Mud % = 2.98
Sand fraction cumulative percentage
100
90
80
70
60
50
40
30
20
10
0
2
1.75
1.5
1.25
1
0.75
0.5
0.25
0
diameter in mm

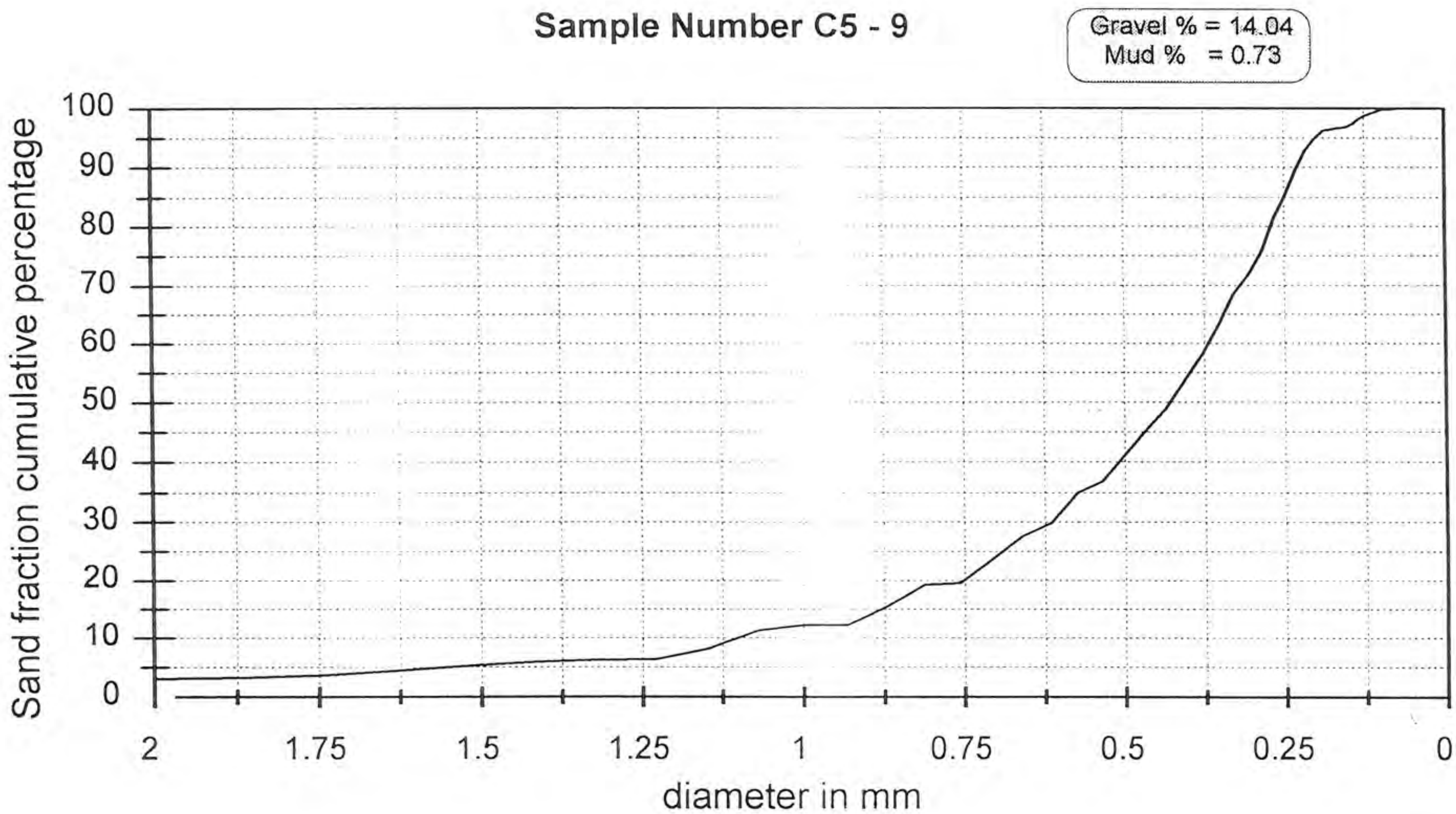

Sample Number C5 - 4
Gravel % = 4.55
Mud % = 1.24
100
90
80
70
60
50
40
30
20
10
0
Sand fraction cumulative percentage
2
1.75
1.5
1.25
1
0.75
0.5
0.25
0
diameter in mm


Sample Number C5 - 5
Gravel % = 1.99
Mud % = 2.38
Sand fraction cumulative percentage
100
90
80
70
60
50
40
30
20
10
0
2
1.75
1.5
1.25
1
0.75
0.5
0.25
0
diameter in mm


Sample Number C5 - 6
Gravel % = 0.57
Mud % = 2.29
Sand fraction cumulative percentage
100
90
80
70
60
50
40
30
20
10
0
2
1.75
1.5
1.25
1
0.75
0.5
0.25
0
diameter in mm


Sample Number C5 - 7
Gravel % = 0
Mud % = 2.47
Sand fraction cumulative percentage
100
90
80
70
60
50
40
30
20
10
0
2
1.75
1.5
1.25
1
0.75
0.5
0.25
0
diameter in mm

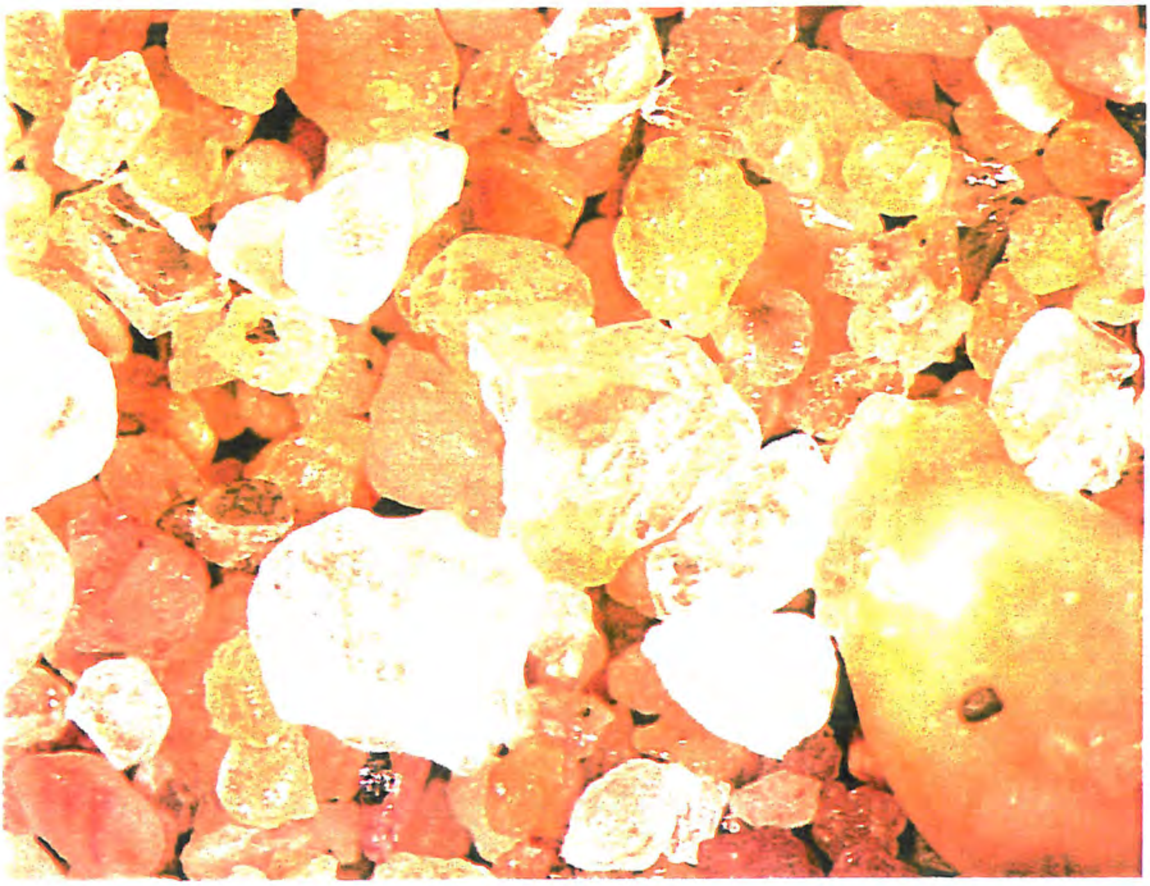

Sample Number C5 - 8
Gravel % = 7.99
Mud % = 1.92
Sand fraction cumulative percentage
100
90
80
70
60
50
40
30
20
10
0
2
1.75
1.5
1.25
1
0.75
0.5
0.25
0
diameter in mm


Sample Number C5 - 9
Gravel % = 14.04
Mud % = 0.73
Sand fraction cumulative percentage
100
90
80
70
60
50
40
30
20
10
0
2
1.75
1.5
1.25
1
0.75
0.5
0.25
0
diameter in mm

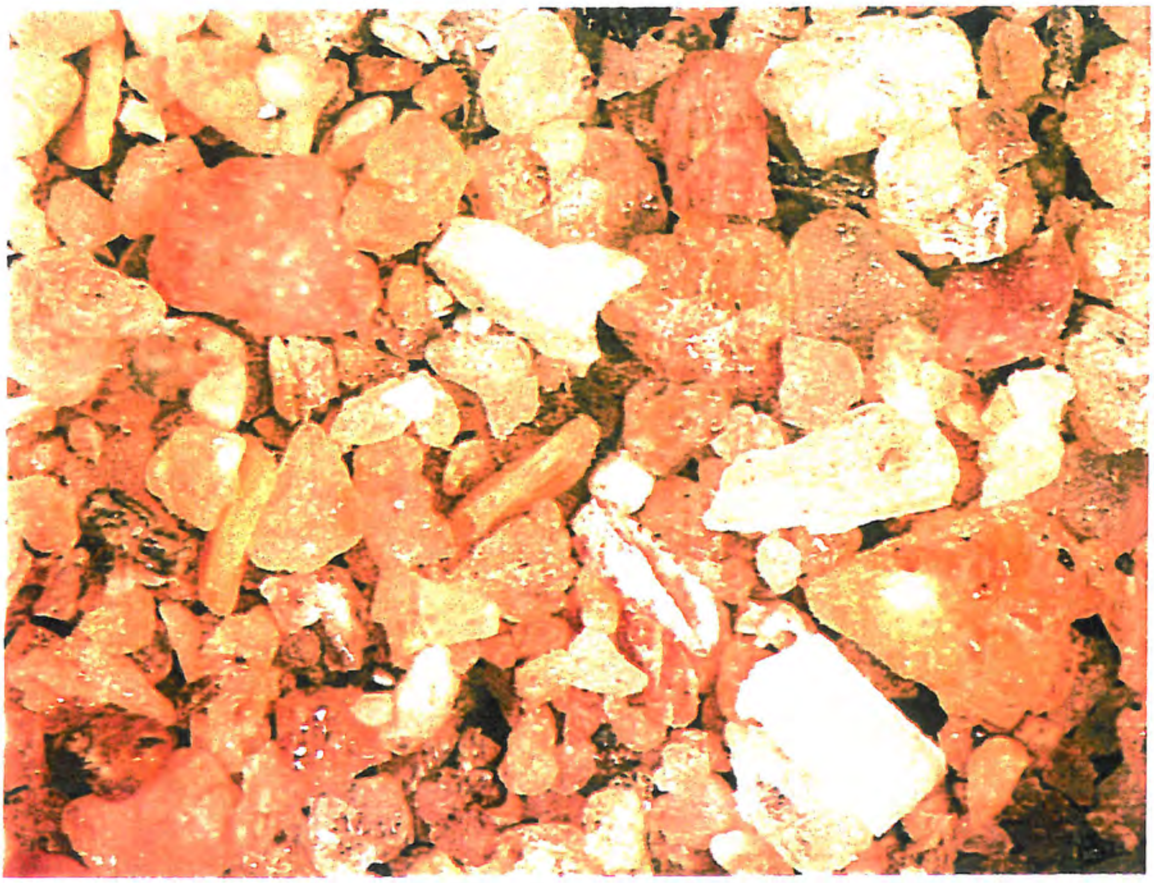
APPENDIX 3

SELECTED SEDIMENT IMAGES

Area 1 grab sample G14. Well sorted, medium-grained, subangular to rounded clean sand. Magnification (X16) Field of view 4.6 mm by 3.6 mm.

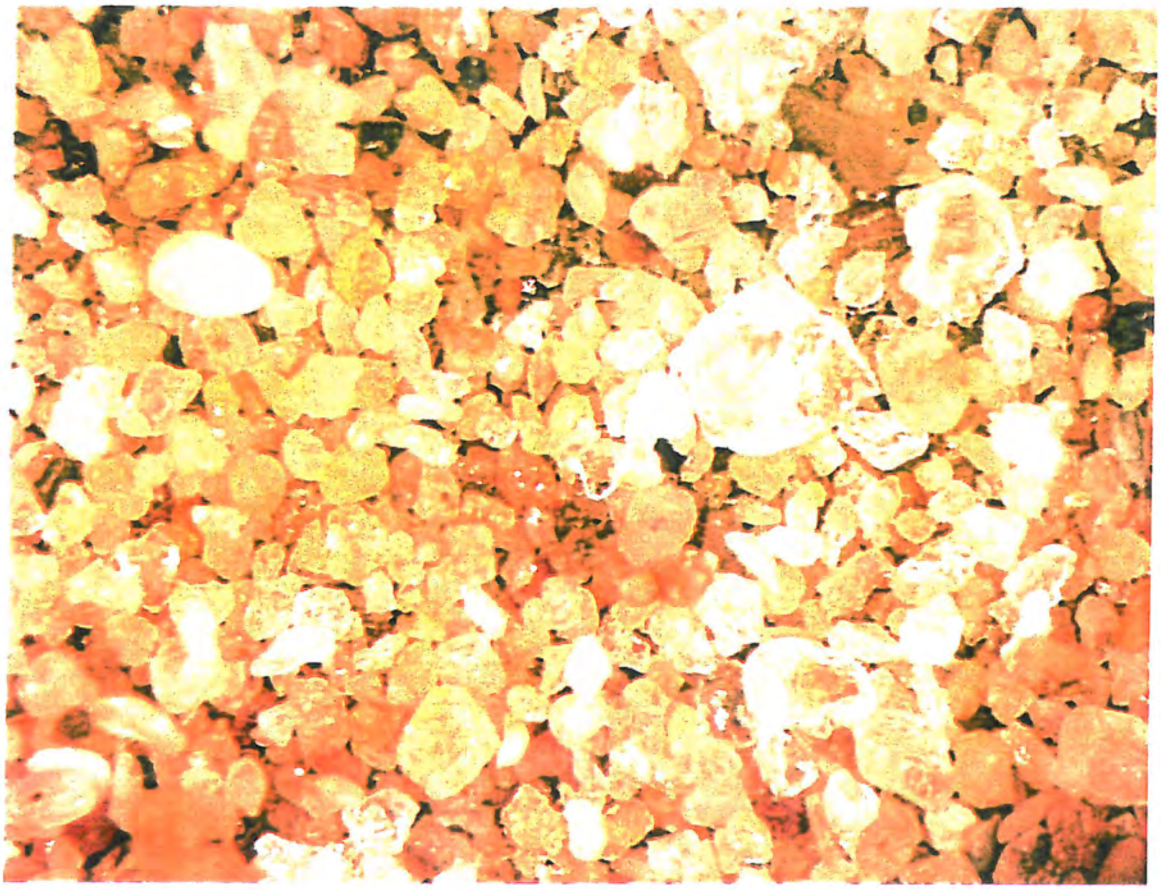


Area 1 grab sample G23. Well sorted, medium-grained, subangular to well rounded clean sand. Magnification (X16) Field of view 4.6 mm by 3.6 mm.

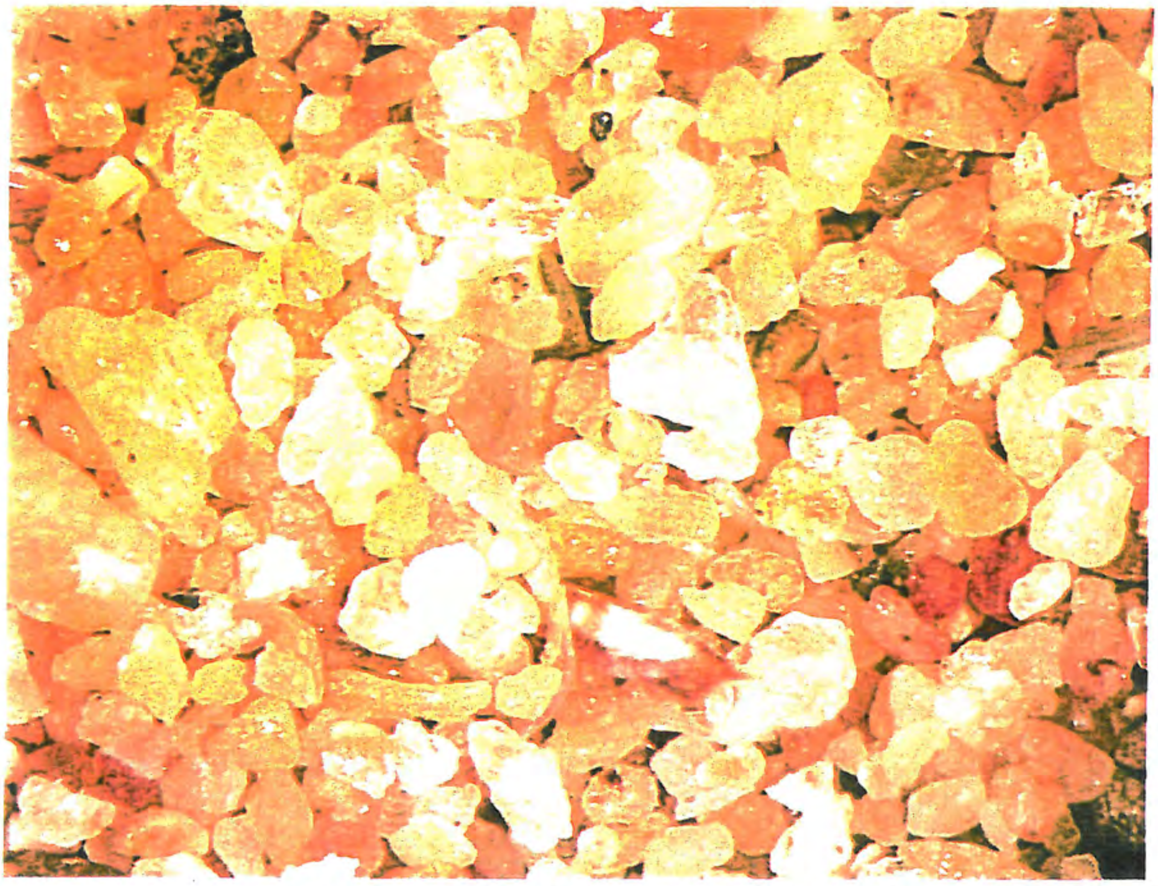


Area 1 core sample C1-9. Well sorted, medium-grained, subangular to subrounded clean sand.
Magnification (X16) Field of view 4.6 mm by 3.6 mm.

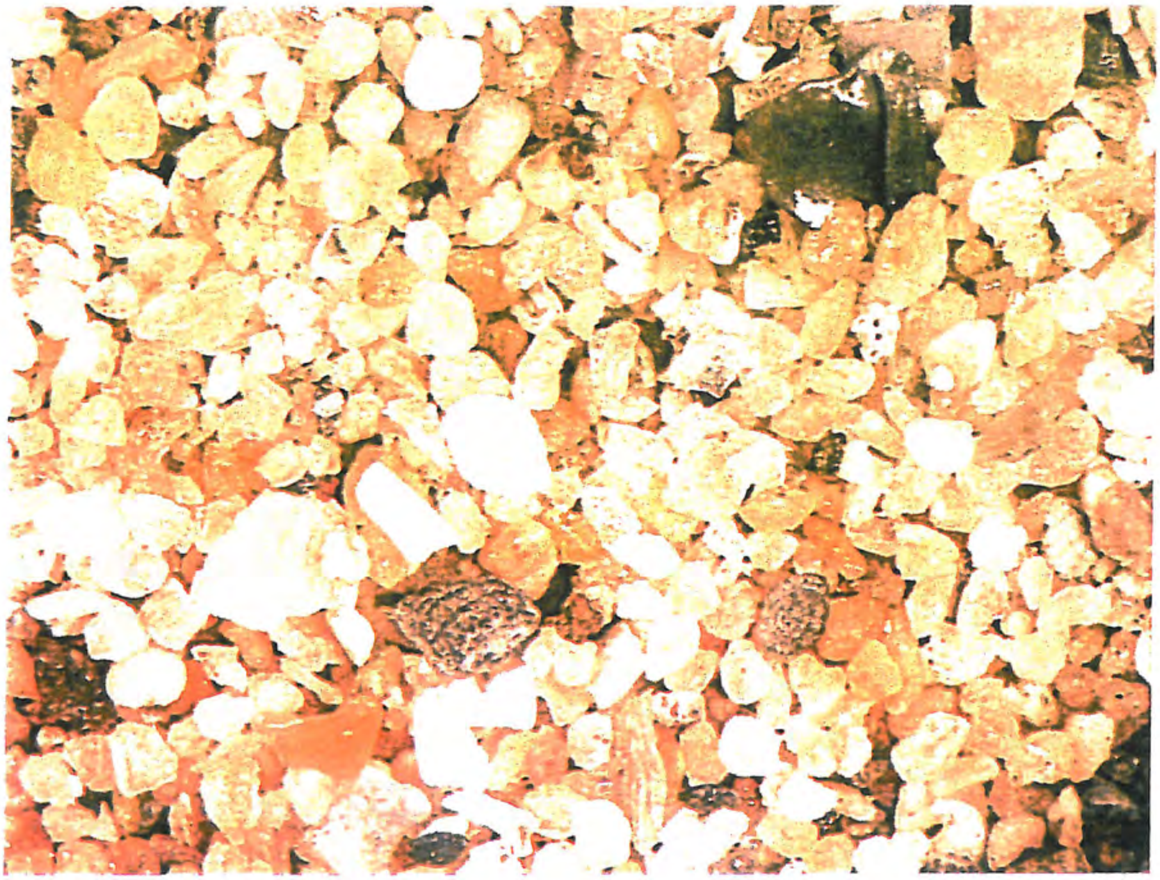
Area 1 core sample C3-3. Moderately well sorted, medium-grained, subangular to well rounded
Note coatings of mud or calcium carbonate on some of the grains.
Magnification (X16) Field of view 4.6 mm by 3.6 mm.



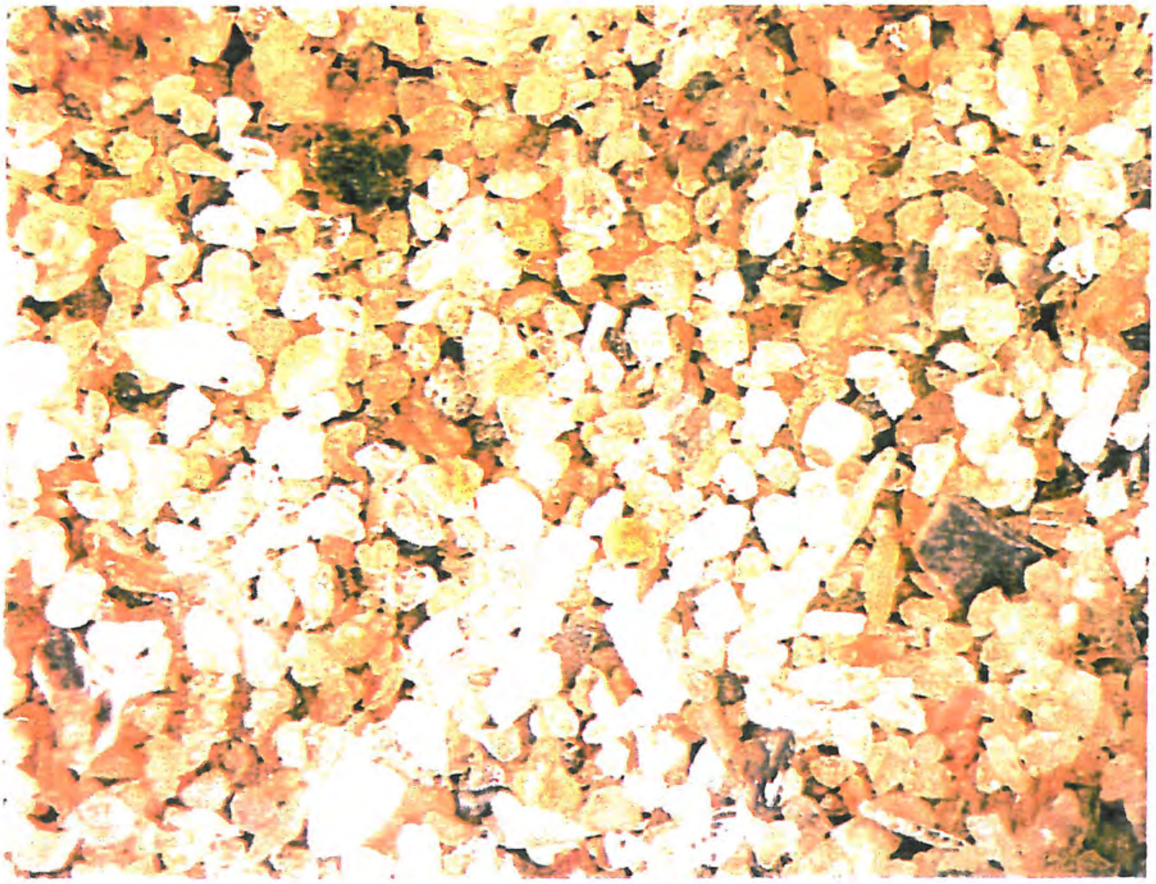
Area 2 grab sample G8. Well sorted, fine-grained, subangular to very well rounded clean sand. Magnification (X16) Field of view 4.6 mm by 3.6 mm.



Area 2 grab sample G12. Well sorted, fine-grained, subangular to rounded clean sand. Magnification (X16) Field of view 4.6 mm by 3.6 mm.



Area 2 core sample C4-4. Very well sorted, fine-grained, subangular to rounded clean sand. Magnification (X16) Field of view 4.6 mm by 3.6 mm.



Area 2 core sample C5-5. Very well sorted, fine-grained, subangular to subrounded clean sand. Magnification (X16) Field of view 4.6 mm by 3.6 mm.

5.6: A Geophysical and Sedimentological Investigation of the Offshore Dredge Disposal Site, Durban

(CGS RPT No. 2001-0002; 2001)

A GEOPHYSICAL AND SEDIMENTOLOGICAL INVESTIGATION OF THE OFFSHORE DREDGE DISPOSAL SITE, DURBAN

Mr W R Miller (MSc, Pr.Sci.Nat.)
Dr P J Ramsay (PhD, Pr.Sci.Nat.)
Mr R Leuci (Bsc. Hons.)

Council for Geoscience
Marine Geoscience Unit
Durban

REPORT NO. 2001-0002

CONTENTS

1. INTRODUCTION

The Marine Geoscience Unit was contracted by Portnet to undertake a marine geophysical investigation of the dredge disposal site east of Durban Harbour. Rather than conducting a new survey, data from a recent survey in the Durban Bight in April and May of 1999 was used for the compilation of this report. A standard suite of geophysical instruments including a digital echo-sounder, 3.5 kHz sub-bottom profiler and a side-scan sonar were used for data collection during the survey. A grab sampling programme was conducted in December 2000 to assess sediment distribution patterns and to ground truth the side-scan sonar data.

The aims of the geophysical investigation were to:

- Produce a bathymetric chart of the dredge disposal site (reduced to LAT).
- Produce a side-scan sonar mosaic of the dredge disposal site to show the nature of the seafloor.
- Assess unconsolidated sediment thickness in the vicinity of the dredge disposal site.
- Collect 10 grab samples from the dredge disposal site to assess sediment distribution patterns in the area.
- Assess the mobility of the dredge spoil after it has been dumped on the seafloor using all the collected data.

2 INSTRUMENTATION

2.1 DGPS

A Fugro StarFix DGPS receiver was used for navigation throughout the geophysical survey. This is a 12 channel Trimble system with an update rate of 10 Hz and sub-metre precision. DGPS corrections are RTCM SC-1 04 Ver. 2.0 format, virtual base station solutions with an RTCM update rate of typically less than 5 seconds.

2.2 Odom Echotrac Digital Echosounder

An Odom Echotrac digital echosounder (Model 3100) with a narrow beam (9°) 210kHz transducer was used to collect bathymetric data of the seafloor. This instrument is capable of recording up to 20 data points per second in digital format whilst undertaking shallow water surveys. An event-annotated paper analogue profile is also produced as a backup to the digital data.

2.3 Klein System 2000 Side-scan Sonar

A Klein System 2000 side-scan sonar and model 2260 digital tow-fish were used to collect the sonographs. The Klein System 2000 is a dual frequency (100/500 kHz) side-scan sonar that is capable of collecting high resolution image corrected acoustic data. The Klein System 2000 incorporates a 7 Gigabyte 8 channel Exabyte tape drive which is used for digital data storage, and a 300 dpi, 256 grey shade thermal printer.

2.4 GeoPulse Sub-bottom Profiler

A GeoAcoustics GeoPulse sub-bottom profiling system was used to collect sub-bottom profiles during the geophysical survey. The sub-bottom profiling system consisted of a Model 5430A GeoPulse transmitter, a Model 5210 GeoPulse seismic receiver and an over-the-side mounted transducer array. The Model 5430A transmitter has a maximum output power of 10 kW and a operator selectable operating frequency range of 2 - 15 kHz. The amplifier has a signal to noise ratio of 20 dB at 100 dB gain, 1 kHz centre frequency and 1 kHz bandwidth. The GeoPulse receiver has an operating bandwidth of 50 Hz to 10 kHz and a user selectable sampling frequency of 4 to 24 kHz.

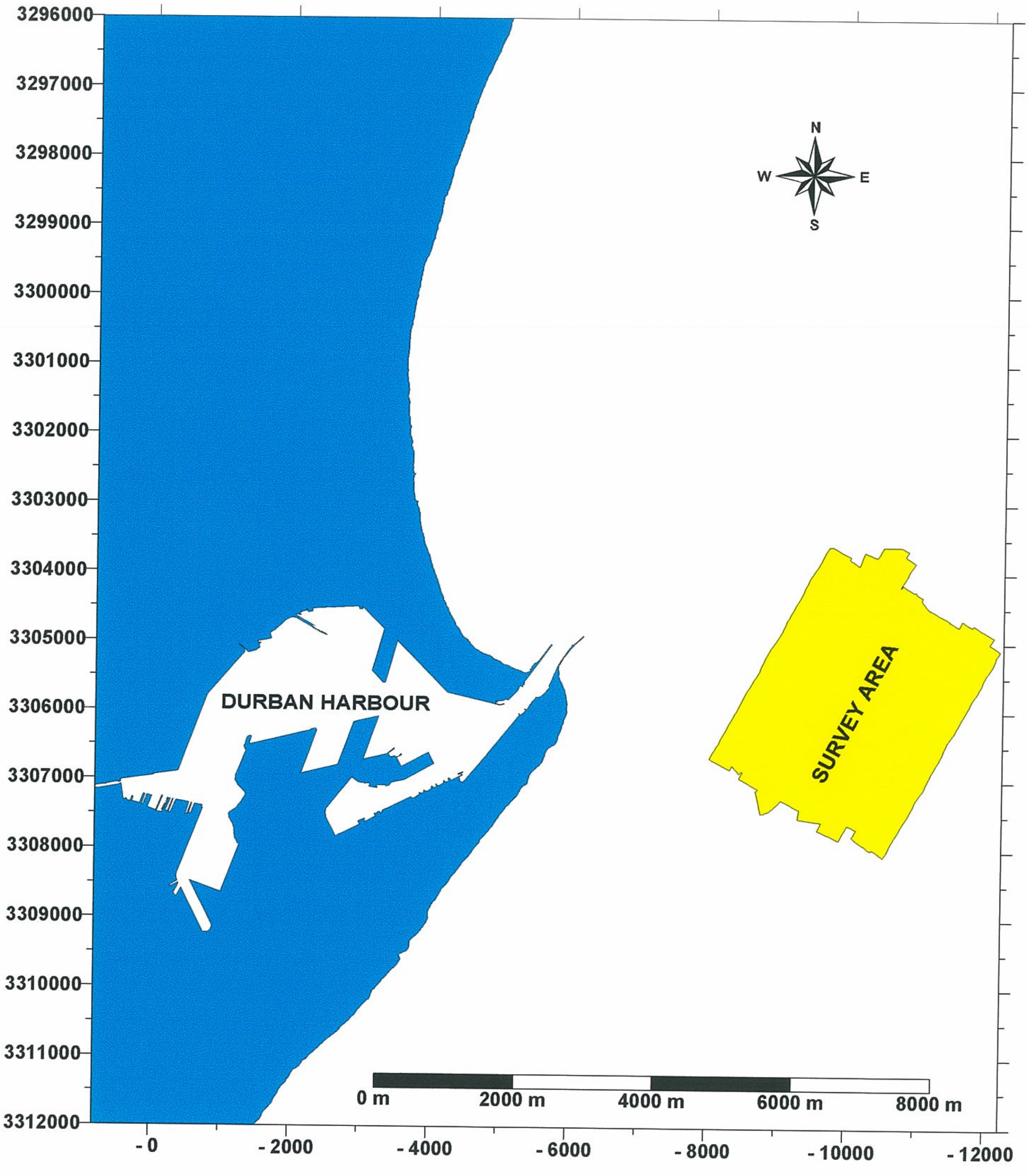


Fig.1 Locality map of the Durban dredge disposal site survey block.

3. SURVEY METHODOLOGY

Geophysical data was collected along predetermined coast parallel survey lines located 150 m apart. The DGPS coordinates were downloaded, in real-time, onto a 486 survey notebook computer via an RS 232 serial cable such that positioning data, survey tracklines and other navigational data were continuously displayed on the computer screen using the *Navlog* software package. The echosounder was calibrated before and after the bathymetric survey using a "bar-check" method. Bathymetric data were logged at 1 or 2 second intervals and downloaded into a spreadsheet along with navigation data.

The Klein System 2000 was used to simultaneously acquire 4 channels of digital side-scan sonar data and one auxiliary channel of sub-bottom profiling data and to store the digital data on Exabyte tape. A scan range of 100 metres was used to collect the side-scan sonographs, thereby facilitating a 50 metre overlap of adjacent swaths. The Klein System 2000 was used to trigger the GeoPulse transmitter and to digitally capture the seismic reflection data.. The GeoPulse receiver was used to amplify and filter the seismic reflection data prior to storage on the Klein System 2000. The Klein System was also used to produce event annotated analogue seismic profiles.

The extent of the survey block as defined by side-scan sonar coverage is illustrated in Figure 1.

3.1 Grab Sampling

Ten grab samples were collected using a *Shipek* grab to ground-truth the side-scan sonar records obtained during April and May 1999, and also to investigate the nature of the sediments on the seafloor. The *Shipek* grab weighs ± 40 kg and takes a 0.15 m^3 sediment sample. Positioning of the grab samples was done with DGPS.

4. DATA PROCESSING

4.1 Navigation and Bathymetric Data

Navigation data were corrected for transducer offsets from the DGPS antenna position and bathymetry data were edited for anomalous values, corrected for tidal variation and reduced to the Lowest Astronomical Tide (LAT) in the *Navlog Systems* software. The corrected bathymetric data were imported as ASCII text files into the *Surfer 7* software package for gridding and contouring. A total of 14379 data points were gridded using the kriging method, an octant search pattern and a search radius of 300 metres to produce a 50 m by 50 m grid file from which the final bathymetric map was produced.

4.2 Side-scan sonar data

The taped System 2000 side-scan sonar data were converted to Klein 5000 format using an Exabyte tape drive installed on a high-specification PC running Windows NT and a proprietary software application designed by Klein Associates, Inc. The Klein software allows the time varied gain (TVG) of the sonar data to be manipulated and the image enhanced. The 5KD format was then converted to Q-MIPS format using the *Navlog Systems* software. This software was also used to mosaic the sonograph data which was then filtered using an algorithm in the *ER Mapper* software. The mosaic was saved in a bitmap format and imported into the *Surfer 7* software where it was geo-referenced and used to digitize different acoustic facies as separate polygons which were integrated to produce a seafloor geology map.

4.3 Pinger sub-bottom profiling data

The navigation data were corrected for the Pinger transducer offsets in the *Navlog* software and then exported to the *Surfer 7* software as an ASCII spreadsheet. The minimum unconsolidated sediment thickness values were measured directly from the sub-bottom profiling analogue records at regularly spaced event marks (30 second intervals) and then manually incorporated into the navigation spreadsheet. These values of unconsolidated sediment thickness were then posted as point data onto the seafloor geology map in their true geographic location.

4.4 Sediment Samples

A sample of ± 130 g from each of the grab samples was taken for laboratory analysis. Sub-samples of the sediment were taken and dried at 100°C and then subjected to a suite of analyses. Wet sieving was undertaken to determine the mud fraction (< 63 μ), settling tube analysis was undertaken to determine the graphic statistical parameters of the sand fraction (> 63 μ), loss on ignition at 600° C was undertaken to determine the organic carbon content and carbonate bomb analysis to determine calcium carbonate content.

5. BATHYMETRY

The bathymetry in the dredge disposal survey area varies from a minimum depth of - 26 m to a maximum depth of -72 m with an average depth of - 57.8 m (Fig. 2). The bathymetric chart indicates that the seafloor is generally very flat except for the presence of a linear reef outcrop which strikes roughly northeast - southwest (044°) in the northeastern quadrant of the survey area. The reef is evident as a series of "bull eyes" where survey lines cross the surface outcrop (Fig. 2). The reef generally displays subdued relief of 2 - 3 m but a maximum of 5 - 6 m of relief is evident on the northeastern exposures of the reef. The reef exposure becomes more subdued towards the southwest, where it eventually vanishes beneath a thin veneer of unconsolidated sediment.

There is a slight discrepancy between the strike of the reef outcrop (044°) and the bathymetric trend (039°). The reef exposure exerts a strong control on the bathymetry in the survey area and is located along a slope break on the continental shelf. Bathymetric gradients to the west of the reef exposure are typically 1.4° but flatten out to an average of 0.5° to the east. This suggests that the reef exposure is acting as a sediment trap and is damming the inshore sediment and preventing it moving into deeper water offshore.

6. SURFICIAL SEAFLOOR GEOLOGY

This section deals with the geological interpretation of shelf acoustic facies interpreted from the side-scan sonar mosaic (Fig. 3). Six acoustic facies were identified from the side-scan sonar mosaic and these include:

A. Description: Highly reflective acoustic facies with a linear distribution and large acoustic shadows.
Interpretation: Moderate to rugged relief, reef outcrop.

B. Description: Highly reflective acoustic facies with a more scattered distribution and smaller acoustic shadows.
Interpretation: Scattered reef outcrop with moderate to little relief.

C. Description: Moderately to strongly reflective granular acoustic facies with a random and widespread distribution pattern.
Interpretation: Silty dredge spoil.

D. Description: Small and localised examples of highly reflective objects with little or no acoustic shadow on the seafloor.
Interpretation: Metal debris or man-made artefacts which have been thrown overboard by passing ships.

E. Description: Weak to moderately reflective, smooth, even-toned planar acoustic facies.
Interpretation: Fine- to medium-grained, unconsolidated shelf sand.

F. Description: Localised examples of highly reflective, cigar-shaped objects with moderate to large acoustic shadows.
Interpretation: These are interpreted as ship wrecks.

The six acoustic facies were digitised as discrete polygons and compiled to form a side-scan sonar interpretation map (Fig. 4).

The areas of reef outcrop are characterised by distinctive highly reflective, linear sonograph images with pronounced shadow areas (white) on their leeward side. The reef outcrops are characterised by even toned sonographs on reef crests and strongly reflective step like sonograph images on reef margins to the east and west (Fig. A - Appendix 1). The even toned sonograph images which typify reef crests indicate that the reef exposures are flat topped plateau-like outcrops, while the strongly reflective step like sonographs of reef margins indicates steep drop-offs with rugged microtopography. The linear nature of the reef outcrop which strikes roughly coast parallel is typical of aeolianite reef complexes along the Natal coastline (Ramsay, 1996; Miller & Ramsay, 2000). The reef areas represent ancient linear coastal dune deposits which accumulated during periods of lower sea-level. By virtue of the shell fragment content of the coastal dune sediments, the dune core underwent cementation by a mechanism of dissolution of calcium carbonate on dune crests by rainwater and re-precipitation of the calcium carbonate at depth when the calcium rich pore waters encountered the meteoric interface. A subsequent rise in sea-level has left the now lithified dune sediments (aeolianite) as linear reefs on the seafloor. The steep step-like reef margins have substantial microtopography which is suitable for habitation by a wide range of marine organisms, while reef crests have little microtopography making these areas less suitable for habitation. The reef outcrop strikes northeast - southwest (044°) and forms the souther extension of No. 1 Reef before it vanishes beneath a thin veneer of sediments near the centre of the survey area (Fig. 4).

Scattered reef outcrops are characterised by more isolated exposures with highly reflective sonograph images which have a more blotchy and granular appearance. The scattered reef outcrops lack the linear nature of the true reef outcrops, and the blotchy/granular nature of sonograph images indicates that the reef exposures occur as small islands emerging from unconsolidated marine sands and have considerable microtopography (< 2 m). The scattered reef outcrops occur adjacent to the main aeolianite reef outcrop (Fig. A, Appendix 1) and as smaller isolated examples closer inshore (Fig. B, Appendix 1). The inshore exposures of scattered reef show a roughly coast parallel distribution which indicates the presence of another linear development of aeolianite which is buried below a thin veneer of sand. Scattered reef outcrops have considerable microtopography which makes these areas suitable for habitation by a wide range of marine organisms.

Dredge spoil takes the form of numerous, often linear dark patches of moderately reflective sediment of variable size and orientation on the seafloor (Fig. 3; Figs. C & D, Appendix 1). The size and degree of reflectivity of the dredge spoil sites is highly variable with size varying from as small as 40 m by 50 m to as large as 120 m by 500 m and reflectivity varying from a dark grey-black colour which contrasts well with normal shelf sand, to subtle grey patches which have diffuse borders. The size of the dredge spoil site and degree of acoustic reflection are probably an indication of how long the dredge spoil has been resting on the seafloor i.e. recent deposits of dredge spoil being more compact in size and more reflective in nature (darker) than dredge spoil that has been lying on the seafloor for longer periods of time. The tendency would be for the dredge spoil to be redistributed by bottom currents into a larger more diffuse area with lower acoustic reflectance as time progressed. It is quite likely that the different generations of dumping activity could be identified by looking at the size and acoustic reflectance of the dredge spoil sites. At least 71 individual dredge spoil sites comprising at least four generations of dumping activity have been identified in the survey area (Fig. 4).

Three small localised areas with scattered highly reflective artefacts are evident in the survey area (Fig. 4). The reflective objects are highly variable in size and shape and none have a characteristic shape that could lead to an unequivocal identification of what these highly reflective objects represent. The objects have a random arrangement but occur in fairly dense clusters and are hence described as debris fields. The objects in question are probably man-made and their occurrence and distribution are probably related to debris being thrown overboard by passing ship traffic.

The vast majority of the survey area is covered by a weakly reflective even toned acoustic facies which is believed to represent fine- to medium-grained shelf sand. Surface exposures of this facies indicate little in the way of bedforms. Only a small area measuring 600 m by 400 m in the shallower water (29 m - 38 m) in the northern area of the survey block shows weakly developed subaqueous dunes with a wavelength of ± 50 m and very low amplitude (Fig. E Appendix 1). This implies that bottom currents in the survey area are generally very weak.

Three wrecks are evident in the survey area and are all located within a kilometre of one another in the central to southern area of the survey block. The largest of the wrecks measures ± 80 m in length and stands as much as 10 m above the seafloor (Fig. F Appendix 1). The other wrecks are smaller and have lower relief above the seafloor (Fig. G Appendix 1). These wrecks probably represent some of the ships that were scuttled in the area offshore from Durban in the mid- to late-1940's following the Second World War. Wrecks form excellent "artificial reefs" and are usually colonised by a wide range of marine organisms.

Environmentally sensitive areas in terms of available habitats suitable for a diversity of marine organisms in the survey area, can be considered to be the steep reef margins of the linear reef exposure, scattered reef outcrops and the three wrecks. These areas represent the most likely foci of habitation by a variety of marine organisms within the survey area, however more suitable reef exposures with wider distribution and greater topographic variation (up to 10 m) occur immediately north of the survey area (No. 1 shallow pinnacles). In terms of artificial reefs or wrecks, at least another 15 wrecks have been identified from side-scan sonar records within the Durban Bight (personal observations). Nevertheless these environmentally sensitive areas should be avoided wherever possible as sites for disposing of dredge spoil. The issue of dredge spoil mobility on the seafloor can be assessed by the presence of discernable dredge spoil sites and subaqueous bedforms. The fact that at least 71 individual dredge spoil sites comprising as much as four generations of dumping activity are recognisable on the seafloor suggests that dredge spoil can spend significant periods of time on the seafloor before it is remobilised by bottom currents. The fact that no sedimentary bedforms are evident on the seafloor and the fact that dredge spoil doesn't appear to be transported in any specific direction but merely becomes more dispersed on the seafloor through time, suggests that bottom currents are weak and ineffectual in redistributing the dredge spoil. Although it is inevitable that the dredge spoil will eventually be homogenised with normal shelf sediments, it is impossible to say how long this process would take. An evaluation of the Dredging Services dumping schedule would help to establish what period of time leading up to April 1999 would have been necessary to accumulate 71 discrete dredge spoil sites i.e. the last 71 dumping episodes. This period of time could then be used as a rough indicator of how long homogenisation of dredge spoil would take on the seafloor.

7. UNCONSOLIDATED SEDIMENT THICKNESS

Unconsolidated sediment thickness values are illustrated as point data on the side-scan sonar interpretation map (Fig. 4). Unconsolidated sediment thickness values range from 0 m to as much as 10 m with an average sediment thickness of 4.4 m. Sediment thickness values is at a minimum in the vicinity of reef or scattered reef outcrop and in areas where linear aeolianite reef continues beneath thin sediment cover in a roughly coast parallel direction. Unconsolidated sediment thickness values to the east of the main aeolianite reef exposure vary from 1 to 7 m with the thickest values occurring in a coast parallel trough between the reef outcrop and the eastern extremity of the survey area. Another trough of thick unconsolidated sediment accumulation occurs immediately west of the linear reef outcrop where an average sediment thickness of ± 6 m is evident reaching a maximum value of 8 m. Sediment thins again towards the west of this trough due to the presence of eroded remnants of another coast parallel aeolianite ridge which exists beneath a thin veneer of sand. This ridge is coincident with the exposures of scattered reef outcrop in the western area of the survey block. The thickest accumulations of unconsolidated sediment occur in a coast parallel trough along the western margin of the survey area. Unconsolidated sediment values range from 2 to 10 m in this area and average ± 8 m. Superimposed on the coast parallel trend of depocentres between exposed or buried aeolianite ridges, there is also an overall thinning of unconsolidated sediment towards the north.

The fact that the reef outcrops are subdued and large areas of reef are buried under a thin veneer of unconsolidated sediments, is (in the authors' opinion) not in any way related to dumping activity. Although the dumping activity has contributed to a small sediment accumulation in the survey area, the amount of sediment required to bury the reef i.e. a thickness of at least 3 m over the southern area of the survey block is probably far in excess of the volume of dredge spoil that has been dumped on this site since it was proclaimed a dumping site. Moreover there is a general increase in No. 1 Reef topography towards the shallow pinnacles immediately north of the survey area, and there is no evidence on the sub-bottom profiling records to suggest that dumping activity has lead to a significant accumulation of sediment in this area (personal observations).

8. SEDIMENT SAMPLES

Ten sediment samples were collected to investigate the nature of sediments from specific sites of dredge spoil concentration and also to investigate the sedimentary character of normal quartzose shelf sand in the survey area. Samples 1, 2 and 3 were sited in shallow areas of normal shelf sedimentation, samples 4, 5, 6, 7 and 8 were located on dredge spoil sites identified from the side-scan sonar records and samples 9 and 10 were sited in deeper areas of normal shelf sedimentation. The location of the grab samples are illustrated in Figure 4.

8.1 Sediment Description

Sample 1.

This sample was collected in 32.4 m of water from the ripple field in the northwestern part of the survey area (Fig. 4).

Grain-size:	Fine- to medium-grained	
Colour:	Light brown (dry)	Dark Olive (wet)
Texture:	Subangular to rounded clean sand	
Sorting:	Very well sorted	
Odour:	None	
Fauna:	Shell fragments (small)	
	Foraminifera	
	Sponge spicules	
	Echinoid spines	

Sample 2.

This sample represents normal shelf sand and was collected in 26.7 m of water in the northwestern part of the survey area (Fig. 4).

Grain-size:	Medium-grained	
Colour:	Light brown (dry)	Dark Olive (wet)
Texture:	Subangular to well rounded clean sand	
Sorting:	Moderately well sorted	
Odour:	None	
Fauna:	Shell fragments (small)	
	Foraminifera & sponge spicules	

Sample 3.

This sample represents normal shelf sand and was collected in 30.5 m of water in the southwestern part of the survey area (Fig. 4).

Grain-size:	Medium-grained	
Colour:	Light reddish brown (dry)	Dark Olive (wet)
Texture:	Subangular to rounded clean sand	
Sorting:	Well sorted	
Odour:	None	
Fauna:	Shell fragments (small)	
	Foraminifera	
	Sponge spicules	
	Echinoid spines	

Sample 4.

This sample was obtained from what appears to be an older current winnowed dredge spoil site in 45 m of water in the southwestern part of the survey area (Fig. 4).

Grain-size:	Medium-grained	
Colour:	Light brown (dry)	Dark Olive (wet)
Texture:	Subangular to rounded clean sand	
Sorting:	Moderately well sorted	
Odour:	None	
Fauna:	Shell fragments (small)	
	Foraminifera	
	Sponge spicules	

Sample 5.

This sample was obtained from what appears to be a more recently deposited dredge spoil site in 42.6 m of water in the western part of the survey area (Fig. 4).

Grain-size:	Fine-grained	
Colour:	Light reddish brown (dry)	Dark Olive to dark brown (wet)
Texture:	Angular to rounded clean sand with lumps of cohesive yellow clay	
Sorting:	Well sorted	
Odour:	None	
Fauna:	Shell fragments (small)	
	Foraminifera	
	Sponge spicules	

Sample 6.

This sample was sited at what appeared to be the most recently deposited dredge spoil site in 56.3 m of water in the southern area of the survey block (Fig. 4).

Grain-size:	Fine-grained	
Colour:	Light grey - dark brown (dry)	Dark grey - black (wet)
Texture:	Angular to subrounded muddy sand with finely disseminated organic material	
Sorting:	Well sorted	
Odour:	Slightly sulphurous	
Fauna:	Shell fragments (small)	
	Foraminifera	
	Sponge spicules	

Sample 7.

This sample was obtained from a dredge spoil site in 65 m of water in the southwestern part of the survey area (Fig. 4).

Grain-size:	Fine-grained	
Colour:	Light grey - dark brown (dry)	Dark grey - black (wet)
Texture:	Angular to subrounded muddy sand with finely disseminated organic material	
Sorting:	Moderately well sorted	
Odour:	Slightly sulphurous	
Fauna:	Shell fragments (small)	
	Foraminifera	
	Sponge spicules	
	Polychaetes	

Sample 8.

This sample was obtained from a fairly recent dredge spoil site in 67 m of water near the central part of the survey area (Fig. 4).

Grain-size:	Fine-grained	
Colour:	Light grey - dark brown (dry)	Dark grey - black (wet)
Texture:	Angular to subrounded muddy sand with finely disseminated organic material	
Sorting:	Moderately sorted	
Odour:	Slightly sulphurous	
Fauna:	Shell fragments (small)	
	Foraminifera	
	Sponge spicules	
	Polychaetes	

Sample 9.

This sample represents normal shelf sand that was collected in relatively deep water (68 m) in the eastern part of the survey area (Fig. 4).

Grain-size:	Fine-grained	
Colour:	Light grey - dark brown (dry)	Dark brown (wet)
Texture:	Angular to subrounded muddy sand with finely disseminated organic material	
Sorting:	Moderately well sorted	
Odour:	Slightly sulphurous	
Fauna:	Shell fragments (small)	
	Foraminifera	
	Sponge spicules	
	Polychaetes	

Sample 10.

This sample represents normal shelf sand collected in deep water (70 m) in the southeastern area of the survey block (Fig. 4).

Grain-size:	Fine-grained	
Colour:	Light grey - dark brown (dry)	Dark brown (wet)
Texture:	Angular to rounded muddy sand	
Sorting:	Well sorted	
Odour:	Slightly sulphurous	
Fauna:	Shell fragments (small)	
	Foraminifera	
	Sponge spicules	

8.2 Sediment Statistical Parameters

The sediment statistical parameters of the ten grab samples are described in terms of graphic settling statistics and are listed in φ units in Table 1 below.

Sample No.	Mean φ	Sorting φ	Skewness φ	< 63 μ %	C org. %	$CaCo_3$ %
1	2.56	0.28	-0.22	1.5	5.15	12.9
2	1.76	0.52	-0.18	0.9	4.76	10.0
3	1.78	0.43	-0.21	1.0	5.13	11.6
4	1.91	0.63	-0.39	1.1	6.31	13.4
5	2.31	0.44	-0.16	14.8	7.49	8.4
6	2.51	0.46	-0.22	38.6	6.14	5.8
7	2.36	0.51	-0.27	24.2	5.67	8.2
8	2.17	0.80	-0.36	34.9	12.27	7.4
9	2.44	0.55	-0.20	14.3	4.90	9.8
10	2.40	0.47	-0.11	15.8	4.87	14.9

Table 1 The sediment statistical parameters for the ten grab samples collected from the Durban dredge disposal site.

The majority of the sediment samples have a fine grained (2.0 - 3.0 φ) sand fraction, while three samples (samples 2,3 & 4) have a medium-grained sand fraction (1.0 - 2.0 φ). Sorting of the samples sand fraction ranges from very well sorted (< 0.35 φ) to moderately sorted (0.71 - 1.00 φ), with the majority of the samples falling in the moderately well sorted (0.51 - 0.7 φ) and well sorted (0.35 - 0.5 φ) classes. The majority of the sediment samples are coarse skewed (-0.10 to -0.30 φ), while two samples (samples 4 & 8) are strongly coarse skewed (< -0.30 φ).

The mud fraction (< 63 μ) of the sediment samples ranges from 0.9 % to 38.6 % and separates the samples into two distinct groups: namely a sand with very low mud content (0 - 2

%) and a silty sand with a mud fraction of between 14 % and 39 %. Organic carbon content varies from 4.87 % to 12.27 % and shows higher values (5.67 - 12.27 %) for the samples taken from dredge spoil sites (samples 4,5,6,7 & 8) than those samples taken from areas of normal shelf sedimentation (4.76 - 5.15 %; samples 1,2,3,9 & 10). Calcium carbonate content varies from 5.8% to 14.9 %.

It is evident from the sediment descriptions and the information provided in Table 1 that the sediment samples represent at least three different sediment types. Not all of the sediment statistical parameters are useful in separating the sediment samples into distinct groups, but rather a combination of statistical parameters used in conjunction with basic sediment descriptions. The most obvious group of sediments is represented by samples 1, 2, 3 & 4 which are all dark olive, clean sands with low mud content and high calcium carbonate content. Samples 1, 2, and 3 are representative of normal shelf sediments in water depths of between 26.7 m and 45 m, while sample 4 was located on an identified dredge spoil site. Other sediments from dredge spoil sites represented by samples 5, 6, 7 and 8 are characterised by a darker sediment colour, higher mud contents, sulphurous odours and low calcium carbonate contents. The elevated mud content, sulphurous odour and reduced calcium carbonate content are to be expected at sites where dredge spoil has accumulated, as these parameters are typical of Durban Harbour sediments. The fact that sample 4 differs from sediments gathered at other dredge spoil sites can perhaps be explained by the amount of time that elapsed between the side-scan sonar survey and the grab sampling survey (18 months), which may have been sufficient time for homogenisation of the dredge spoil to take place. Offshore shelf sediments (samples 9 & 10) occur in water depths in excess of 65 m and are characterised by a moderately high mud content and a sulphurous smell which makes it difficult to distinguish between these sediments and dredge spoil. In this case it is the sediment colour (dark brown as opposed to dark grey), higher calcium carbonate values and lower values of organic carbon content relative to dredge spoil which are the diagnostic criterion. A typical sedimentary description for each of the identified sediment types is given below.

Inshore quartzose shelf sand (Samples 1, 2, 3 & 4) is characterised by light brown, fine- to medium-grained, subangular to rounded, moderately to well sorted, clean sand with small shell fragments, foraminifera, sponge spicules and echinoid spines. The mud fraction of this sediment is typically less than 3 %, the calcium carbonate content ranges from 10 - 13.4 % and organic carbon content varies from 4 - 6.5 %.

Dredge spoil (samples 5, 6, 7 & 8) is characterised by light grey to dark brown, fine grained, moderately to well sorted, angular to subrounded, muddy sand with finely disseminated organic material and a slightly sulphurous odour. The faunal content of the dredge spoil contains numerous polychaetes, shell fragments and foraminifera. The mud fraction of the dredge spoil is typically high (14.8 - 38.6 %), calcium carbonate values low (5.8 - 8.4 %) and organic carbon values range from 5.67 - 12.27 %.

Offshore muddy shelf sand (samples 9 & 10) consists of light grey to dark brown, fine grained, angular to rounded, moderately well sorted to well sorted, muddy fine sand with a slightly sulphurous odour. The mud fraction of the offshore shelf sands is moderately high (14.3 - 15.8 %), the carbonate content is fairly high in comparison to dredge spoil (9.8 - 14.9 %) and organic carbon contents are low (4.87 - 4.9 %).

A comparison of the inshore and offshore shelf sediments shows significant similarities between these two sediment types (Table 1). Organic carbon content, sediment sorting and calcium carbonate contents of the two sediment types are comparable while the most notable contrasts are a finer grain-size, darker colour and an increased mud fraction in the offshore sediments. While it could be argued that these differences are in accordance with normal sedimentation patterns, it is quite likely that the elevated mud fraction in the offshore samples is related to an offshore movement of the mud fraction of the dredge spoil.

5. DISCUSSION

Discrete areas of dredge spoil accumulation can be identified from side-scan sonar records and the spatial distribution of these areas can be mapped from a side-scan sonar mosaic of the survey area. A total of 71 dredge spoil sites comprising at least four different generations of dumping activity were identified from the side-scan sonar mosaic. This testifies to the fact that some of the dredge spoil has been resting on the seafloor for considerable periods of time. It is also clear from the side-scan sonar mosaic that the dredge spoil sites slowly get reworked into larger more diffuse deposits with time and eventually get homogenised with the normal shelf sediments. The distinct lack of subaqueous bedforms on the seafloor, suggests that bottom currents are typically weak and that the homogenisation is probably quite slow. The clastic sediments ($> 63\ \mu$) would probably only be mobile during storm conditions when bottom currents are at their strongest. The dredge spoil would be repeatedly winnowed of the mud fraction and would eventually take on the characteristics of normal shelf sand (i.e. homogenisation).

Sampling of the dredge spoil sites has shown that dump sites are associated with slightly anoxic conditions, elevated levels of mud content ($< 63\ \mu$) and reduced levels of calcium carbonate content (in comparison to normal shelf sediments). Analysis of the offshore shelf sediments suggests that the mud fraction from dredge spoil dumped inshore is probably contributing to elevated levels of fine sediment ($< 63\ \mu$) in the offshore environment. This offshore movement of fine sediment is in keeping with normal sedimentary processes in the marine environment, but a more widespread sampling programme would have to be conducted to investigate if the elevated mud fraction is a localised effect adjacent to the dump site or whether it is representative of normal marine sedimentation for the area.

Dumping activity in the area seems to hold little threat to habitat destruction as obvious areas of habitation such as reef outcrops and wrecks together comprise less than 5 % of the surface area of the seafloor in the survey area. Moreover, an analysis of the sub-bottom profiling records suggests that dumping activity has not lead to significant sediment accumulation in the survey area.

6. RECOMMENDATIONS

Future monitoring surveys of the dredge disposal site should involve a shorter time delay between the geophysical survey and the grab sampling programme. A more comprehensive grab sampling programme is also recommended for future surveys and should only be undertaken after the geophysical records have been interpreted as this will enable a clearer understanding of sediment distribution and sediment movement on the seafloor. The grab sampling programme should also be carried out over a larger area which incorporates areas out of the direct influence of dumping activity so that normal shelf sedimentation can be properly understood. In addition to normal sedimentary analytical techniques, an evaluation of benthic communities within the sediment samples is also recommended.

An analysis of the Dredging Services dumping manifest would also be very useful in the determining the length of time it takes to homogenise the dredge spoil i.e. determine the length of time it took to complete the 71 most recent dumps in the dumping ground leading up to April 1999. If possible Dredging Services should expand their dumping log to include the source of dredged sediment, dumping co-ordinates and how many individual dumps are executed at the dump site. This will lead to a better understanding of sedimentary processes within the dredge disposal site and will ultimately result in better management of this facility.

Although the dredge disposal site is impoverished with respect to good marine habitats such as high relief reef exposures with rugged topography and abundant marine growth, environmentally sensitive areas such as the reef exposures and wreck sites in the vicinity of the proclaimed dumping area should be avoided wherever possible.

7. REFERENCES

Miller, W.R., & Ramsay, P.J. (2000). Geophysical Survey of the Rhino JCD1 Drill Site, KwaZulu-Natal Shelf, South Africa. *Council For Geoscience Report 2000-0032,* Council for Geoscience, P. Bag X112 Pretoria, 0001, South Africa, 68 pp.

Ramsay, P.J. (1996). Quaternary marine geology of the Sodwana Bay shelf, northern KwaZulu-Natal. *Bulletin of the Geological Survey of South Africa, 117,* Council for Geoscience, P. Bag X112 Pretoria, 0001, South Africa, 86 pp.

APPENDIX 1.

Selected Sonograph Images

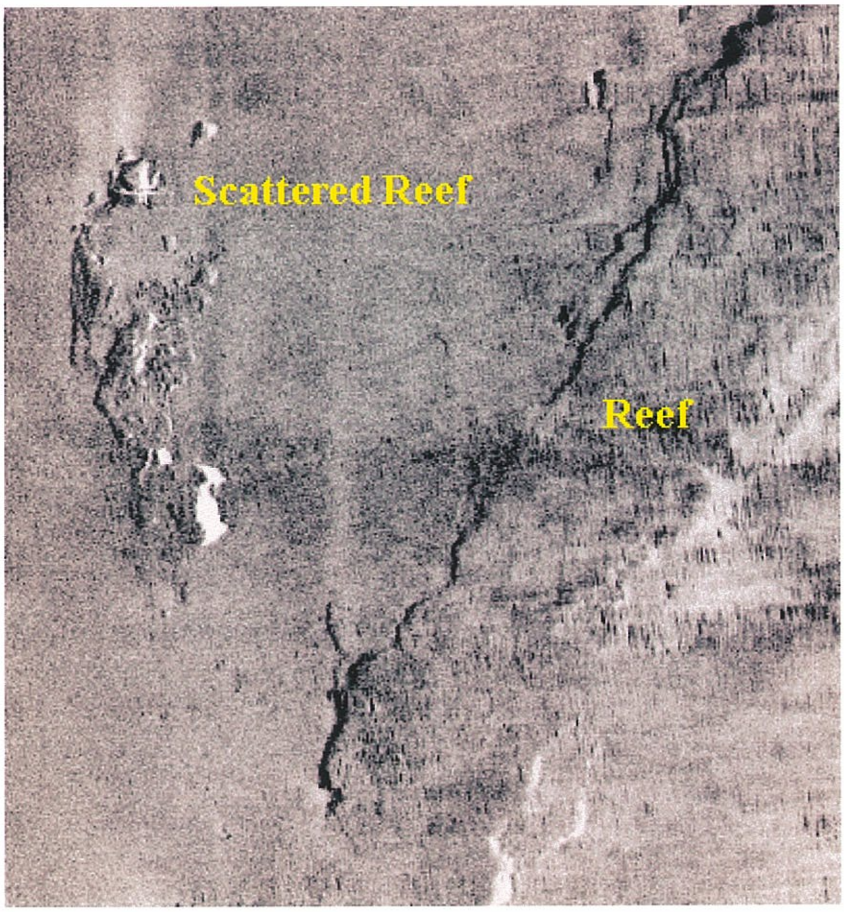


Fig. A An example of a side-scan sonograph showing reef and scattered reef exposures.

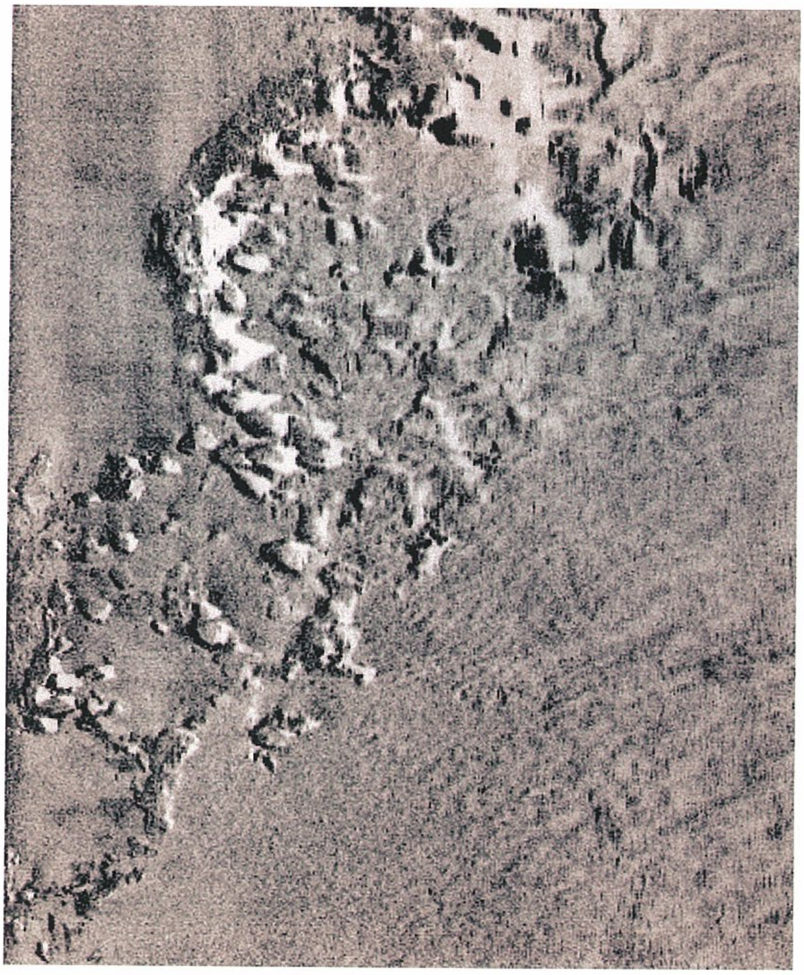


Fig. B An example of an inshore scattered reed exposure.

Fig. C An example of a highly reflective dredge spoil site.

Fig. D An example of a moderately reflective linear dredged spoil trail.

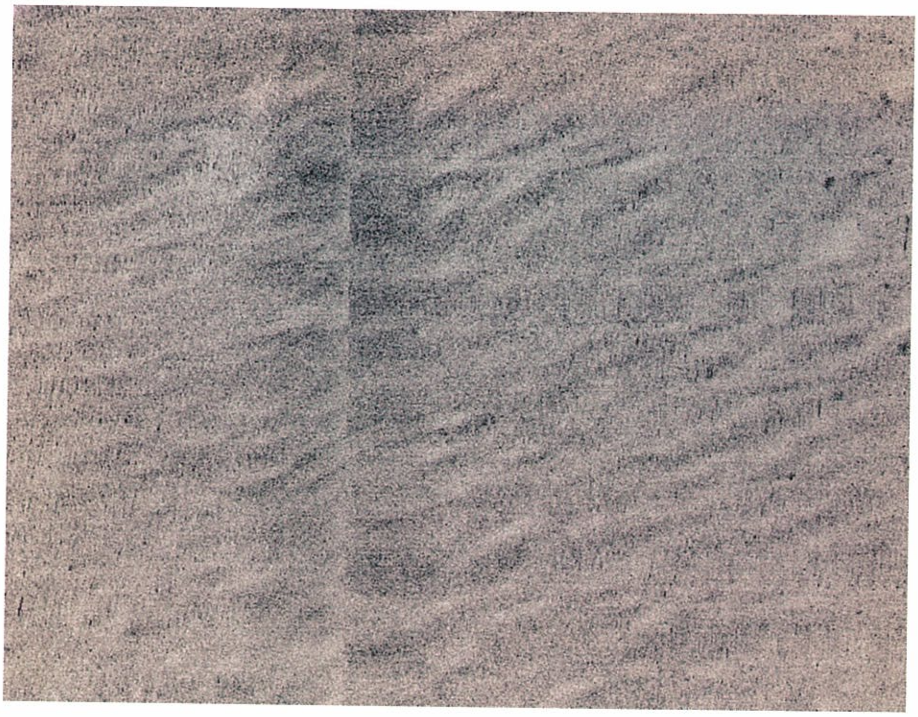


Fig. E A side-scan sonograph showing the sub-aqueous bedforms located in the shallow northeastern area of the dredge disposal site.

Fig. F A side-scan sonograph of Wreck 1, the wreck is ±80m long and stands ±10m off the seafloor.

Fig. G **A side-scan sonograph of Wreck 3, the wreck is ±55m long.**