44

INLAND WATERS BRANCH

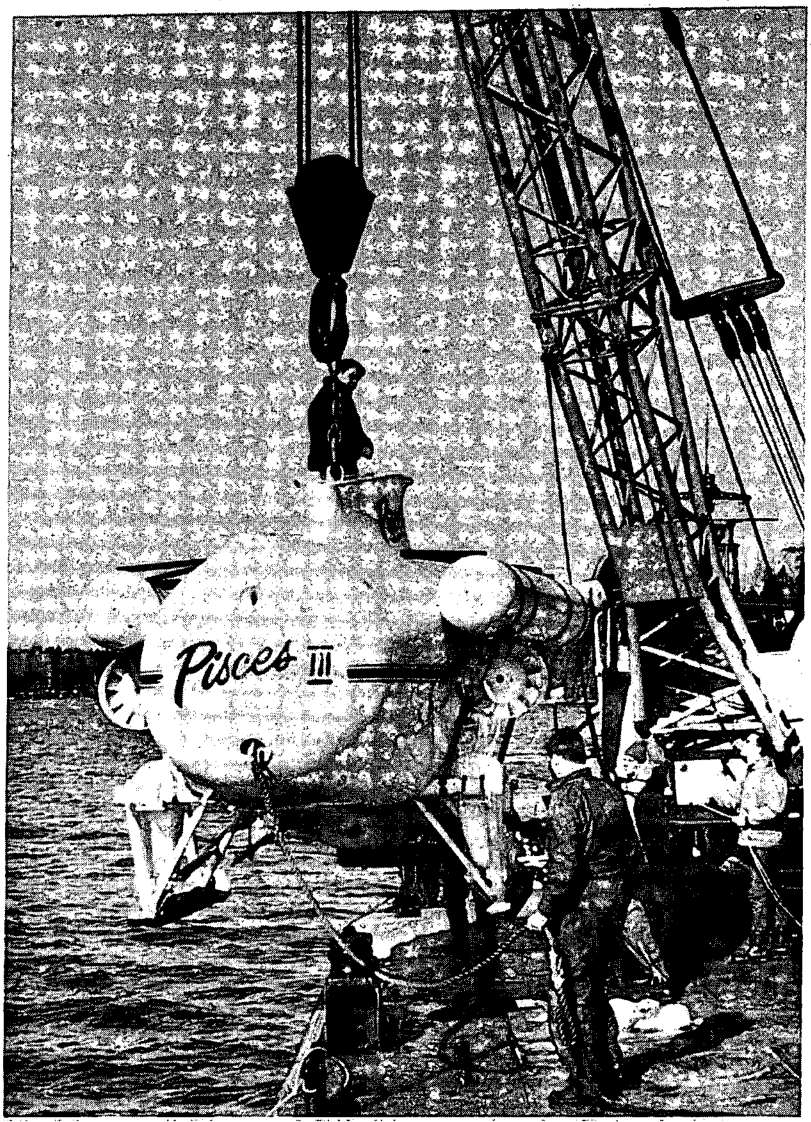
DEPARTMENT OF ENERGY, MINES AND RESOURCES

Submersible Operations in Georgian Bay and Lake Erie – 1970

P.G. SLY

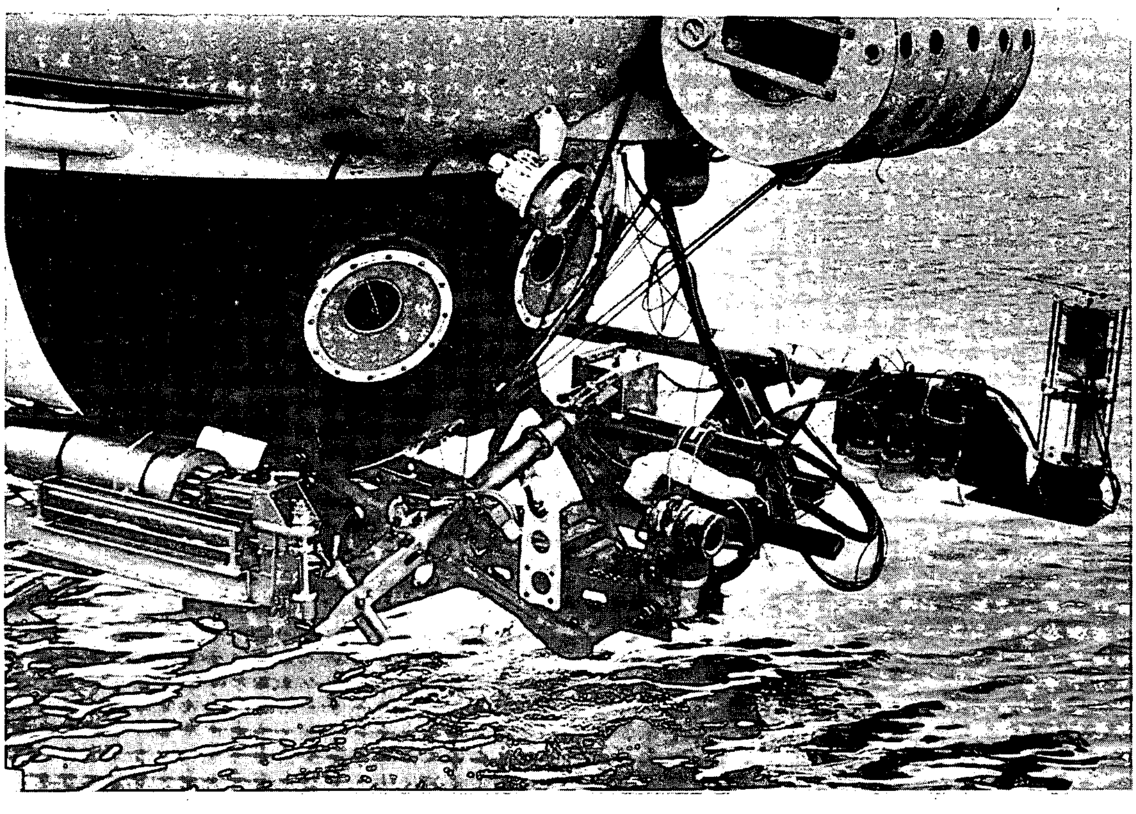
TECHNICAL BULLETIN NO.44

Frontispiece



Pisces III being launched at the Big Tub Harbour, Tubermory.

Pisces III, front-end equipment showing manipulator arm, sensors, underwater lights and underwater television.



CANADA

TECHNICAL BULLETIN NO.44

Submersible Operations in Georgian Bay and Lake Erie - 1970

P.G. SLY

INLAND WATERS BRANCH
DEPARTMENT OF ENERGY, MINES AND RESOURCES
OTTAWA, CANADA, 1971

Contents

Illustrations

Submersible Operations in Georgian Bay and Lake Erie

P.G.SLY

INTRODUCTION

Most of the studies undertaken by the Limnogeology Section are directed towards obtaining a clearer understanding of geologically recent and present environmental controls, particularly those related to eutrophication and pollution. Research activities have mostly been conducted from surface vessels, using standard sampling, coring and sensing equipment. However, some detailed surveys and equipment trials have been supported by scuba diving techniques (Sly 1969a), and over the past three years, the demand for diver supported operations has grown progressively. The need to understand sediment distributions and to quantify variations, which can be used to reflect short-term environmental changes as they relate to specific problem areas (Sly 1969b), has also become more and more evident.

Bearing in mind the need to apply the most appropriate tools and methods to answer complex environmental problems and to ascertain, in particular, the suitability of various diving techniques as they relate to Great Lakes research, planning was begun early in 1967 on a program to study the use and application of various scuba and submersible equipment and systems.

An extensive literature review was undertaken and various meetings and discussions were held with other groups previously experienced with submersible operations. Of particular interest were the activities of the Great Lakes Research Division of the University of Michigan (Ann Arbor), who made use of *Star II* in Lake Michigan during the summer of 1967 (Schneider, 1968); the use of the Perry *Cubmarine* in the Gulf of St. Lawrence and Bay of Fundy in July, 1968 (Caddy and Watson, 1969); and the use of *Pisces I* in the eastern Arctic during August and September, 1968 (Pelletier, 1968).

A request to charter a submersible, suitable for a series of dives in the Great Lakes, was approved early in 1969, but it was not until November that a vessel became available for the proposed operations. Arrangements were initially made for the use of *Pisces I* (International Hydrodynamics - Vancouver) but these were subsequently changed when the Canadian Armed Forces obtained the submersible, *Pisces III*. Most operational planning was completed by early April, 1970 and the final planning was completed on April 23. The operations began a week later, on May 1.

Footnote: The Limnogeology Section of Lakes Division, Inland Waters Branch, of the Canadian Federal Department of Energy, Mines and Resources (DEMR) was established in 1966 with the responsibility for defining the physical and chemical characteristics of lake sediments and their distribution and occurrence.

GENERAL PROGRAM

Objectives

Four distinct objectives were established for the proposed submersible operations:

(1) To attempt a number of different operational tasks directed at resolving a number of specific problems.

(2) To assess the suitability of the submersible actually used in undertaking the various tasks.

(3) To determine the optimum roles of free diving, excursion diving and habitat support, and submersible operations, with regard to the *in situ* research needs of the Great Lakes.

(4) To suggest what might be the most suitable and practical type of submersible vessel (and logistical support), required for the types of environmental research for which a submersible would obviously be the best choice.

Participating Groups

Although the operation was funded by DEMR, a number of other groups from different agencies and universities were invited to participate. These included:

(1) Brock University, St. Catharines, Ontario (Geology and Biology)

(2) MacMaster University, Hamilton, Ontario (Geology).

(3) University of Michigan, Ann Arbor, Michigan (Biology and Oceanography).

(4) University of Toronto, Toronto, Ontario (Greak Lakes Research Institute).

(5) Central Hydrographic Region, Marine Sciences Branch, DEMR.

(6) Chemical Limnology Section, Lakes Division, DEMR.

(7) Geological Survey of Canada, DEMR.

(8) Ontario Provincial Department of Lands and Forests, Research Branch Stations at: Maple, Sault Ste. Marie, Thunder Bay, Wheatley, Glenora (Fish Biology).

(9) The National Sand and Material Company.

(10) The Petroleum Drilling and Production Section of the Ontario Department of Energy and Resource Management.

Four other groups representing different aspects of the resource and engineering industries were also invited; for various reasons, however, they were unable to take part in the operations.

Task Force

The task force consisted of the following units:

(1) One submersible, *Pisces III*, with support personnel (6) and equipment on charter from the Canadian Armed Forces.

(2) One tug (21 m), *Lac Erie*, with complement of 3.

(3) One barge (32 m), *Handy Boy*, with deck mounted crane (27,000 kg).

(4) One helicopter (jet ranger - 4-seater), with pilot and ground crew; provided by the Department of Transport.

Pisces III Specifications and Equipment

Much of the following information has been supplied by the manufacturer of *Pisces III*:

Maximum operational depth	- 1,000 m (approximately)
Crew	- Pilot 1 - Observers 1-2
Life support	- 72 man hrs. (Lithium hydroxide CO_2 scrubber, O_2 supply and rebreathers)
Ballast and buoyancy	- Oil displacement - Drop weight (approximately 180 kg) - Compressed air
Trim	- Oil ballast transfer
Batteries and power	- Lead acid, 400 ampere hrs., 12.24.60.120 v
Speed (maximum submerged, clear hull)	- 7 km/hr. approximately
Cruising (submerged, clear hull)	- 3.5 km/hr. approximately
Endurance	- 9 hr. at 1.0 km/hr.
Maximum weight	- 12,400 kg
Least exterior dimensions (reduced and clear)	- Length - 8 m - Beam - 3 m - Depth - 2.6 m

Forward looking avoidance sonar

Magnetic compass

Surface R/T communications

Underwater telephone	- (Transducer type) 8 khz.
External lighting	- Quartz iodide 2 x 1000 watt
Temperature indicator	- Range 20°C ± 1°
Depth gauge	- Pressure type ± 2 per cent
Depth sounder	- Dual range recording/flasher indicator type 0-30 m, 0-90 m
Mechanical arm	- Articulated, reach - 1.5 m lift - 70 kg, grip - 180 kg, jaw opening - 8 cm
View ports	- 3 (overlapping) - 15 cm I.D.
Voice tape recorder and stero tape replay system	

The following additional equipment was provided by DEMR:

one 70 mm underwater camera

two (100 watt/sec.) strobe units

one underwater television camera

one underwater television monitor and control

one television monitor for edit and display

one pan and tilt control unit

one super 8 mm movie camera

one 16 mm movie camera

two portable cassette tape recorders

one portable 1/2 in. video tape recorder (under lease)

one 1 in. video tape recorder

one sensor boom (mounted externally) and extending to nearly 2 m, mounted forward on port side of the submersible, carrying prototype underwater sensors for: temperature, pH, Eh, DO, current D and V

one sample basket

AREAS OF OPERATION

Two separate areas were selected for the conduct of programmed operations. The first series of dives were made in central west Georgian Bay, near Tobermory at the northern tip of the Bruce Peninsula. The area, and various dive locations, are shown on Figure 1. The second series of

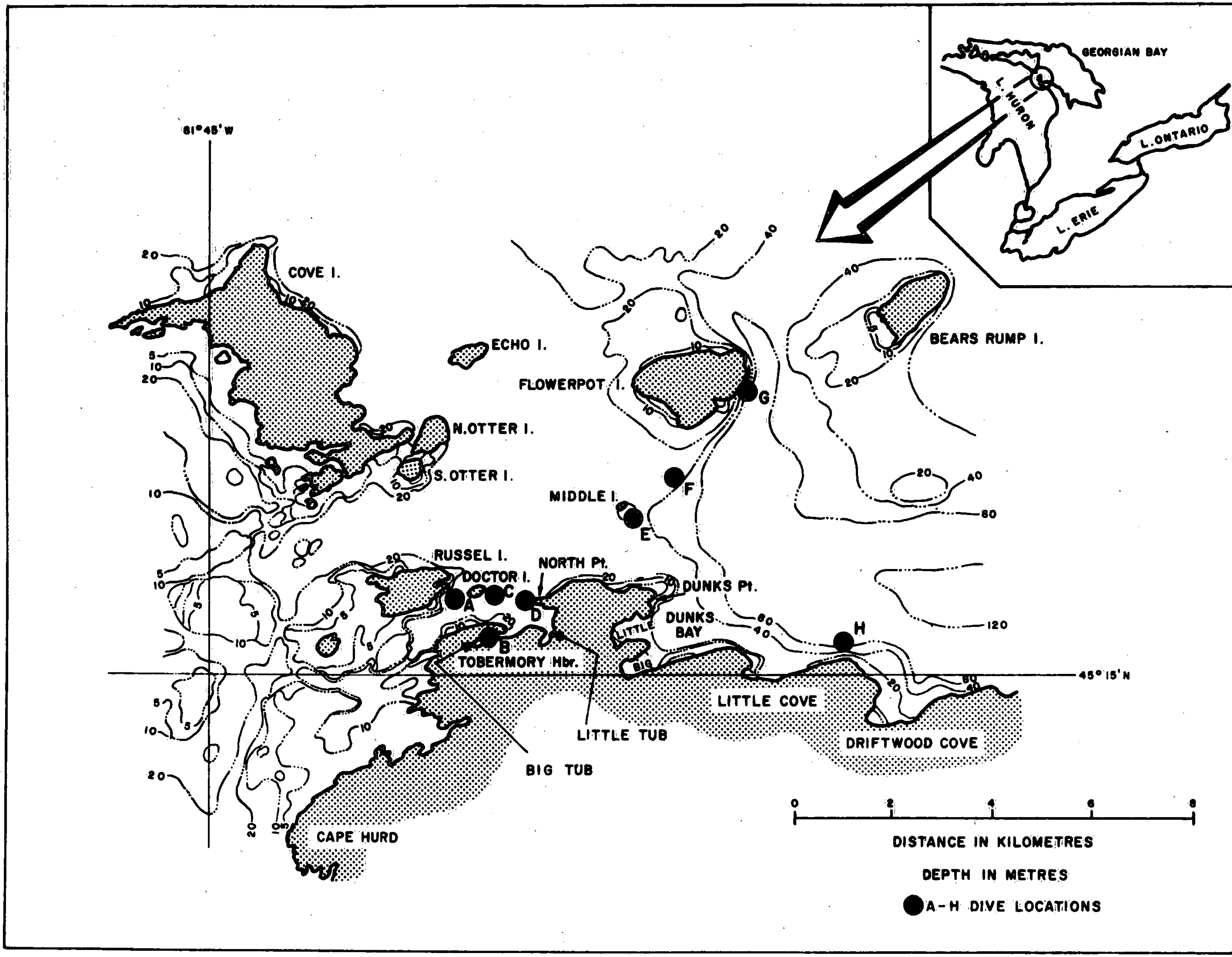


Figure 1. Map showing submersible dive locations, Georgian Bay.

dives were made in west central Lake Erie, in the area bounded by the western islands and Erieau (on the Canadian shore), and is shown on Figure 2.

The Georgian Bay area was chosen because of the proximity of relatively deep water (in excess of 120 m), because it was expected that there would be an abundance of underwater bedrock exposure and because (from previous studies) it was expected that underwater visibility would be extremely good. The Lake Erie area was chosen as a contrast; the water clarity was known to be poor, the water was shallow (10-15 m), and bottom conditions were expected to be continually active (in response to the relatively high energy of the environment).

SUMMARY OF PROPOSED PROJECTS

The detailed outlines for all the planned programs were drawn up and specified prior to the commencement of field activities (Sly and Roe, 1970). The programs, in summarized form, are listed as follows:

<u>Georgian Bay</u>

(1) A study of fish behavior, spawning, feeding and general environmental conditions (T.R. Porter - May 16).

(2) A study of the thermal bar, turbulence and diffusion and internal water movements distinct from surface wave motion and locally induced current activities (G.K. Rodgers and W. Simpson - May 16, G.K. Rodgers and A.H. Lee - May 17).

(3) A study of the detailed lithology and changes in the surface appearance of bottom sediments on a continuous slope to depths in excess of 160 m, and a study of the exposed bedrock on a sub-marine scarp rim (C.F.M. Lewis and B.V. Sanford - May 14, part completed).

(4) A study, by means of a series of vertical profiles, of detailed facies changes and lithology, structure, weathering and erosion of a sub-surface scarp (program cancelled).

(5) A study, by means of a series of vertical profiles, of bio-communities related to these scarp faces. The comparison of submersible observations with those made by free scuba diving support (A.R. Emery and L.H. Somers - May 13, part completed).

(6) A study of the usefulness of a submersible as a means of providing detailed charting of shoal areas for hydrographic and navigational purposes (G.H. Goldsteen and J.F. Freener - May 14).

(7) A study of the occurrence of manganese nodules (program cancelled).

(8) A study of the bottom sediments, their structure and bioturbidity, at various depths in a mid-lake environment. A study of the underwater exposure of bedrock outcrops and a comparison of various major physiographic features with specific bedrock formations (program cancelled).

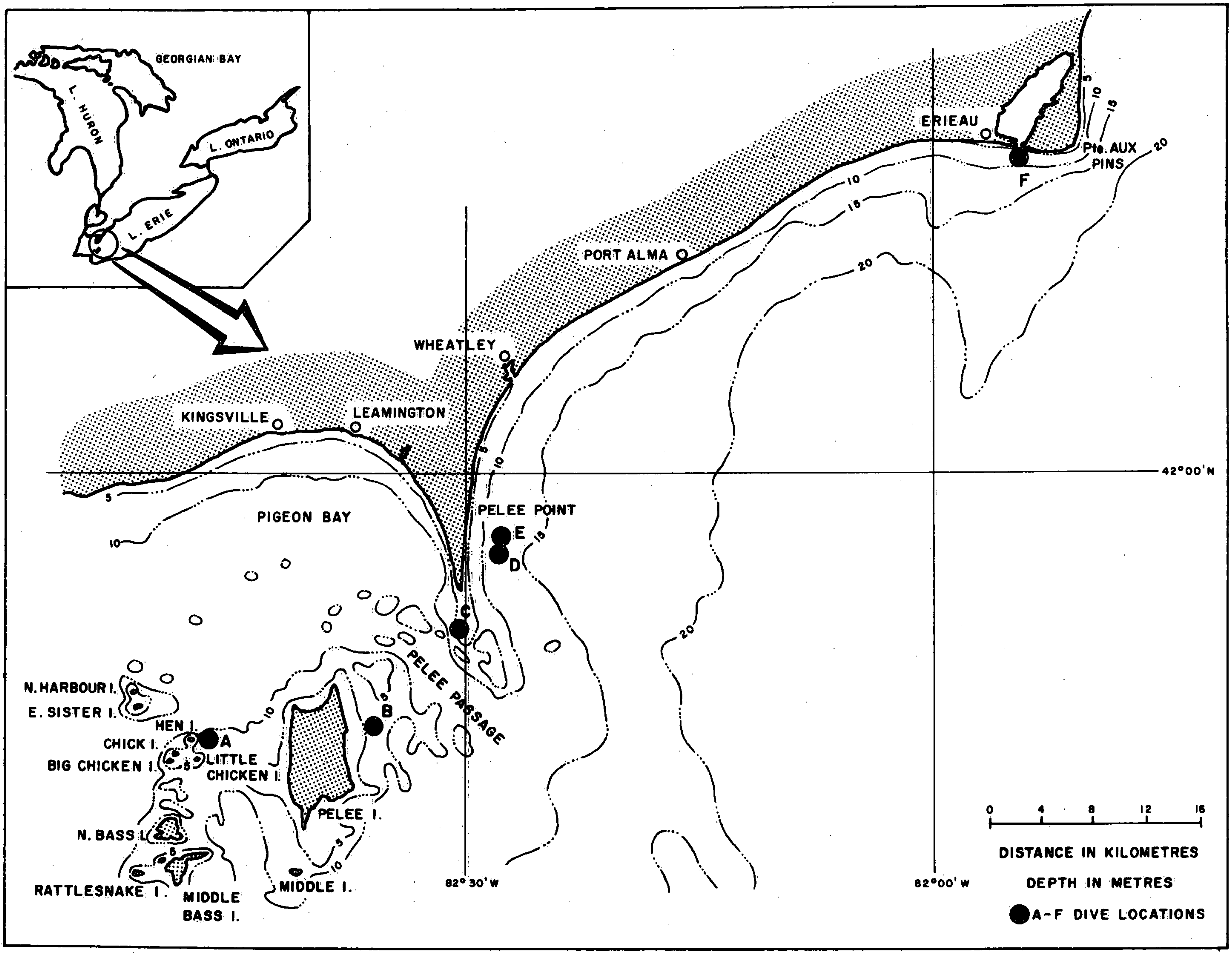


Figure 2. Map showing submersible dive locations, Lake Erie.

(9) A study, in detail, of the facies and lithological characteristics of the exposed bedrock, its weathering and erosional features, and the major physiographic features as observed on an underwater scarp face (C.F.M. Lewis and B.V. Sanford - May 16, part completed).

(10) A study of a deep channel and its physiography and erosional features as they relate to its possible origin in the form of a low lake level discharge channel (program cancelled).

Lake Erie

(1) A study of the environmental conditions of the lake bottom, with particular reference to sensor studies and an investigation of the presence of any bottom fauna (S. Nepszy and J. Leach - May 20, J.R. Coleman and J. Leach - May 20, P.G. Sly - May 21, N. Burns and others - May 22).

(2) A study of the habitat of the Walleye (S. Nepszy and J. Leach - May 20, J.R. Coleman and J. Leach - May 20).

(3) A study of the sediment and bedrock relationships, bottom structures and erosional features (C.F.M. Lewis and P.G. Sly - May 20).

(4) A study of the outcrop and occurrence of peat deposits (C.F.M. Lewis - May 21, J. Terasmae - May 21, part completed).

(5) A study of the difference between shallow seismic profiling using source and receivers close to the sediment/water interface, as opposed to "near surface" propagation and recording (program cancelled).

(6) A study of bottom sediment types and, in particular, sand wave structures, located by previous surveys (W. Ellicott and B. Blanchard - May 21, part completed).

THE SUBMERSIBLE OPERATIONS, AS CONDUCTED

Transportation and Handling

It was originally intended to transport *Pisces III* by air, from Vancouver to Toronto, on May 2 or 3. However, final arrangements were made for *Pisces III* to be landed from a Hercules transport at Trenton Air Base, where re-assembly facilities would be immediately available on May 1.

From Trenton Air Base, the submersible was transported, by road, to Tobermory. During transit, however, the sub shifted slightly on its cradle and sustained damage to the drop weight mechanism. It arrived in Tobermory on May 6. The submersible underwent extensive repairs and replacements (including repair to the drop weight mechanism, replacement of ballast bags, repair to mechanical arm, attachment of increased buoyancy and installation of additional equipment). The tracker launch arrived by road trailer on May 7 and the *Lac Erie* and barge (delayed by poor weather) arrived on May 8.

On May 11, despite additional problems and a faulty charger bank for the submersible's batteries, diving operations commenced at 2150 hrs., nearly 3 days later than originally planned.

Abbreviated Dive Log

The following account consists of slightly edited versions of the original log sheets which were completed in regular debriefing sessions after the end of each dive. Metric equivalents have been given which replace non-metric values that were recorded in the original log sheets. The log sheets show that little of the original program planning could be adhered to. Figure 3 summarizes, in graphic form, the complete submersible operation.

Georgian Bay

May 13

A.R. Emery (Ontario Department of Lands and Forests) and L.H. Somers (University of Michigan). Started dive at 2150 hrs. Sub towed to entrance of Big Tub Harbour (location B on Figure 1) by the launch, *Bruce*, released and set course at 330°t. Dive aborted after port motor siezed at 2250 hrs. Sub towed back to barge and lifted aboard. Trouble found to be a rope caught up in motor, apparently inside the gear box. This was the same piece of rope which had been fouled in the Little Tub Harbour during earlier trials; it had obviously not been completely removed. Dive recommenced at 2335 hrs. at approximately same location as that at which dive had been aborted. Changed course after about 15 min. to compensate for strong current, changed to 020°t. Continued on 020°t for about 150-200 m and then adjusted course to 340°t. Water turbid, maximum horizontal visibility about 3 m, yet surface tracking launch reported that the lights of the sub were easily visible at the surface, 26 m above. Most of the bottom appeared to be a flat silty plain (at a depth of 24-30 m), devoid of weed cover. A few outcrops of pitted limestone were noted. Fish were abundant, including smelt, sculpin (2 species), alewife, crayfish (1 specimen), perch and others. When stopped or stirring up the bottom, mysids and insect larvae were visible everywhere. Fish were always in sight and population counts varied from 2-3 per m^2 to 20-30 m^2. Several dead suckers were observed. The current (at bottom) was estimated at 2.5-4 cm per sec. Sub continued on course until approximately 50 m southwest of Doctor Island; it then changed course for North Point at the entrance to Tobermory Harbour. Sub surfaced about 450 m east-southeast of Doctor Island (location C on Figure 1) and was towed back to the barge by the *Bruce*. Dive completed 0200 hrs. Observers commented about poor lighting on sub and reflections off bright work and aluminum fittings. Vertical buoyancy control was noted as very poor. Sub temperature (inside) at start of dive 5°C, at finish 1-2°C. Surface conditions during dive were estimated at: sea state - 1, wind force - 1, direction - northeast, air temperature - low, 6-7°C.

May 14

G.H. Goldsteen (Canadian Hydrographic Service), J.F. Freener (Canadian Hydrographic Service). Dive started 1211 hrs. Trouble in staying down, ballasting problem, maneuverability poor, surfaced involuntarily at 1222 hrs. Dive recommenced, on southeast edge of Russel

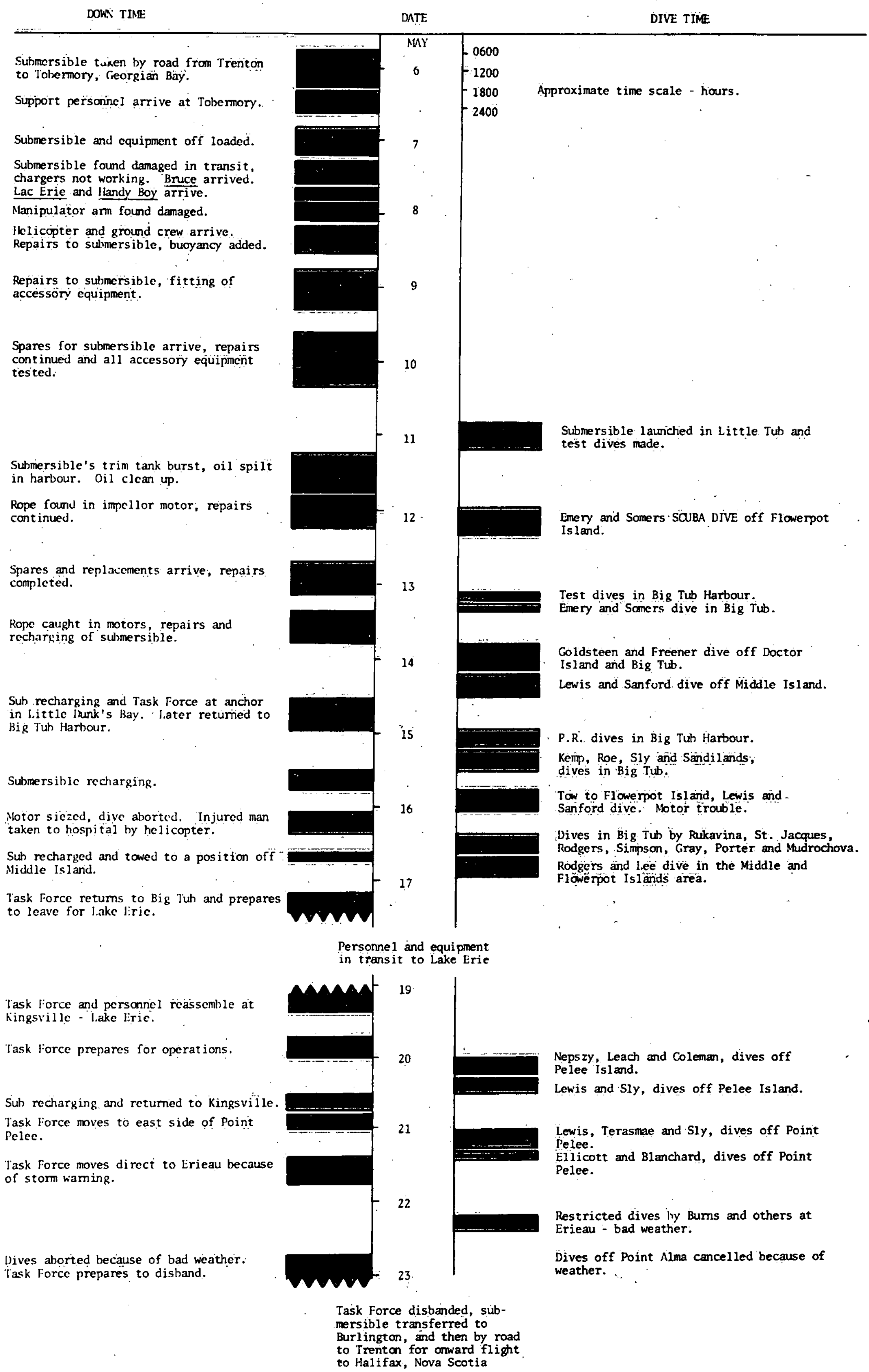


Figure 3. Summary of complete submersible operations.

Island Shoal (location A on Figure 1), at 1238 hrs. Personnel accidentally released too much cable on the acoustic transmission (transponder) cable (on the launch, *Bruce*), it was cut by propellors of the *Bruce*. *Lac Erie* brought in spare transponder and cable. Dive continued until about 1400 hrs. The *Bruce* then towed the submersible back to the Big Tub Harbour. A dive on a wreck at the western end of the Tub (location B on Figure 1) was commenced at about 1555 hrs. This terminated at 1649 hrs. Visibility was again poor in all areas 3 m or less. A well marked east to west current, flowing at about 25-40 cm per sec. was noted at a depth of 26 m, southeast of Russel Island Shoal, missed intended site, and sub also proved difficult to maneuver. Apart from the fact that the range of visibility was greatly restricted, the lack of all around view ports and the lack of visibility when at the surface made observations very difficult. The upward curvature of the skids appeared to be insufficient and they became partly entangled with a wreck in the Big Tub. During the whole dive, only 2 or 3 sculpins and 1 crayfish were observed. In the Big Tub, fine sand was observed in patches between weeds and weed covered boulders. Observers were briefly affected by the CO_2 scrubber and initially felt cold. However, at the close of the dive period, comments came to the effect, "...began to like it, bit cramped, no closed-in feeling, if only I could have seen...". Temperature at start of dive (inside sub) 8°C, at finish 5°C. Surface conditions: sea state - 1-2, becoming 2 or greater, wind force - 1-2 and becoming 2 or greater, wind direction - northeast, air temperature - 12-15°C.

May 14

C.F.M. Lewis (Geological Survey of Canada), B.V. Sanford (Geological Survey of Canada). Dive commenced at 1930 hrs. and descent took place just south of Middle Island (location E on Figure 1 and Figure 4). Sub traversed continuously on a course of 156°t and covered a distance of approximately 590 m. Visibility at 30 m depth was about 5 m without the sub's lights and about 4 m with them; this condition persisted throughout the dive. Very considerable problems were encountered with ballasting and trim but, once on bottom, sub was able to control height above lake bed and to retain about 80 per cent (time) visual contact with the bottom. The sub was used to investigate the outcrop of what appeared to be thin, platey, shale beds (in appearance, like varved clays). On detailed investigation, the outcrop appeared to be thinly bedded dolomite (rusty coloured) probably associated with the Eramosa formation. The manipulator arm was used. One of the connector cables came away from the manipulator control switch; fuses and repair parts were not immediately available and further use of the manipulator was abandoned. Traverse continued. The bottom was covered with a veneer of pebbles, cobbles, boulders, and blocks of carbonate and Precambrian material. A "ridge" and "low" structure appeared to be developed in places, frequently with sand patches in the "lows" (up to 6-7 m across). Linguoid ripples were noted in places, and also scouring around one boulder, near the island, in 30 m of water. Considerable fauna were noted including: sculpins, smelt, "fingerlings" (?), and crayfish. An old style beer bottle and a beer can were also recorded. There was no clear evidence of any sub-aerial erosion (which might have been expected since, at one time, lake levels were considerably lower). The more massive dolomitic limestone blocks (and outcrops ?) appeared to be deeply pitted and "vuggy". A continuous east-west water flow was noted at all depths (probably less than 10 cm/sec.). Surface wave action appeared to cease at a depth of about 6-7 m. The sub traversed at a forward speed estimated at 0.9 km/hr. The dive was completed at about 2230 hrs., and the sub was then towed back to the barge by the *Bruce*. The temperature inside the sub at the finish of the dive was about 3°C. Comments were received about "kinks in

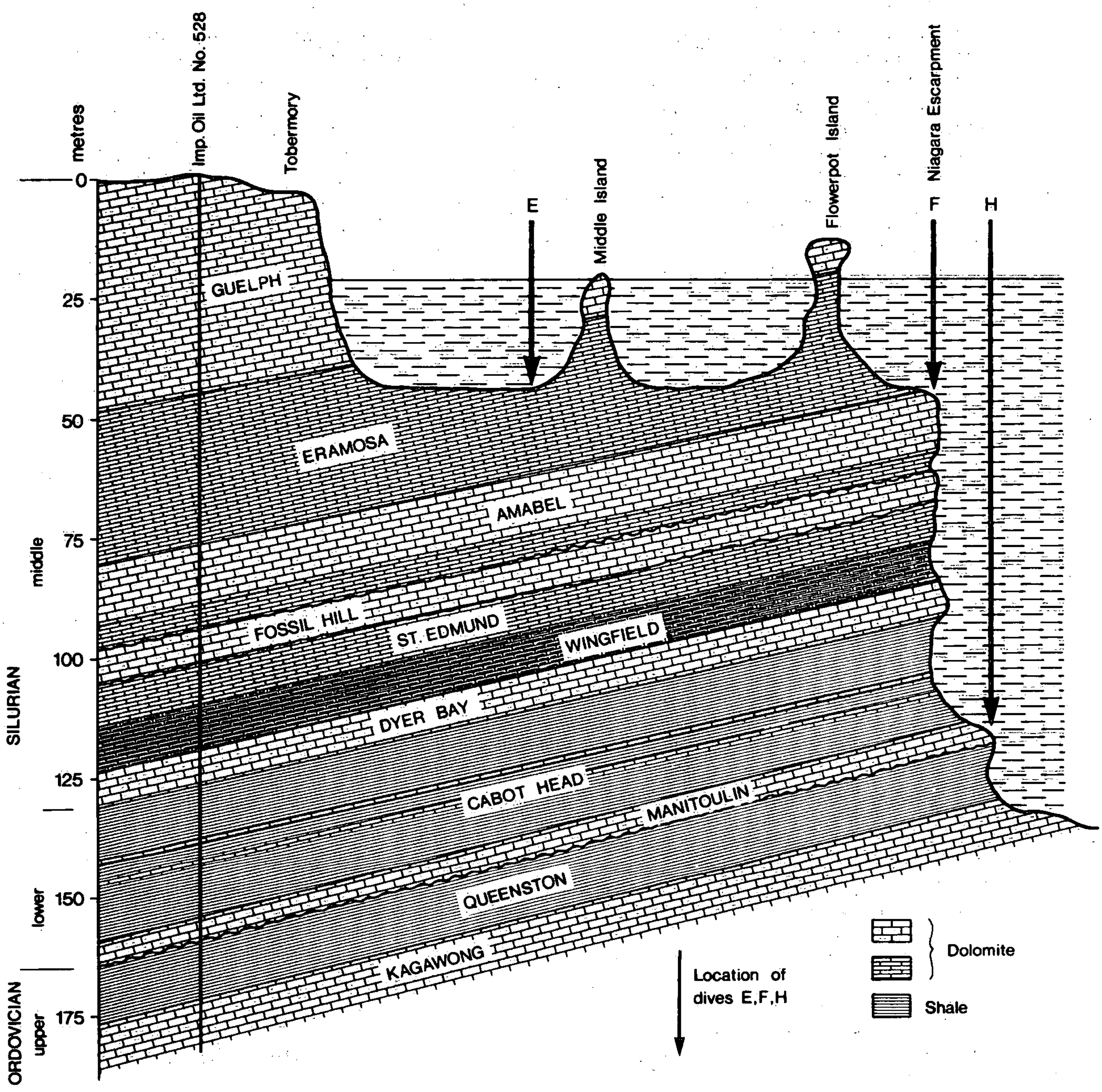


Figure 4. Diagrammatic section across the Bruce Peninsula and adjacent Islands showing relative location of dive sites E, F and H.

the neck and back", from both observers and the pilot. Much of the observation had been done, viewing in a prone position. At the start of dive, sea state was estimated at 1-2, wind force 1-2, and direction east-northeast; by the end of the dive, sea state was greater than 2, wind force about 2-3, and direction northeast.

May 15

P.G. Sly (Canada Centre for Inland Waters), J.T. Roe (Canada Centre for Inland Waters). Dive in Big Tub Harbour, down at 1100 hrs. Sub went down approximately 50 m off the Big Tub lodge and dock. Visibility about 3 m (horizontally) in 15 m of water. Bottom undulating, of soft sandy silt. The surface colour was pale yellowish grey, but at a depth of only 2-3 mm below the surface, the colour changed to grey. Chara weed growth was well developed and covered probably 40-50 per cent of the bay floor. Small lamellibranchs, crayfish, mysids and sculpins were evident. There were many bottom tracks (probably lamillibranchs). There was also much suspended "floc" material and many small dead crustaceans in the water column; presumably this was related to the effects of some recent seiche conditions and intrusions of deep, cold water in the Tub. A forward traversing speed of about 0.6-0.9 km/hr. was found to be optimum for this survey work; it allowed a fair rate of progression and yet did not blur observation. The shear limestone walls of the Tub appeared to be deeply pitted and a rusty brown in colour (as noted by earlier observers). Colours under conditions of ambient lighting (the quartz-iodide lamps of the submersible had no noticeable effect) appeared: lime-green for the water, pale lemon-yellow for the sand, rust-brown and blotchy-grey for rock outcrops and "stoney" material. The manipulator arm was operated very effectively, enabling selective sampling of pebbles, the turning over of cut timbers (waterlogged), and scooping-off of the surface to show the micro-structure of the sediments. However, unless the submersible was actually sitting on the bottom, forward movement of the arm badly affected fore and aft trim. Throughout this dive, lateral maneuverability was good, but vertical control was very poor. Temperature in the cabin at the start of the dive was 8°C and 4°C at the finish; neither observer noticed any discomfort. The dive terminated at 1145 hrs. Local conditions during the dive: sea state - 1, wind force - 3-4, direction - northeast.

May 15

1200 hrs. to 1730 hrs. repeated, short distance and shallow water dives, with members of the press and television, and invited guests, in the Big Tub Harbour.

May 15

A.L.W. Kemp (Canada Centre for Inland Waters), R. Sandilands (Canada Centre for Inland Waters). Dived at 1925 hrs. in Big Tub Harbour, in same general area as other dives on this date. The wee cover (chara) observed during this particular dive was extensive, with only a few small (open) patches of flat sandy material. The grain size of the bottom material could not be distinguished from within the sub. The manipulator arm was pushed into the bottom to observe sediment structure and variations. Clouds of fine "floc" silty material went into suspension but cleared quite quickly; a clear east to west flow existed in the Tub, near the bottom. Again, numerous small fish, sculpins (and probably smelt) were observed. A series of irregularly-spaced depressions, about the size of a half dollar (and roughly polygonal) were noticed in many "sandy" patches and near the edge of the weed cover. Later, comment suggested that these might have been formed by crayfish. Despite the fact that the retrieval basket was poorly placed, a large limestone boulder (about 30 cm x 45 cm x 1.5 cm) and weighing 16 kg (in air) was "prized" out of the bottom sediment and lifted into the basket with the manipulator arm. In one place, an old gill net was observed, still with some dead fish caught in the mesh. Some of the floats were collapsed. At the sides of the Tub, a well-marked notch appeared to be "cut" into the limestone face about 30 cm above the lake bed; this notch persisted (irregularly) for some distance. R. Sandilands took a number of photographs (still and movie) of the operations from within the submersible. Impressions commented upon by the observers included a high degree of satisfaction with regard to the horizontal maneuverability of the sub, and the use of the manipulator arm. There was, however, poor visibility from the submersible, and the skids, if they "grazed" the bottom, tended to stir things up and put material into suspension very rapidly. The observers were warmly dressed and comfortable but suffered from some urinary pressure near the end of the dive. The CO_2 scrubber produced a slight "tickling" sensation in the throat when in use. Surface conditions throughout the dive were noted as calm. The dive was completed at 2140 hrs.

May 15

J. Terasmae (Brock University) and J.C. Lewis (Brock University). Dive in Big Tub Harbour, dive started 2200 hrs. Noted five distinct bottom types: (1) chara (weed) in patches but with no apparent organization; (2) coarse and fine gravel (near the sides of the Tub); (3) sand (in a narrow band at the foot of the rock wall forming the sides of the Tub); (4) the rock wall; and (5) areas of large scattered boulders. Beer and coke bottles were noted in several places but they were not deeply buried. Additional observations included: mating (?) crayfish of various bottom types; many fish (sculpins, sticklebacks, and at least five other species); many crustaceans in the water column (gammerids). The pitting of the limestone surface forming the rock walls was very selective and was probably related (in depth and size) to the slight differences in rock type (carbonate content). Several comments were made with regard to the poor layout of the various internal controls on the submersible, and again with regard to the difficulties experienced in maintaining vertical control. The manipulator arm was tried out and some photographs were taken from inside the sub. Surface conditions throughout the dive, were calm; the dive terminated at 2330 hrs. The observers noted that they had felt some effect from the CO_2 scrubber and the cabin space was too cramped (particularly with the view ports placed as they were).

May 16

C.F.M. Lewis (Geological Survey of Canada) and B.V. Sanford (Geological Survey of Canada). Dive commenced at 1028 hrs. at a site approximately 300 m north of the point between Little Cove and Driftwood Cove, on the north shore of the Bruce Peninsula (location H on Figure 1 and Figure 4). The echo sounder of the tracking vessel registered 120 m depth; the submersible "bottomed-out" at 117 m at 1034 hrs. Both observers sat on starboard side during spiral descent and trim adjustment. Course set at 190°t to traverse from deep to shallow water and to look for the ancient submerged shoreline of Lake Hough (Lewis, Tovell, McAndrews, 1971). Sub descended smoothly and did not sink noticeably into the soft layered glacio-lacustrine sediments (as recorded on the MS26 echo sounder on the *Bruce*). The bed material appeared to be flat and composed of a uniform fine silt which could have been easily stirred up. Only a small amount of particulate matter was visible on the bottom (both large and small particles), and no unidirection flow was observed at the bottom. An excellent descent; however, the dive was aborted at 1055 hrs. because "a gurgling sound was heard in the port motor"; the port motor was not drawing full current at full speed and motor flooding was suspected. Surfaced at 1100 hrs. Sub towed back to barge for repair 1137 hrs.

May 16

N.A. Rukavina (Canada Centre for Inland Waters) and D.A. St. Jacques (Canada Centre for Inland Waters). Observers dived at 1545 hrs., in the Big Tub Harbour again, as soon as the port motor had been replaced. This dive again suffered from the excessive time required to ballast the submersible. The manipulator arm was used to pick up items on the bottom, and to assess its dexterity. The manipulator arm was accidentally ejected during this work and a small oil loss occurred at this time. A diver recovered the arm which was later re-fitted at the surface. N.A. Rukavina anticipated suffering from claustrophobia in the confined space; however, immediate interest of the surroundings and play-back from a portable stereo tape recorder with the sub put him completely at ease (the calming effect of the music should not be overlooked; it was remarked upon by several observers, and clearly eased the tension produced by the number of failures and long ballasting periods which so plagued the dives). Internal condensation and the fogging of the ports were bothersome during much of this dive. It was terminated at 1650 hrs. Surface conditions, as with the morning dive, were ideal...calm. Additional comments were mostly "in line" with those made by earlier observers in this area.

May 16

G.K. Rodgers (Great Lakes Institute - University of Toronto), W. Simpson (Great Lakes Institute - University of Toronto). Dive in Big Tub Harbour at 2100 hrs. During this dive, use was made of the sensors mounted on the boom extension on the port side of the submersible. These included a current meter, a DO sensor, Eh and pH sensors, and a temperature sensor. Use was also made of a small bag of dye, from which about 10 cc shots of liquid were ejected by squeezing it with the manipulator arm. It had originally been intended to move the boom up and down (through a vertical arc of about 20°), using the manipulator arm as a lever. This was not possible. It was found that, because of the way in which the lever bar on the boom had been temporarily fitted, the manipulator arm could not quite reach it (about 2 cm short). In order to raise or lower the boom head, therefore, the whole submersible had to be trimmed fore and then aft...a very time-consuming operation. Within the Tub, it was found that the temperature profile only varied by 2°C and that the DO (set at 10 ppm at the lake bed) only varied by 5 ppm. Photography of the dye release sequence was quite successful, and the release was well controlled using the manipulator. Comment was made, however, that a dark patch had been seen at the surface before any dye release had been attempted. The dye release was surprisingly successful, despite the restricted view of its dispersion from the low angle ports. Visibility was estimated at 3-4 m. Many fish were observed during this dive, including schools of minnows and both live and dead crayfish were seen on the bottom. Many suggestions were made regarding the improvement of *in situ* recordings. The dive terminated at 2245 hrs.

May 16

T.R. Porter (Ontario Department of Lands and Forests), C.B. Gray (Canada Centre for Inland Waters). Dive at 2300 hrs. in the Big Tub. During this night dive, the effects of the submersible on fish behavior was noted. Some species of fish were attracted by the lights. The movements of the manipulator arm, and mechanically-induced sounds, however, tended to scare the fish away (temporarily). The main comments made were that the submersible made a very excellent place for observing fish behaviour and that because of its added mobility and the manipulator arm capability, it had great potential in terms of observing and sampling the biotic environment. It was also felt that the submersible might provide a good way in which to study the various processes of sediment bioturbation. The Big Tub, however, did not appear to be a good location for this, at this time.

May 16

A. Mudrochova (Canada Centre for Inland Waters). Dive 2400 hrs. to 0100 hrs. in Big Tub. Much the same comment made, as in previous dives in this area. The manipulator arm was used very successfully to pick up many selected pebbles and small cobbles, partly exposed, on the surface of the bottom sediments. Many of the pebbles were probably deposited during the spring thaw of ice-rafted land debris.

May 17

G.K. Rodgers (Great Lakes Institute, University of Toronto), A.H. Lee (Great Lakes Institute, University of Toronto). Dive site, midway between Middle Island and Flowerpot Island (location F on Figure 1 and Figure 4) in water depths ranging from 27-40 m. Dive commenced at 0930 hrs., intending to locate the anchor block of a dye release buoy. Submerged about 50 m west of marker buoy. Descended to 33 m when sensor boom hit scarp, came to rest at 40 m on a ledge (?) covered with silt. Horizontally-bedded limestone was exposed in the scarp face which appeared to overhang. The sub rose slowly up scarp and then traversed towards buoy. Massive and thick bedded limestone was seen, overlain by thin beds at a depth of about 33 m. The echo sounder on the *Bruce* showed a shear rock face 24-100 m in this same area. "Weeds" were recorded as growing at a depth of 27 m but no fish were seen. At a depth of 23-27 m, large dolomitic blocks and boulders, up to 0.6 m across were recorded, all deeply pitted. A "highly weathered" bedrock surface was believed to be exposed near the buoy at a depth of about 23 m ("spikes" between surface weathering pits were exposed in patches through a very thin veneer of silt). The marker anchor was easily found, with aid of surface directions, although the bottom visibility was only 3-4.5 m. Little turbidity was evident except that caused by the sub and the anchor block; there was no visible evidence of recent currents. The current meter needle jammed, and so the rpm of rotor was counted. Photographed block and line. The sub then moved up and down the line but had difficutly in estimating where, along it, it was (no reference points). Dye is normally released (sub-surface) by the up and down (wave induced) motion of the buoy ...the sub became involved in a dye release and may also have fouled the marker buoy line. After retrimming and ballasting, the pilot took the sub to the bottom and rose, filming again. The crew surfaced from dive at about 1200 hrs. and was then towed to Flowerpot Island, to be taken on board the barge. Although one of the observers was initially warm, both ended up with cold feet. At the start of the dive, surface conditions were nearly calm but at the end of the dive, sea state had increased to 1-2, wind force to 3, and wind direction was westerly. K. Rodgers commented, again, that the dive was remarkably successful considering the lack of good visibility through the ports and the possible effects of the mass of the submersible itself on the dye release and dispersion.

After the completion of the dive by G.K. Rodgers, the submersible was secured to the deck of the barge and all other equipment was made fast. The tug, barge and submersible, left for Lake Erie on the evening of the 17th and arrived at Kingsville in the afternoon of May 19. All other personnel and equipment transferred from Tobermory to Kingsville, by road, and were also re-established by the evening of the 19th.

Lake Erie

May 20

S. Nepszy and J. Leach (Ontario Department of Lands and Forests). Dive commenced at 1300 hrs., approximately 0.8 km east of Hen Island in the Bass Island area (location A on Figure 2). External water temperature was recorded at 15°C, none of the occupants felt cold during the dive! Submerged in about 10 m of water, visibility was about 1 m (horizontally) at the bottom. The sub remained stationary allowing maximum clearance of particulate material. An 0.6 cm thick layer of organic material was observed to cover the bottom like a mat. The manipulator was used to "punch" into this. On lifting up the arm, the "mat" parted and exposed underneath, a fine sandy gravel of an undetermined thickness. The "mat" fragment was lost during the dive but it is most probably that it was part of a submerged peat deposit. Where covered by loose sediment, the bottom was rippled (l = 10 - 14 cm, h = 1 - 3 cm). Large, dead lamellibranch shells and separated valves lay scattered randomly over parts of the bottom, often with patches of stoney material. Much organic material was noted in suspension and an east to west flow, at the bottom, was estimated to be at a rate of about 25-40 cm/sec. Orbital motion of particles in suspension, related to wave action, ceased at a depth of about 2 m. The sub hit an unseen object during the dive (probably a rock) but no damage was discovered. No weed growth or fish were seen. The observers (familiar with the area and weather) felt that conditions were optimum and said that the water rarely became any clearer. The vast quantities of organic material (planktonic and detrital) were a great surprise to the observers...they had not believed that so much was present in suspension. Several ambient light value readings were taken (using a Weston Master II light meter) to show the decrease in ambient light with depth. The submersible lights were ineffective even at 11 m depth because of high and diffuse, background levels. The dive was terminated at 1630 hrs.

May 20

J.R. Coleman (Ontario Department of Lands and Forests) and J. Leach (Ontario Department of Lands and Forests). Dive site approximately 0.5 km east of Hen Island in the Bass Island area, submerged at 1635 hrs. Both observers were, again amazed at the sheer quantity of material seen in suspension (mostly organic)...the medium looked a bit like a "split-pea soup". The observers felt that even under such conditions, the sub could be of considerable use. By remaining still on the bottom and using some form of a sensor, to detect fish, it should be possible to study their behavioral patterns. This would be much more suitable than the present use of high level illumination, which so disturbs fish habits. It was also felt that by "tagging" the fish (acoustically or by using some other means) it would be possible to follow fish movements from their introduction or during their spawning....and to stay remote (at a short distance), so as not to affect the behavioral environment. It was also noted that it would be highly desirable to use the submersible to follow trawl nets and thus assess the effect of them on the lake bottom and the fish, themselves. With regard to water quality sensors, it was felt that a combined chart and direct reading "all immersed" package, which could be used either by divers or viewed from inside a submersible, would be better than the presently installed system requiring through-hull penetrators. It was also noted that the "through-hull" direct sampling system would be potentially of great advantage. One of the observers commented that studies of seawater plankton (species identification) in some Scottish lochs, using a submersible, had been unsuccessful; he did not think that similar studies in the Great Lakes would be any more likely to succeed. The dive terminated at 1415 hrs., during which time, a couple of dark shadowy objects (about 15-30 cm long) were seen - presumably fish, near to the maximum range of visibility from the submersible.

May 20

C.F.M. Lewis (Geological Survey of Canada), P.G. Sly (Canada Centre for Inland Waters). Dive at 2105 hrs., on the east side of Pelee Island, about 1.9 km east of Middle Point (location B on Figure 2). The temperature inside the sub remained warm during all of the dive, probably helped by the port motor switch, which was running hot. During this dive, the tracking launch, *Bruce*, was not available, and so a small rubber boat from the *Lac Erie* was used as a surface tracker; the submersible surfaced every 30 min. for a visual check and for radio contact. The *Bruce* arrived on site about 1 hr. after the start of the dive, and then took over surface tracking. Visibility from the submersible was estimated at 1-3 m near the surface, and 1 m at the bottom (in about 11 m of water). The bottom appeared to be generally flat, covered by fine silty sand and with varying (small) amounts of organic detritus. It was very difficult to observe the bottom, and the loose sediment veneer may well have overlain a "ridged" till. The observers explored by randomly sampling with the manipulator arm while moving shoreward on an approximately east to west traverse line. Penetration to a depth of 5-8 cm was usually possible, and items were brought up to the view ports for examination. During these exploratory samplings, pebbles and lumps of till (?) material were recovered. One pebble was inspected (underwater) and "pronounced" to be a manganese nodule; on surfacing, it was more closely viewed and was indeed found to be Fe/Mn coated, although not a nodule. This pebble was about 0.8 x 2.5 x 4 cm in size and was mostly buried in the sediment. The ability to make a "reasonable" identification of specimens while under water, was assuring. Vast numbers of fish were seen during the dive, mostly 6-9 cm in length, while larger fish (up to 15-22 cm) appeared to stay at the limit of visibility; this may have been an optical illusion but the observers felt that, in general, the estimate of size was correct since these larger fish occasionally came closer to view. Visibility tended to be better with 1/2 power lighting (from the submersible) rather than with full power. In addition, both the number and variety of fish tended to reach a maximum with half, rather than full power lighting. Suspended material, in general, appeared to be "stringy" and "shredded" and it was usually a light greenish-grey in colour. Several chironomid larvae were noted, and it was estimated that zooplankton probably represented 5-10 per cent of the fine suspended material (with half power lights and with a good background of some of the equipment on the sensor boom; the fine material was quite easy to observe). The observers also noted that it was essential, to view particulate motion from both side-ports simultaneously so as to estimate the rate and direction of "flow", because of the "parting" effect of the fore-part of the submersible. Both observers felt that much improved visibility (particularly of the bottom) could have been possible, despite the high content of suspended material, if optimum lighting and filters had been available. The dive was completed at 2305 hrs. During the whole day, the sea and weather conditions had remained roughly the same: sea state - 1-2, wind force - 1-2, and direction - easterly.

May 21

C.F.M. Lewis (Geological Survey of Canada). Dive started at 1300 hrs. at a location approximately 1.5 km east of the east beach of Point Pelee and opposite the boat ramps about 2-3 km north of the tip of Point Pelee (location D on Figure 2). During this dive, the underwater television system was used; it was found to be operating improperly and to be suffering from several forms of interference. Only one observer was able to dive in the submersible because of the added weight of the television system. Visibility was estimated at about 1 m near the bottom. The submersible descended, after overcoming many ballasting problems (and a diver cutting loose one of the added buoyancy tanks) in 11 m of water. The cloud of sediment stirred up by the skids, on grounding, cleared quickly, but the bottom was not really visible at any time, from the submersible. During this dive, conditions were calm and the temperature of the water was about 16°C. Both occupants (pilot and observer) of the submersible were soaked when opening the hatch at the end of the dive ...a surface transfer was made at about 1410 hrs. Despite the rather "amateur" results obtained, using underwater television, there can be no doubt at all as to its very real value. These tests were considered to be most successful. The dive was terminated at 1530 hrs., still with calm surface conditions.

May 21

J. Terasmae (Brock University). The dive began at 1415 hrs., about 2-2.5 km off shore of the boat ramps, on the east beach on Pelee Point (location E on Figure 2). During the surface transfer of personnel, more water splashed inside the submersible, from water caught in the sail. The temperature remained at about 18°C throughout the dive; roughly the same as the temperature of the surrounding water. The underwater television was not used in this dive, and visual observations were made with the sub trimmed forward. At this angle, the crew cabin was brought closer to the bottom. A firm, smooth, silty clay bottom (free of pebbles) was observed, with a thin veneer of sand. This sand was rippled (l = 14 - 28 cm, h = 7.5 - 10 cm (?)), trending parallel to the shore. Visibility at a water depth of about 13-15 m appeared to be about 2 m; probably the best encountered anywhere in Lake Erie, during these trials. The dive was completed at about 1500 hrs.

May 21

P.G. Sly (Canada Centre for Inland Waters). The dive commenced at about 1500 hrs. in 11 m of water off the east beach of Point Pelee (location E on Figure 2). The sole intention of this dive was to operate the underwater television system and to see what could be viewed on the monitor screen, that could not be seen from inside the submersible. Eventually, with most of the sub's electrical systems shut down, the interference patterns were reduced to an acceptable level. In addition, a problem with the operation of the video tape recorder was isolated and corrected sufficiently to make the system work - although not perfectly. Results were amazing! Using only ambient lighting (the sub's lights had no apparent effect), a pebble strewn fine sandy bottom was clearly visible on the monitor screen. Ripple marks (l = 10 - 15 cm and h = 1 - 2.5 cm) were noted, together with what appeared to be a few fragments of till material. Shell fragments and possible "lamellibranch tracks" were also visible. Absolutely nothing of the bottom was directly visible from within the submersible! At this time, the manipulator arm was also used, visual control being maintained by following the movements on the television monitor. This system of operation with the manipulator arm appeared to be most successful, the opening and closing of the jaws, the attitude and tilt and the extension, all being easily viewed. Unfortunately, because of the way in which the television was mounted, it was not possible to view, close up, the pebbles picked up by the manipulator. The television was operated at a distance of 15 cm to about 45 cm off the bottom. During the replay of the tape, several images were held "frozen". They were certainly not as clear as they had appeared in the "continuous play". The rapid strobe effect produced by the picture scanning of the "continuous play" seemed to act, visually, to clarify the picture (similar perhaps to an image intensifier).

May 21

W. Ellicott (National Sand and Material Co.). This dive began at about 1710 hrs., just southeast of the crib buoy at the southern end of Pelee Point (location C on Figure 2). The temperature inside the submersible was warm at the start but became chilly and cold towards the end of the dive. Again, because the television equipment remained mounted on the sub, only one observer could dive at any one time. Bottom visibility was estimated at 1.2 m, but because the light cover had been accidentally left on the TV camera, the TV system was inoperable. The submersible "sailed" over a rippled, fine sandy bottom (l = 15 cm, h = 2 - 5 cm), and a few large cobbles were seen, though no fish. The manipulator arm was successfully used to sample the bottom several times. The material, which was then brought into view in front of the ports, was easily identified (though in a cursory fashion). The sub traversed from a point approximately 50 m north of the crib buoy to a point about 50 m north of the crib; a surface transfer was made at 1810 hrs. Weather conditions at this time were deteriorating, a sea state 1/2 and a wind force of 2, from the southeast, were recorded.

May 21

B. Blanchard (National Sand and Material Co.). This dive was intended to continue on from that of Mr. Ellicott after a surface transfer. The sub was towed by the *Bruce* to a point about 100 m southeast of the submerged crib, at the south end of Pelee Point. Despite continued attempts to submerge, from 1810 to 1845 hrs., the submersible remained too buoyant. The dive was eventually aborted, when it was clear that there was no possibility of success (unless the sub was given a full surface check-out, vented, and reballasted aboard the barge; a job which could take upwards of 4 to 5 hrs., even allowing for only a minimal re-charge).

May 22

Dives at Erieau (location F on Figure 2), during the late morning and early afternoon. The following report and comments have been abbreviated and edited after a report by N. Burns (Chemical Limnology Section of Lakes Division).

The party which I co-ordinated consisting of Dr. J.R. Kramer, Nels Conroy, Chris Guenther of McMaster University, K.O. Klaveno of FWQA, Cleveland, Bill Hunter of Ann Arbor, Michigan, and myself arrived at Kingsville, Ontario on the afternoon of Thursday, May 21. It was intended that a dive would be executed that night in the deepest part of central Lake Erie as the barge was enroute from Kingsville to Erieau, Ontario. In spite of the apparently good weather conditions, this major dive was cancelled because the tracking launch was short of gasoline, and a poor weather warning had been issued on the Mayfor broadcast. The next morning, May 22, the program was limited to three 10 m submersions 400 m due south of Erieau Harbour. This limited program was caused by a wind force of 4 which prevented the submersible from being lowered from or lifted onto the barge in an exposed area. The submersible, therefore, had to be towed out to the dive site from protected waters. It was possible, however, to perceive whether or not the submersible offered promise as a useful tool for Chemical Limnology. The main functions that a submersible can carry out, and which would be of use to a chemical limnologist are: (i) chemical profiling, (ii) interface sampling, and (iii) bottom inspection. Due to its comparatively large size, and the many protuberances about it, the submersible caused interference about itself, sufficient to disturb immediate chemical profiles. A bathyanalyzer or submersible pump would probably be capable of a much more precise sampling. The only advantage of the submersible appears to be that the electrical leads from the sensors to the recording instruments are shorter on the submersible than on a ship. A ship would also be capable of providing space for much more sophisticated recording equipment. With regard to interface sampling, the multiple-syringe sampler or corer with closing valve, or a bottom-triggered bottle, would all be capable of use from either a submersible or a surface vessel. Bottom inspection, in deeper clear waters, can best be carried out with a submersible. However, in shallower waters, less than 30 m and where most bottom activity occurs, bottom inspection may best be done by a free diver or diver on a towed sled. This is especially so in the case of more turbid waters, where the viewer has to be within 15 cm of the bottom.

May 23

All dives aborted because of unsuitable weather conditions. This day had been set aside for well-head inspections by members of the Petroleum Drilling and Production Section of the Ontario Provincial Department of Energy & Resource Management, off Port Alma.

The submersible operations were terminated at 1200 hrs. on May 23. The submersible was secured to the deck of the barge and all other equipment made fast. The tug, barge and submersible left for Burlington early in the evening of May 23. All other personnel and equipment also left Erieau at this time. The tug, barge and submersible arrived at Burlington at 1000 hrs. on May 25, having passed through the Welland Canal.

The submersible was brought ashore and disassembled for onward air transport to Halifax; it left Burlington at 1130 hrs. on May 26 for Trenton, by road.

ADDITIONAL REPORTS

After the completion of the submersible operations, additional reports and comments were received from some of the groups concerned. The following additional information (by order of program) has been abstracted and partially abbreviated:

Bedrock Observations from *Pisces III*, Georgian Bay - B.V. Sanford

Because of the vastly different weathering characteristics of the Paleozoic formations in southwestern Ontario, bedrock geological maps can be constructed of various parts of the Great Lakes by means of bathymetric charts and seismic (sparker) profiles. The extrapolation of geology from land into the offshore regions is feasible providing some form of stratigraphic control can be established on the lake bottom, either from drill holes or from first-hand observations such as from a submersible.

My participation in the recent diving trials of *Pisces III* off Tobermory, Ontario, in May 1970 was to determine whether useful observations could be made on the bedrock exposures beneath Georgian Bay and northern Lake Huron, sufficient to establish correlation with formations in the land areas of southwestern Ontario. It was an excellent location to conduct an experiment of this type because of the wide variety of Paleozoic rock units that are well exposed in the nearby areas of Bruce Peninsula and adjacent offshore islands. The area selected was in close proximity to a submerged segment of the Niagara Escarpment where it dips beneath Georgian Bay (see Figure 4).

Above the drowned escarpment and in water depths of less than 30 m, the Middle Silurian Eramosa dolomite forms the bedrock surface; this unit was examined at several localities. Bedding and weathering characteristics were clearly observable from the submersible and the formation was readily identified. Colour was one deceiving characteristic, however, particularly under the high intensity illumination from the submersible. The beds, normally consisting of dark brown and black bituminous dolomite, exhibited a distinct reddish cast that in combination with their thinly laminated character could have been easily mistaken for red Cabot Head shales, known to be present lower in section. However, solution pitting was very much in evidence and this is a common sub-aqueous erosional phenomena in carbonate rocks. An attempt was made to secure lithological samples of the bedrock, and a procedure was established for locking the visegrip jaws of the mechanical manipulator onto a fragment typical of the nearby bedrock. However, mechanical breakdown of the remote control device prevented us from securing any samples of bedrock whatever.

The Eramosa dolomite is known to be 30 m thick at the northern extremity of Bruce Peninsula as determined from a deep stratigraphic test well located two miles southeast of the village of Tobermory. An identical thickness was indirectly confirmed in the immediate offshore region of Lake Huron by G.K. Rodgers (personal communication) of the Great Lakes Institute of Toronto during his investigation of current movements southeast of Flowerpot Island. Following his dive (see dive log p. 15), Rodgers described an abrupt lithological break in Middle Silurian carbonate rocks at the crest of the submerged Niagara Escarpment, which could only have been the Eramosa-Amabel contact. This observation was made in approximately 30 m of water, and as the upper boundary of the Eramosa with the succeeding Guelph formation occurs at about lake level in several nearby islands (i.e. Flowerpot and Bear's Rump), the thickness of the Eramosa as established by observations from the submersible coincides very well with the known thickness of the formation.

The deepest dive of the trials was made off a point between Little Cove and Driftwood Cove about 5 km east of Tobermory. The dive was in approximately 117 m of water and located adjacent to the steepest part of the submerged Niagara Escarpment. Here we expected to encounter a complete succession of Lower and Middle Silurian dolomites and shales. The descent was made to a firm, uniform bottom composed of compacted light grey silt. The traverse towards the escarpment was begun but had to be terminated due to mechanical breakdown of the propulsion system.

Conclusions

As a result of the diving trials in *Pisces III*, it was established that useful bedrock observations can be made from a submersible; geological mapping techniques similar to those conducted on land can be applied in the offshore regions of the Great Lakes, particularly in Georgian Bay and Lake Huron where exposures will probably be encountered in considerable number. From the submersible it will be possible to map formational boundaries, measure rock successions and sample and establish correlation on a lithological basis with the formations on land. Once a gridwork of stratigraphic observations have been established offshore by means of a submersible, it should be a relatively straight-forward task to construct an accurate geological map of the lake bottom aided by detailed bathymetric charts and sparker profiles.

Although attempts were made during the diving trials to use *Pisces III* as a traversing vehicle to locate bedrock, it is doubtful if this particular vehicle is suitable for this purpose because of its relatively slow speed. Perhaps instead, probably bedrock sub-lake exposures could be located in advance by sparker profiles or from bathymetric charts, and the submersible be used specifically for diving to an individual outcrop. Once a section is examined, the submersible would surface and be towed to the next station.

Pisces III Submersible Operations in Georgian Bay - R. Porter

A high frequency noise was produced by the hydraulic system of the mechanical arm. This noise could be heard at the surface from a depth of 20 m. The noise disrupted the behaviour of the smelt and alewives that were schooling in front of the submersible. Bright lights scared away most larger fish before they could be identified. Several large perch were blinded by the light and remained motionless close to the bottom.

The submersible does not seem practical for the study of fish populations or species composition unless it remains stationary on the bottom with lights out. The submersible is difficult to stop in a short distance because of forward momentum and lack of visual contact (± 3 m was considered good). It seems that this submersible is not practical for undertaking a grid survey for a detailed study of bottom fauna due to maneuverability problems and because the sediment becomes stirred up while cruising close to the bottom.

ATTAINMENT OF OBJECTIVES

1. "...to attempt a number of different operational tasks directed at resolving a number of specific problems."

The different operational tasks, referred to in the above statement, are those same tasks outlined in the summary of proposed projects, pages 6 and 8. If the summary is compared and contrasted with the abbreviated dive log, the differences become obvious. It would probably be fair to say that not more than 20-25 per cent of the original program was attempted and of that only about half was successfully completed. This means that little more than 10 per cent of the original planning and project aims were actually achieved!

Three main factors were responsible for this: (a) Equipment failure (mostly related to the submersible). (b) Unfavourable and persistently poor weather conditions. (c) Insufficiently experienced personnel...expecting to do too much too quickly.

(a) Equipment failure continually plagued the operations...damaged drop weights, damaged manipulator arm and support struts, broken ballast bags, rope in the impellers, burned-out motors, non-functioning chargers, insufficient buoyancy, electrical interference, and shorting etc...every effort was made to overcome these problems, which stemmed from many causes. The principal one was that the submersible had been transshipped after months of continuous operation on the west coast, without receiving a full overhaul.

(b) For nearly three weeks before, and during, the diving operation in Georgian Bay, the wind remained easterly or northeasterly. It only rarely became light or variable during most of the workable time. A persistent "slop" and an irregular swell was almost always present, even during calm periods. It was impossible to launch the submersible or to undertake surface transfers of either crew or observer personnel, in unprotected areas. The weather also greatly impeded any operations involving the use of the barge crane (for over-side lifts), the *Bruce* for tracking (or towing), or the helicopter (for landings on the deck of the barge). Although, at no time was a storm condition recorded, the wind/wave action was more than sufficient to produce an excessive response in terms of vessel movement.

(c) There can be little doubt, "knowing what we do now", that the overall management of the program and the way in which individual problems were handled, could have been improved. At the time, however, what was lost in terms of efficiency, was also largely caught up with the aid of large "helpings" of enthusiasm. The points of most concern, here, however, were: (i) insufficient preparation, testing and evaluating of equipment (both the submersible and ancillary equipment), and (ii) a gross underestimation of the time required to move out to a dive location, submerge, make the required observation and return.

(i) Because of the time constraints of many contract operations, this problem is likely to remain a significant barrier to "immediate and reliable" operations, particularly if, because of limitations in funding, much of the ancillary equipment is supplied "in-house" by the leasee. Problems of mismatch equipment, different attachment points, separate control systems and interference (electrical and mechanical) can not be quickly overcome, particularly in field operations. It would be advisable, therefore, to ensure (as far as possible) that future contracts are "package deals" - with all required systems built-in when supplied by the contractor. The total system should be in proper operational order before being put into field use.

(ii) The program planners can be excused for their failure to estimate time requirements correctly. The weather was unexpectedly poor in the Georgian Bay area at the time of year chosen, and the repercussions of this on increased tow times, delayed transfers, and lengthy shipboard preparations could not have been fully realized beforehand. The greatest time losses were undoubtedly caused by the failure of the buoyancy and trim system of *Pisces III* to function properly under the demands of shallow, freshwater dives. Nothing in the planning would have foreseen this. Recharging, although this had been considered, would probably have proven to be another great "time waster" had not so much time already been lost in the ballasting and trim problems.

The original requests for a submersible, by Limnogeology, had specified the use of the vessel *Pisces I*. This vessel would almost certainly have proved more successful than *Pisces III* since it does not have the same type of problems to contend with, regarding the ballasting and trim systems, and because it operates with interchangeable batteries (thus allowing for one or the other of the battery sets to be on charge, at all times).

Despite the ways in which operations from the submersible were variously hampered, many of the dives were extremely successful, if somewhat limited. The most important results can be summarized as follows: (a) The ability of the scientist to observe the "living" environment, firsthand. (b) The ability to search, scan and selectively sample the bottom and to selectively retain or reject sample material. (c) The ability to install, test and observe equipment, and thereby to improve the design and operation of structures, floats, sampling equipment and sensors.

(a) There can be no doubt as to the value of *in situ* observations for both biological and geological research. The bottom in the shallow water areas studied (less than 100 m deep), was evidently much more variable than one was led to believe from the observation of a few bottom samples. The ecological relationships between the biotic communities and their host sediments are obviously both highly complex and interdependent. The studies of such relationships are of great importance, particularly with regard to the understanding of biological responses to environmental pollution and eutrophication.

Of particular importance were the specific observations on the characteristics and behaviour of the suspended material in both Georgian Bay and Lake Erie, the identification of bottom sediments, the recordings of bottom scour and sand ripples, the recording of weed growth (at depths to 27 m) in Georgian Bay, the recordings of partly buried artifacts (which can be used to estimate present sedimentation rates), and the comparisons of *in situ* observations with others previously obtained from similar sites by remote sensing/recording.

An immediate first impression and possibly a correct one is that these *in situ* observations suggest a much more complicated interlinkage of environmental systems than has been expected from the analysis of remotely sensed data. This is probably unavoidable because of the space/time restrictions imposed upon remotely sensed data and because of the fact that only selected parameters can be recorded. Undoubtedly, many more important physical and chemical interactions may take place which, so far, have not been fully appreciated. Direct, *in situ* observations may well place such relations in a better perspective.

(b) The observations made during selective sampling, scanning and searching were probably of greatest value. The abilities to search for and to identify lithological types, eg. Fe/Mn nodules or coated pebbles, to observe surface sediment layering (in considerable detail) and to locate and sample peat materials, are of great value.

(c) The value of direct underwater observations of equipment, structures or installations, particularly for test or monitor applications, is obvious. A question which is particularly applicable here, however, and which also applied in various degrees to the previous statements, is "can't the same or similar results be obtained more easily and directly by using divers, rather than by using a complex submersible and its logistical support?" Under some conditions, of course, divers are more suitable and their place will be considered later. The really important point here, however, is that such observations, for example, the report by K. Rodgers of the Great Lakes Institute on dye dispersions, can be successfully made from a submersible.

2. "...to assess the suitability of the submersible actually used in undertaking the various tasks."

The first comment, of course, is that the submersible actually undertook only a small number of the tasks originally planned. However, it would probably have received a much higher "success rating" if many more of the intended deep dives had been accomplished. *Pisces III* was definitely best suited to deep water operations; it was not generally suitable for shallow water work.

Negative Aspects of *Pisces III* - Shallow Water Work

(a) Restricted underwater visibility.

(b) No visibility at surface, unless hatch is open.

(c) Ballasting and trim systems are very slow to respond in shallow water.

(d) Exterior lighting is ineffective against high ambient light levels.

(e) Submersible is too slow and cumbersome to maneuvre easily and to navigate at surface...unless under ideal conditions.

(f) Surface and near surface activities tend to require continual re-adjustment of the submersible, hence available power sources are consumed at a higher rate than during a deep dive.

(g) The submersible is excessively heavy and over specified.

Negative Aspects - General

(a) Poor ballasting, buoyancy, and trim systems, particularly unsuitable for freshwater operations.

(b) Restricted battery charge, with no system for quick interchange of exhausted batteries.

(c) Low efficiency motors with unprotected impeller ducts, subject to damage from loose ropes and any other partly floating debris.

(d) No internal control of humidity or temperature in the submersible.

(e) Poorly arranged control valves and facia; pilot continually required to stand, kneel and crouch to operate vessel.

(f) Awkward to retrieve and launch from most generally available vessels and hoists...requires very sheltered or near calm conditions.

(g) Excessively loaded with scientific equipment (CCIW equipment).

Positive Aspects - General

(a) High safety record and ample life support system.

(b) Generally an unspecialized design, robustly constructed.

(c) Ample space for long duration, two-man operations.

(d) Sufficient space for a comfortable three-man operation, providing that total duration does not exceed more than about 2-3 hrs.

(e) A well designed, reliable and highly maneuverable manipulator arm.

(f) Excellent visibility, for deep dive (forward/horizontal) viewing when port and starboard aspects are clear of ancillary equipment.

(g) Excellent submersible to surface underwater communication system.

(h) A good simple stereo-tape system for providing background music...to ease tension and to calm potentially worried observers.

(i) Good carrying capacity.

The submersible appears to have a strong and continuing application to biological and geological studies which involve traversing of the lake bed or underwater cliff slopes, scanning, searching and both randomly and selectively sampling the lake bed interface. It has a limited application for studies involving geophysics, lake dynamics and water chemistry.

3. "...to determine the optimum role of free diving, excursion diving and habitat support and submersible operations with regard to the *in situ* research needs of the Great Lakes."

Shallow Water Studies 0-10 m (approximately)

Most studies requiring *in situ* observations, recordings or work at this depth are best supported by scuba or hooka diving methods. There are, however, four important conditions that should be recognized as necessitating a modification to the diving technique.

(1) The distance over which the diver is required to operate is excessively demanding on his swimming ability...this requires that he either be taken from place to place on a towed underwater sled, or that he make use of some form of underwater propulsion unit.

(2) The diver is required to remain below water for very considerable periods of time...under these conditions, a habitat refuge or a simple ("telephone booth" type) rest station with a trapped bubble of air (as described by Somers and Anderson, 1971), is required to allow for eating, drinking, resting, checking of equipment and making notes and records.

(3) The diver is required to work in excessively cold conditions ...heated suits, with or without some form of umbilical are almost essential. These, generally, severely restrict the range and movement of the diver.

(4) The diver is required to transport heavy payloads or operate equipment with high power requirements...under these conditions, some form of buoyant support must be provided for the heavy payload and an umbilical will be required to provide power from a surface support vessel.

In all of the above, scuba and hooka diving techniques are directly applicable and best suited to the needs involved. However, in the case of a scientist or technician whose presence is essential or highly desirable during underwater *in situ* studies and who, for one reason or another, cannot dive, the submersible vessel offers the only other means of support.

Moderate-Shallow Underwater Studies 10-40 m (approximately)

Most of the points made with regard to shallow water diving also apply to moderate water depths, with some additional comments and re-emphasis.

The controlling factor at these depths is that most dives are subject to decompression requirements. Nearly all dives that are made SURFACE - DEPTH - SURFACE must allow for decompression time on the return to the surface. This depends upon both the depth at which the diver has been working and the duration of the dive at that depth. As a result of this, the deeper one dives and the longer one works at depth, the greater the decompression time required. In fact, using standard scuba techniques, a time of between 1 and 1 1/2 hrs. of diving at depths of 35-40 m would normally represent a day's work.

Bounce diving and/or saturation diving techniques can be used to extend the usable time period of deep dives but saturation diving depends largely upon the availability of staging points (mid-water refuge) where personnel can rest, change, eat and warm up etc. Such staging points must have the facility to remain pressurized and to allow for a personnel retrieval and transfer to a surface decompression chamber.

In effect, then, moderate depth diving from the surface for short durations is no problem (although an emergency decompression chamber should be readily available). Extended period dives, however, definitely require decompression facilities and, if for periods of 2-3 hrs. or more, a staging point is essential (such as an underwater habitat or lock-out submersible).

Moderate-Deep Underwater Studies 40-100 m (approximately)

The preceeding points, again apply to dives made into these greater depths. Effective work periods become even shorter and back-up support in terms of medical supervision, mixed gas (and compressed air) supply, resting areas, habitats, lock-out submersibles, decompression facilities and support ships become increasingly greater.

Deep Water Studies Greater than 100 m (approximately)

Although diving technology has advanced sufficiently to allow specialized groups to regularly dive to 200 m and occasionally to 300 m or more, this type of diving is certainly beyond CCIW requirements for the foreseeable future. The submersible is clearly the most suitable means at our disposal for continuing deep water studies.

Submersible Operations

It is clear that no one submersible will be able to meet all the operational and scientific demands placed upon it. However, the results of the submersible trials in both Georgian Bay and Lake Erie suggest the following: (a) There is the potential for a high utilization of a submersible operating in shallower areas of the Great Lakes to depths of 150 m to study, primarily, the biological and geological processes in this most "active" part of the lakes. (b) There will be a continuing demand for submersibles to be used in the deeper parts of the lakes, but for relatively short periods (2-3 weeks per year), to undertake specialized studies in restricted areas. For these studies, it is most probable that different submersibles will suit different tasks. (c) The same submersible is NOT suitable for both shallow and deep water work. (d) It is not at all easy, and rather impractical, to try to integrate submersible studies covering widely differing tasks. (e) A persistent but relatively low demand will likely be placed on submersible support for purely physical and chemical lake studies but that the need to support geophysical studies may increase rapidly with the development of suitable measuring techniques covering such widely different activities as : sparker and side scan sonar surveys, magnetometer and gravimeter surveys, sediment resistivity, and acoustical transmission, laser scanning, I.R. and acoustic surveys for biological material.

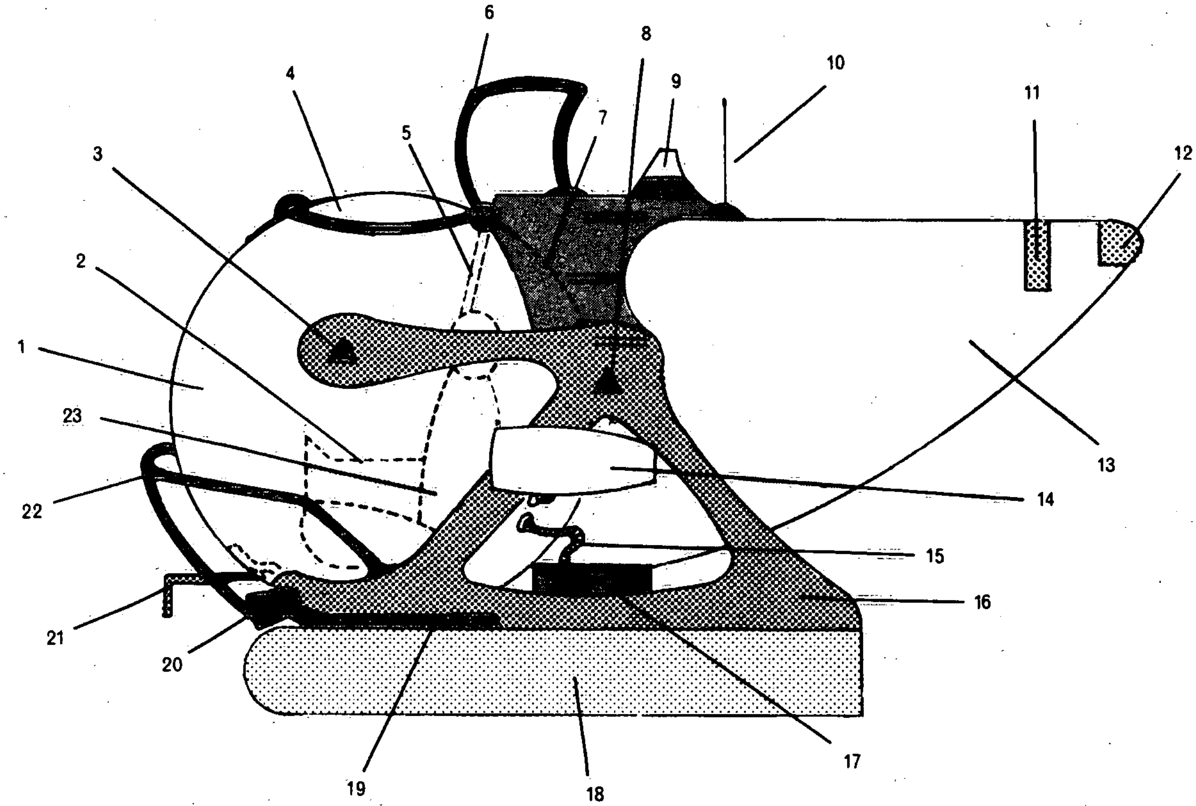
4. "...to suggest what might be the most suitable and pratical type of submersible vessel (and logistical support), required for the types of environmental research for which a submersible was obviously the best choice."

None of the submersible vessels currently available can properly meet the requirements for shallow water diving (to about 150 m) in the Great Lakes, though some are beginning to approach the type of specifications necessary. From the experience with *Pisces III*, it is also clear that "make do" systems are not satisfactory; better to do one job well than several badly.

This report has taken into account the needs and requirements as outlined by actual user groups and has added further considerations based upon both technical and logistical needs. As a result of this, two proposals are made: (1) A listing of outline specifications is given below, together with a conceptual diagram (Figure 5) describing the operational layout of a proposed submersible for shallow water use. (2) The contracting of specific submersibles for deep diving studies is suggested.

(1) Submersible (shallow water) Specifications

Cost	- About $100,000.
Depth range	- 0-150 m (approximately).
Capacity	- 2 people and 250 kg payload.
Maximum under-water speed	- 6 km/hr.
Weight	- Gross not more than about 3,500 kg.
Tow	- Towable at depth or surface up to 10 km/hr.
Emergency	- Life support for 48 hrs. with emergency battery power, releasable marker (beacon) and line.
Control	- Rapid ballast, buoyancy and trim control, to be equally effective in fresh, brackish and salt water.
Vision	- All around, main cabin to be made of clear plastic for 75-80 per cent spherical vision.
Propulsion	- Water jet or impellor type; nozzles rotating in vertical plane 360°.
General	- Sub to be fitted with beacon, skids, bucket seats, *Pisces III* type manipulator arm,



1 TWO MAN SPHERE
2 CONTROLS & NAVIGATION INSTRUMENTS
3 ATTACHMENT POINT FOR TOWING, ALSO ACTIVE AS A LIFT POINT.
4 ACCESS HATCH
5 ACCESS LADDER
6 GUARD & HAND RAILS
7 PROTECTIVE SHIELD & STEPS
8 LIFT POINT
9 BEACON
10 R.T. ANTENNA
11 EMERGENCY RELEASE CAPSULE WITH BEACON, R.T., FLOAT, & MARKER.
12 ATTACHMENT POINT FOR SURFACE AIR SUPPLY & POWER
13 FAIRING OVER BUOYANCY TANKS, CONTROL, TRIM TANKS, AIR SUPPLY, SERVOMECHANISMS, PROPULSION CONTROLS & TRANSDUCERS, ACCOUSTIC PINGER & LOCATOR SYSTEMS
14 PROPULSION
15 THROUGH HULL PENETRATORS
16 MAIN FRAME
17 PORT & STARBOARD BUS BOXES FOR MULTIPLE CIRCUIT INPUT / OUTPUT CABLES.
18 RAPID RELEASE / CHANGE BATTERY BOX SKIDS
19 PORT & STARBOARD ATTACHMENT PADS FOR EQUIPMENT PACKAGES AND REMOTE SENSORS AND MECHANICAL ARMS.
20 PORT & STARBOARD QUARTZ–IODIDE LAMPS MOUNTED ON TELESCOPIC BOOMS.
21 THROUGH HULL SAMPLE PROBE
22 GUARD RAILS
23 SEATS

Figure 5. Schematic diagram of idealized two-man shallow water submersible, operational to depths of about 150 m.

internal heater, movable underwater lights on telescopic boom, underwater cameras, underwater television, video and acoustic tape recorders, underwater communications (to divers or surface), surface RT, sample basket, selected sensors, through-hull sampling port. The sub should be supported by either its own air and 12 VDC power supply (quick change batteries fitted into skids) or by external air and power (12 VDC). On external power, it would remain tethered to a surface support. All controls should be located in the sub, which should also be capable of continuous underwater operations in excess of 24 hrs. using external air and power supplies. In support of these operations, a single vessel, probably a mobile barge and hoist, would be quite adequate for many nearshore studies. If offshore work was to be undertaken, an additional vessel, such as a tug, should be quite sufficient.

Additional Comments

A number of significant developments, in the design of shallow water submersibles, took place at about the time of the *Pisces III* operations in Georgian Bay and Lake Erie.

The MaKai Range, in Hawaii, successfully conducted evaluation and operational trials with its plastic hull submersible, *Kumu*. *Nemo*, another clear plastic hull submersible was evaluated by the U.S. Naval Civil Engineering Laboratory and made a test dive in excess of 150 m depth off Grand Bahama Island during May (Oceanology, 1970). At the Second Annual Offshore Technology Conference, held in Houston in April, details were released of another shallow water acrylic submersible (for use by the Smithsonian Institute) to be built by the Alcoa Company and Edwin Link.

It is most probable that a further development of these prototype vessels and others (not yet announced) will soon meet the conceptual requirements as outlined for shallow water studies in the Great Lakes.

Although surface support systems, utilizing barges and tugs, are already available and must continue to be relied upon for the immediate future, recent developments in the new submersible launch and recovery systems offer a potentially significant advance. Of particular interest is the MaKai LRT (launch, recovery and transport) system, which was initially developed for less than $20,000 (Ocean Industry, 1970). The submersible launch and recovery platform has been used for operations ir sea state 5, supporting both *Star II* and *Nekton* submersibles. Such a system offers considerable potential to Great Lakes research studies, where sea states are unpredictable and can increase rapidly (in the form of short period but steep waves), and where logistical considerations are both complex and economically significant.

(2) Submersible (deep diving)

It is suggested that for all dives in excess of the depth capability of the proposed shallow (150 m) water submersible, a suitable submersible be chartered or obtained under contract. This would also apply to occasions when a lock-out facility was required for operations in depths of less than 100 m.

RECOMMENDATIONS

The following comments indicate the preferred usage of various diving techniques, as they apply to *in situ* research studies, at the present time.

(1) Scuba and hooka compressed air methods plus "telephone booth" type underwater rest station and decompression facility.
- Shallow depth, short and medium duration diving.
- Shallow and some moderate-deep diving, short duration.

(2) Mixed gas methods (with underwater rest station and decompression facilities).
- May occasionally be required for medium duration, moderate-deep dives. The techniques and facilities should be considered as a possible requirement.

(3) Habitat and life support systems.
- These, mostly, require considerable logistical support from either a shore station or tethered vessel. Most systems are non-mobile and require to be transported by surface vessels, even for short distances. Because of the high operating cost of such systems, they may only become valid for specific tasks which require long duration life support in a limited area. For many tasks, a combination of type (1) techniques and/or a suitable submersible can provide the necessary support.

(4) Submersibles.
- It is clear that no single submersible will be able to meet all the operational and scientific demands placed upon it. However, from the results of the trials of *Pisces III* in the Great Lakes, the following comments can be made: (a) There is considerable potential for limited depth studies (to depths of about 150 m) for geological and biological programs in this, the most active, depth zone of the lakes. (b) There will be a continuing demand for submersibles to be used in the deeper parts of the lakes, to undertake specific studies in a number of small survey areas. Such studies will likely require 2-3 weeks of operations, per year, and it is likely that different submersibles will be required for different tasks. (c) Generally, the same submersible is NOT suitable for both shallow water and deep water tasks. (d) It is impractical to try to integrate submersible operations covering widely differing tasks, and fitted with a great variety of equipment. (e) The value of submersibles for physio-chemical studies, in the lakes, has not yet been properly evaluated. The potential for certain geophysical and/or remote sensing studies is virtually unknown, though it could be considerable.

The main theme of the *Pisces III* operations in the Great Lakes was to evaluate how effectively a submersible could provide a means for scientists to observe, record and sample the environment *in situ*. From the user point of view, *Pisces III* was not suitable; it did, however, provide the experience necessary to suggest what type of submersible could be used for various purposes.

Submersible operations may be considered under three general headings: (a) Shallow and limited depth operations. (b) Deep water operations. (c) Diver lock-out operations.

(a) Figure 5 shows, in schematic form, an idealized submersible for use in limited depth operations (to depths of approximately 150 m). Such a vessel, supported by a submerging launch/recovery and transport vessel (LRT), could provide the necessary logistical support and mobility for most limited depth studies. The development of acrylic-subs is certainly trending towards an integration with this type of small, compact, mobile and highly flexible system.

(b) There are, already, numerous submersibles which could be considered suitable for deep water work (Lange, 1969). Each has its own peculiarities of design which makes for suitability in certain types of work. When using deep water submersibles, the characteristics of each should be carefully matched against the task requirements. Some deep water submersibles can be used with submersible LRT systems but many have their own surface support vessels. As was found in the *Pisces III* operations, surface support is logistically complex and subject to even slight wind/wave and weather conditions.

(c) No use has yet been made of a lock-out submersible in the Great Lakes. It is hoped, however, to make future use of the Royal Canadian Navy (RCN) lock-out submersible, *SDL I*, in the Great Lakes. The need for this facility is, however considered minimal at present.

Based, then, upon the preceding remarks, the presently preferred submersible support is as follows:

(a) A clear-hull type submersible for studies in water depths of 150 m or less. Such a vessel should also be capable of extended duration activities when provided by an umbilical with external life-support and power. The submersible should be supported by an LRT type tender vessel. Launch and recovery should be possible under sea state conditions of 4-5. Because of the potentially "high" usage of such a system (for fresh, brackish and salt water activities), it would be advantageous to have user/owner operation.

(b) For deep water submersible activities, the exact scientific tasks, required methods of use, geographic locations and likely surface conditions, should be clearly outlined. Based upon this information, then, the most suitable submersible and surface support system can be obtained. Since activities with such vessels (in the Great Lakes) are likely to be irregular and of relatively short duration, chartering or leasing could provide the best means of program support.

(c) The RCN already operates a lock-out submersible, *SDL I*. Any activities planned for the Great Lakes, which involve lock-out diver support from a submersible, might well involve this vessel.

ACKNOWLEDGMENTS

I would like to acknowledge the assistance of the Inter-Departmental Committee on Submersibles, without whose involvement the 1970 submersible operations in the Great Lakes would not have been possible. Special thanks go to Dr. A.T. Prince, Director, Inland Waters Branch, Mr. J.P. Bruce, Director, Canada Centre for Inland Waters, Commander N. Brodeur, Department of National Defence (DMSE), Mr. H.B. Macdonald, Head, Technical Operations Section (CCIW) and to Mr. T. McCulloch, Director, Central Region Hydrographic Service (MSB) for their encouragement and support.

Special acknowledgments, too, go to the pilot and ground crew of the DOT helicopter, to Lt. B. Ridgewell, officer in charge of naval support, to J.T. Roe, Chief Diving Officer (CCIW) and in charge of logistical support. I would also like to thank all those persons who took part in the operations and who put so much into the planning and conduct of the various scientific projects, and who provided the detailed comments which form the basis for this report.

I would like to express my special and very particular thanks to Dr. C.F.M. Lewis for his work as co-leader during the program activities and for his many helpful suggestions and review of this manuscript. I would also like to thank Drs. N.A. Burns, A.L.W. Kemp, B.V. Sanford and N.A. Rukavina and all the many other persons who have been involved in the submersible operations and the preparation of this report.

REFERENCES

Caddy J.F., and J. Watson, 1969. Submersibles for Fisheries Research. Hydrospace. March.

Hanson J.A., and D.E. Well, 1970. Launch and recovery of submarines underwater. Ocean Industry 5 (12), pp. 16-18.

Lange P.A., 1969. A critical review of manned submersibles used in oceanographic research. Clearinghouse, Pub. 189109, U.S. Department of Commerce.

Lewis C.F.M., W.M. Tovell and J. McAndrews, 1971. Differential uplift and low levels in the Huron and Georgian Bay Basins (in preparation).

Oceanology International, 1970. Plastic hull submersible logs 500-foot excursion. 5 (6), p. 19.

Pelletier B.R., 1968. The submersible *Pisces* feasibility study in the Canadian Arctic. Maritimes Sediments 4 (2), pp. 69-72.

Schneider R.S., 1968. Research submersible dives in Lake Michigan. Limnos. 1. 1. pp. 2-5.

Sly P.G., 1969a. Bottom sediment sampling. Proc. 12th Conf. Great Lakes Res., Internat. Assoc. Great Lakes Res., pp. 883-898.

Sly P.G., 1969b. Sedimentological studies in the Niagara area of Lake Ontario, and in the area immediately north of the Bruce Peninsula in Georgian Bay. Proc. 12th Conf. Great Lakes Res., pp. 341-346.

Sly P.G. and J.T. Roe, 1970. Preliminary report on the *Pisces III* submersible operations in Georgian Bay and Lake Erie, May 1970. Canada Centre for Inland Waters, unpublished report, 48 p.

Somers L.H., and R.F. Anderson, 1971. Underwater habitats for scientific research in the Great Lakes. Proc. 13th Conf. Great Lakes Res., Internat. Assoc. Great Lakes Res., part 2, (in press).