Olav Løken

Canada

GEOGRAPHICAL PAPER No. 30

(Étude Géographique Nº 30)

Déplacement de Blocs par la Glace le long du Saint-Laurent

Movement of Boulders by Ice Along the St. Lawrence River

Michel Brochu

GEOGRAPHICAL BRANCH
Department of Mines and
Technical Surveys, Ottawa

DIRECTION DE LA GÉOGRAPHIE
Ministère des Mines et des Relevés
techniques, Ottawa

Price:
Prix: *50 cents*

le 30 janvier ...

A mon collègue Olav Løken, en très c... je,

Michel Brochu

CANADA

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NOTE: Les figures 5 à 11 ont été dessinées par Jean-Claude Olivier à partir de photographies prises par l'auteur.

NOTE: Figures 5 to 11 were drawn by Jean-Claude Olivier from photographs taken by the writer.

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PREFACE

La présente étude constitue une édition revisée d'un travail préparé à l'origine pour le Conseil de recherches pour la défense (Ottawa), et publié en 1957 à un tirage très limité par le même organisme.

Cette édition bilingue est publiée par la Direction de la géographie dans le cadre de la campagne de recherches actuellement en cours dans le domaine de la géomorphologie littorale et périglaciaire.

N.L. Nicholson,
Directeur,
Direction de la géographie.

This study is a revised edition of a report originally prepared for the Defence Research Board, Ottawa, and published by that organisation for limited distribution in 1957.

The present bilingual edition was prepared for publication in the Geographical Branch as part of its current program of research into coastal and periglacial geomorphology.

N.L. Nicholson,
Director,
Geographical Branch

MOVEMENT OF BOULDERS AND OTHER SEDIMENTS BY ICE ON THE TIDAL FLATS OF THE ST. LAWRENCE RIVER ABOVE QUEBEC

INTRODUCTION

The existence of boulders and lines of boulders on tidal flats along both shores of the St. Lawrence River at the limits of low tide has long been known. Their general alignment is also plotted on the Canadian Hydrographic Service charts of this area.

Some authors have recognized that winter ice plays an essential part in the transport of boulders; however, the reason for the arrangement of boulders in single, double, or triple chains along the lower edges of tidal flats has not previously been explained. The writer (Brochu, 1954) attempted to clarify this problem, and summarized the process as follows:

- During the winter, the ice increases in thickness and freezes to the bottom along the shores of the St. Lawrence and the mouths of the tributary rivers where there are pebbles, and blocks up to 2 to 3 cu. ft. in size (0.6 to 0.9 cu. m.). The ice may then grip many of the boulders lying on the shore or in the shallows.
- In the spring, when the ice is weakened by thawing, tidal action lifts it and breaks it up into floes which move up and down, together with the adhering boulders and other sediments.
- With the progress of the thaw, these floes lay down at random a part of their boulders and sediment content on the intertidal zone.
- During the following tides, the ice floes, shoving like a bulldozer, move the boulders abandoned in the intertidal zone towards the lower part of the zone, or low-tide limit.
- The lower limit of these movements on the tidal flats is logically attributed to the two main levels of spring and neap low tide. Beyond this intertidal zone, the ice can no longer have a bulldozer effect since the increasing depth of water eliminates the shoving action of the ice as it causes the ice to float over the boulders. This downward movement of the boulders across the intertidal zone is confirmed by the fact that almost all the boulders are to be found near the low-water mark, whereas in the middle and upper tidal zones there are almost none.

As a result of these general observations it became apparent that further studies were necessary to provide more precise data on the annual frequency of the removal and replacement of boulders and other types of sediment by drifting ice.

METHOD: 1. FIELD SURVEY

The following are the essentials of the field survey method employed in a study of tidal flats located in the Cap-Rouge-St-Augustin region.

Autumn 1955. Five series of boulders lying in the lower part of the intertidal zone were marked with a painted line perpendicular to the shoreline, and where possible, these lines were carried from boulder so as to form continuous straight lines over groups of 3, 4 or 5 blocks. This was done to facilitate the analysis not only of movement in any direction, but also of displacement by rotation. A further refinement of this idea would be to number boulders. A reddish house paint was used but during the winter this paint was much scratched by the ice or peeled off by frost action.* The disposition, dimensions, lithology, and form of the boulders were noted, and the nature of the bedrock was also taken into consideration. A detailed sketch made of the series of marked boulders proved useful in recognizing the changes caused by ice during the spring. Photographs were taken in the autumn to illustrate the general aspect and size of the marked boulders, and again in the spring to show the new elements brought in by ice, and the appearance of the ice itself.

As the low-tide period is very short, it is advisable for more than one person to do the painting; sketching and photographing in order to complete the work.

Winter 1956. During the winter no observations were possible because the tidal flats were covered with 4 to 4.5 feet (1.2 to 1.35 m.) of ice.

Spring 1956. The spring observations began with the first signs of break-up on the tidal flats. It is essential to make the first spring survey when there is still floating ice and ice attached to the shore, because it is during the period of 1 to 3 weeks that all changes caused by ice transportation and sedimentation are to be noted.

---

*An aluminum paint was used in the spring of 1956, and this held much better than the first type of paint, being still visible in the spring of 1957. However by the spring of 1958 it had almost completely disappeared. Thus a long-term survey would require the boulders to be re-painted at 2-year intervals.

2. AERIAL SURVEY

As the observations and techniques described above were necessarily confined to restricted zones, it was considered important to obtain a more general view of a wider area, and thus an aerial survey was made at low altitude, 300 to 600 feet (100 to 200 m.) over the intertidal zones of both shores of the St. Lawrence. This survey covered a 25-mile (37 km.) stretch between Quebec and Cap-Santé (north shore) and Pointe Platon (south shore), and was carried out at low tide. The features studied were sketched on Canadian Hydrographic Service Charts 1333 and 1334 (See Figures 1, 2, 3, 4). Available air photos had been taken at high or half-tide, and thus were of little value for this study.

OBSERVATIONS: 1. PHYSIOGRAPHY OF THE SHORELINE

The intertidal zone

In the Cap-Rouge and St-Augustin region, where the field observations were carried out, the intertidal area presents two well-defined zones; an upper and central zone, and a lower zone (Figure 1).

In the upper and central zone boulders are rather rare. The upper part is 100 to 500 feet (30 to 150 m.) wide and is covered with sand and shingle, and by mud in the inner parts of the bays. The central part, 200 to 1,000 feet (60 to 300 m.) wide, has, in general, bare outcrops of schist and quartzite bedrock, the harder quartzite outcrops sometimes standing 3 to 10 feet (1 to 3 m.) higher than the schistose rock. Boulders occur in both parts of this zone, but they were observed more frequently on unconsolidated deposits.

The lower zone is characterized generally by a single chain of boulders lying parallel to the shoreline; in places off Cap-Rouge this chain is double. The main boulder chain is mostly made up of secondary lines, one or two boulders wide. Where there is a single chain of boulders the zone is 100 to 150 feet (30 to 45 m.) wide. Where the chain is double it is up to 500 feet (150 m.) wide, and the two parts are separated by 100 to 200 feet (30 to 60 m.) of rock or sand where some boulders are scattered on a sandy or rocky substratum (Figure 5).

Boulder characteristics

Disposition: Each chain of boulders is made up of short discontinuous secondary chains, one, two, or three boulders wide, including many irregular patches of boulders disposed at random toward its exterior margin. Within each chain the largest boulders are found at the limits of extreme low tide and here they are at a maximum density. Density and size diminish inshore towards the upper margin of the chain where groups of boulders may alternate with patches of sand and coarse shingle. However, owing to the limits of effective ice shove already explained, both the upper and lower limits of this zone are sharply defined.

Dimensions: The average size of the boulders is between 2 and 4 cu. ft. (0.6 to 1.2 cu. m.) at the lower extremity of the tidal zone. Some boulders are 5 to 6 cu. ft. (1.5 to 1.8 cu. m.) in size, this being the maximum.

Form: Most of the boulders are rounded or sub-angular in form (Figure 6), but angular forms are rare.

Petrographic nature: Most of the boulders are crystalline (granite, granulite, and diorite). It was, however, often difficult to determine their exact nature owing to the grey weathered surface of the boulders and the lack of irregularities from which hammer samples could be obtained. In addition to the crystalline rocks which made up 90 per cent of the blocks, 8 to 9 per cent were of metamorphic schist and quartzites originating in the outcrops of the tidal zone itself, and 1 to 2 per cent of limestone coming from formations lying 10 miles (16 km.) upstream on the north shore. Thus, 90 per cent of the material of the boulders are of a different origin from the rocky substratum of the tidal flats.

Substratum: The boulder chains of the lower tidal zone lie on a bottom of clay or sand largely composed of shingle and schist debris.

Aerial survey of intertidal zones

A comparison of Figures 1, 2, 3 and 4 shows that the wider survey agrees, for the most part, with the detailed observations in the Cap-Rouge and St-Augustin area.

The upper and central zone: On both north and south shores the upper and central part of the intertidal zone is consistently clear of boulders where bedrock is exposed, and even where it is covered by sand or mud, boulders are very rare. There is, however, an exception; on the north shore upstream from St-Augustin, boulders are scattered throughout the upper intertidal zone. The Dombourg Islets, included in this area, are themselves composed of an agglomeration of boulders and sand, and it seems that these boulders are derived from a fossil chain of boulders that runs ashore here and forms the actual bank of the river. Elsewhere there are only a few scattered boulders on sand or mud in the upper zone, sometimes, but more rarely, in groups of two or three.

The lower zone: With the exception of a few gaps, chiefly between St-Nicolas and Ste-Croix on the south shore, the lower zone is edged at the low-tide mark by a continuous chain of boulders. Off some bays and coves, tidal flats are wide on the north especially where the chain doubles, for example on the east side of the Jacques-Cartier River and west of Cap-Santé on the north shore, and between St-Nicolas Point and Pointe à Basile on the south shore. In one place, between Neuville and Les Ecureuils, where the mean width of the tidal flats is around 4,000 feet (1,300 m.) the chain is triple.

There are marked differences between the features on the two shores of the St. Lawrence. On the north shore, the alignment of boulders is continuous and wider and there is a greater density of blocks, triple chains are found only on the north shore. On the south shore however, the alignment becomes a simple row only one or two blocks wide. In certain places, as for example immediately to the southwest of St-Antoine and west of Ste-Croix, there is a complete break in the continuity of the boulder alignment.

There are apparently two reasons for the uneven distribution of the alignments of boulders on the tidal flats:

There appears to be a wider exposure of bedrock on the south shore, so that boulders can be rolled more easily to the river by the shoving and gripping action of the ice.

As the majority of the boulders lying on the tidal flats are constituted of morainic material from the Laurentians and are carried downstream to the banks of the St. Lawrence by the numerous streams and rivers of the north shore, it is natural that there should be more of this material on the north shore.

The double and triple chains of boulders are separate phenomena. As they occur where the intertidal zone is very wide and has a low gradient they seem to correspond to the tide levels which may vary from 3 to 4 feet (1 to 1.30 m.) between spring and neap levels. An extreme neap level may explain a triple alignment. Where the intertidal zone is more than 1,500 feet wide (480 m.), the horizontal distance between the marks of spring, neap and normal tides is sufficient for more than one line of boulders to develop. This does not necessarily mean that all tidal flats exceeding this width will have a double line of boulders; on the south shore, even where the intertidal zone is wide, the chain tends to remain single because there are fewer boulders.

2. THE ICE

Conditions and characteristics

Duration of ice season: The annual cycle of ice on the St. Lawrence in the region of Quebec begins between the first and third week of December and ends between the first and third week of April (Brochu, 1958).

The St. Lawrence freezes from shore to shore upstream from Trois-Rivières. Downstream from this point, only the intertidal zone freezes over completely. The tidal flats are frozen over solidly by the end of December. During the 10 or 20 days at the beginning of the season, ice formed on the tidal flats is still too thin to resist the pressure of tidal movement and is carried away by the river current. Unless there are marked temperature rises above freezing point during the winter, the tidal flats ice remains static after it is firmly frozen over, apart from some marginal breaking.

Near the end of March or at the beginning of April the ice progressively breaks off by sections, from offshore toward the shore, the heads of the bays being the last to be freed.

Ice thickness: The ice normally reaches a thickness of 4 to 4.5 feet (1.2m to 1.35 m.) but by rafting and hummocking it builds up in places to blocks with dimensions from 10 to 20 cu. ft. (3 to 6 cu. m.). Blocks of this size are not uncommon, and their erosive and transporting power can be readily imagined (Figure 7).

Extraneous elements in the ice

An inspection of the stranded and shore-fast ice in the region of Cap-Rouge-St-Augustin in the spring of 1956 revealed much extraneous matter:

Boulders. Owing to the difficulty of examining the lower surface of the ice, only one boulder was actually seen in the ice itself. That does not imply, however, that this was an exception (Figure 8).

Fine sediments. A layer of 2 to 10 in. (5 to 25 cm.) of earthy material was frequently found adhering to the underside of the ice. This usually consisted of black mud or clay and often included roots and other parts of plants (Figure 9). One or more layers were often interbedded in the ice itself, probably the result of successive layers being taken from the bottom by the action of tides combined with freezing conditions that favour the gripping of sediments by adhesion.

MOVEMENT OF BOULDERS BY DRIFTING ICE

Erosion and transport by ice

During the period when the ice is attached to the shore, there appears to be no direct morphological action (with the exception of the gripping of boulders) even though ice is lifted each day by two cycles of 15- to 18-foot (4.5 to 6 m.) tides.

It may be concluded that the transport role of the ice occurs during the periods of free drifting, from the beginning to the end of December and particularly from the end of March to mid-April. The role of scraping, shoving and transportation played by the ice in December seems to be negligible in comparison with these actions in spring, because in December the ice is too thin to be able to detach, shove, or lift up large boulders. On the tidal flats this ice action is confined apparently almost exclusively to the spring period.

Details of erosion and transport of materials in the study area are summarized in the two principal zones.

Upper and central zone: From this zone, particularly from the muddy bottom at the heads of bays, comes most of the earthy material held in the ice; the areas of bare bedrock composed of schist provide little material beyond occasional boulders or frost-loosened rock fragments. In this zone it was impossible to determine by field observation what materials had been moved by the ice, thus the volume of sediments in the ice itself was estimated. This showed that 1 cu. m. of ice lying on a tidal flat covered with sedimentary material can grip 1 to 2 lb. (0.5 to 1 kg.) of sediment in its dry state. It is thus possible to assume that the extensive ice cover resting on a terrigenous or sandy bottom may remove many hundreds of tons of sedimentary material. This is later redeposited by ice either on the tidal flats themselves, or on the bed of the St. Lawrence. The ice is a powerful agent of erosion (by adhesion of material to the frozen subsurface), of transport (by the movement of upstream and downstream tidal currents), and of sedimentation (by deposition on the bed of the St. Lawrence, and by grounding and melting of the ice on tidal flats).

Lower zone: In this zone, characterized by the boulder chains, observations in the spring of 1958 showed that all the blocks remained in their original position at the end of the ice season. The reasons for this appear to be that close spacing of the boulders prevented the ice from enveloping them completely, and that the boulders were lying on a sandy bottom which froze, and they, in turn, were firmly frozen to this surface.

It seems therefore that in the intertidal area, the movement of boulders by floating ice is almost nil. This stability suggests that the chains of boulders have reached a mature state and are unlikely to show much change in the future, except for the addition of new boulders.

Deposition by Ice

Erosion and transportation are balanced by deposition; the ice, being a seasonal feature, must deposit in the spring what it picks up along the shores in the winter. The new elements in the intertidal zone, however, represent only a fraction of the sediments that are deposited in deeper water. This is evidenced by the observation that clouds of clay particles may be seen in the water in spring when ice floes are struck by the ferry-boats between Québec and Lévis.

The following material was identified as having been deposited by ice in the spring of 1956:

Fine sediments and vegetal debris: Lumps of clay, almost always associated with debris of plants and their roots, 10 to 20 inches (25 to 50 cm.) long and 4 to 5 inches (10 to 13 cm.) thick (Figure 10). The relative density of the lumps seen in the intertidal zone is about one or two per thousand square feet (304 $m.^2$). This relatively low density suggests that the ice carried out into deep water possibly more than 75 per cent of the fine sediments taken from the tidal flats. It was impossible to recognize redeposited free clay on the tidal flats.

Rocky material: In the study area at Cap-Rouge, a granite boulder 3 feet (1 m.) in diameter was observed deposited on the bare rocky part of the upper zone; another boulder 20 inches (50 cm.) in diameter, was seen in the sandy part of the zone; a slab of limestone 20 inches (50 cm.) long, 10 inches (25 cm.) wide and 4 inches (10 cm.) thick was noted close to a group of paint-marked boulders (Figures 1 and 7). This limestone slab probably originated in the Palaeozoic limestone formation situated 10 miles (16 km.) upstream near Neuville (Figures 5 and 11).

During the spring of 1956, when there was still drifting ice, it was possible to observe on the tidal flats within the bay of Cap-Rouge, many furrows in the sand, each leading to a boulder; this seems to prove that the boulders had been pushed by ice. In other places, holes 10 to 20 inches (25 to 50 cm.) deep were seen from which a boulder had recently been carried away. In other places larger blocks, which had scarcely moved had a ridge of sand in front of them due to the pushing action of ice; behind them was a depression in the form of a crescent, showing that this part of the hole had been occupied by a block. Apart from the area where blocks were paint-marked, it is impossible to present precise data on the movement of blocks by the action of the ice; however, the available information suggests that such annual movements do exist. From field observations it was concluded that the density of new boulders is between

25 and 50 per square mile (1.6 km.^{2}).

Bedrock fragments: Frost-shattered fragments of the tidal flat bedrock were recognized by their sharp angularity, and by the fact that they were of the same petrographic nature as the local bedrock, i.e. schist and quartzite. Schist fragments rarely exceeded 1 inch (2,5 cm.) in diameter; quartzite fragments measured up to 1 foot (30 cm.) in diameter.

PRACTICAL APPLICATIONS

This preliminary study suggests that there are practical considerations concerning the possible utilization of tidal flats for landing purposes.

Stability of aligned or dispersed blocks

The upper and central part of the intertidal zone is an area of great stability with regard to boulder movement, and few changes take place from year to year.

The lower zone with its single, double or even triple chains, shows maximum stability, although some new boulders may be added to the chains each spring. There was no evidence in this survey that the boulders had been or were likely to be moved by ice. Additional boulders, however, may be added to the chains during spring.

In this part of the St. Lawrence River, and presumably in other similar areas, movement of boulders by ice is on such a small scale that good air photos taken at low tide, and mapping of the tidal flats and their chains of boulders may be considered as a semi-permanent representation of the profile.

Sedimentation by ice of harbors and channels

In the St. Lawrence, the problem of sedimentation in harbors and navigation channels is much more serious than the changes that may occur on tidal flats. It was estimated that ice carries away many tons of sediment each year, and thus plays an important part in the processes of erosion and deposition. This process should be taken into account when attempting to solve problems of sedimentation in harbors and channels.

Comparison with the Arctic

This study was initiated to acquire an idea of the action of ice on boulder-strewn tidal flats similar to those found in many locations in the Arctic.

As ice conditions in the Arctic differ from those in the St. Lawrence region, the conclusions of this study may not be directly applicable to northern regions. Ice thickness is usually greater than on the St. Lawrence, and therefore its transport efficiency may be higher; the density of boulders may increase or decrease according to local topography and rock types, and this may affect the amount of seasonal movement; newly-detached angular blocks from cliffs and other rock outcrops almost free from vegetation, may be a more common feature in the Arctic.

Thus, in the Arctic, there may be more modifications of tidal flats from year to year than were observed on the St. Lawrence. In consequence, further surveys would be required in the Arctic in areas of differing lithological, tidal, and current conditions in order to ascertain if the conclusions reached in the St. Lawrence valley are applicable in the Arctic. It would greatly facilitate future research if air photos, taken at extreme low tide, were available for the areas to be surveyed in the Arctic as well as in the St. Lawrence.

CONCLUSION

From this preliminary study it was observed that the upper and central intertidal zone of the beaches surveyed had few boulders. Those that were noted were highly sensitive to the transporting action of ice, especially when they lay on rock or coarse sand. At the low tide limit, there was usually a chain of boulders on both shores of the St. Lawrence. On the north shore there was often a double chain, and in some instances, a triple chain. Within these chains it was observed that the boulders were very stable, the ice apparently having little or no transporting effect. Some additional blocks were observed, however, during the spring of 1956.

Ice should be recognized as a powerful agent of erosion, transportation, and deposition of finer sediments. A fraction of these sediments is deposited on the tidal flats, but most is probably laid down on the bed of the St. Lawrence River. It was concluded therefore that ice plays an important part in the silting up of harbors and navigation channels.

ACKNOWLEDGEMENTS

The writer gratefully acknowledges the assistance of Jean and François Hamel in the field.

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2. La zone inférieure de l'estran est caractérisée par la présence d'alignements de blocs rocheux généralement simples, sur les deux rives du Saint-Laurent, parfois doubles, et même triples sur la rive nord. Au sein de cette zone, le contrôle établi à la peinture, à Cap-Rouge, montre que l'ensemble des blocs est très stable sous l'action de la glace, même si l'on a pu y observer quelques apports de nouveaux blocs rocheux.

3. On est en droit de considérer que la glace arrache, transporte et dépose chaque année des milliers de tonnes de sédiments, argileux et sableux. Une fraction encore non appréciée de ces sédiments est déposées sur l'estran; la plus grande partie est vraisemblablement déposée dans le lit du Saint-Laurent. On peut en inférer que la glace joue un rôle important dans le colmatage des ports et des chenaux navigables.

REMERCIEMENTS

Au terme de cette étude, l'Auteur tient à exprimer sa plus entière gratitude à Messieurs Jean et François Hamel pour leur collaboration dévouée à nos observations de terrain.

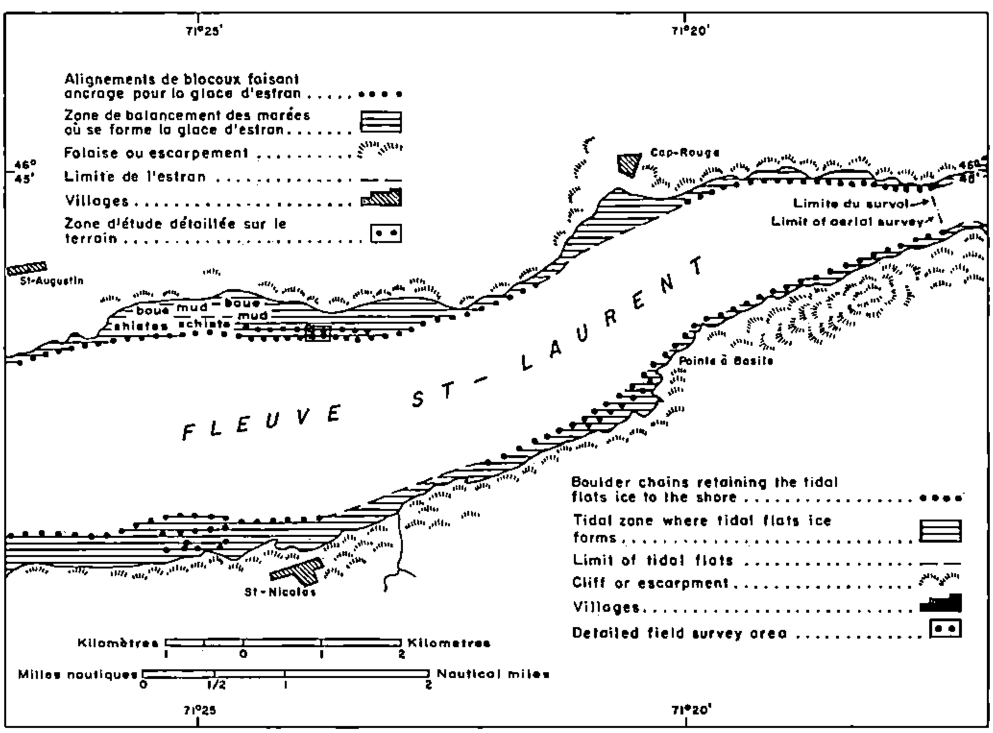

Figure 1. Alignements de blocs sur les estrans du Saint-Laurent entre St-Augustin-Cap-Rouge et le pont de Québec.

Alignment of boulders on the tidal flats of the St. Lawrence River between St. Augustin-Cap-Rouge and the Quebec bridge.

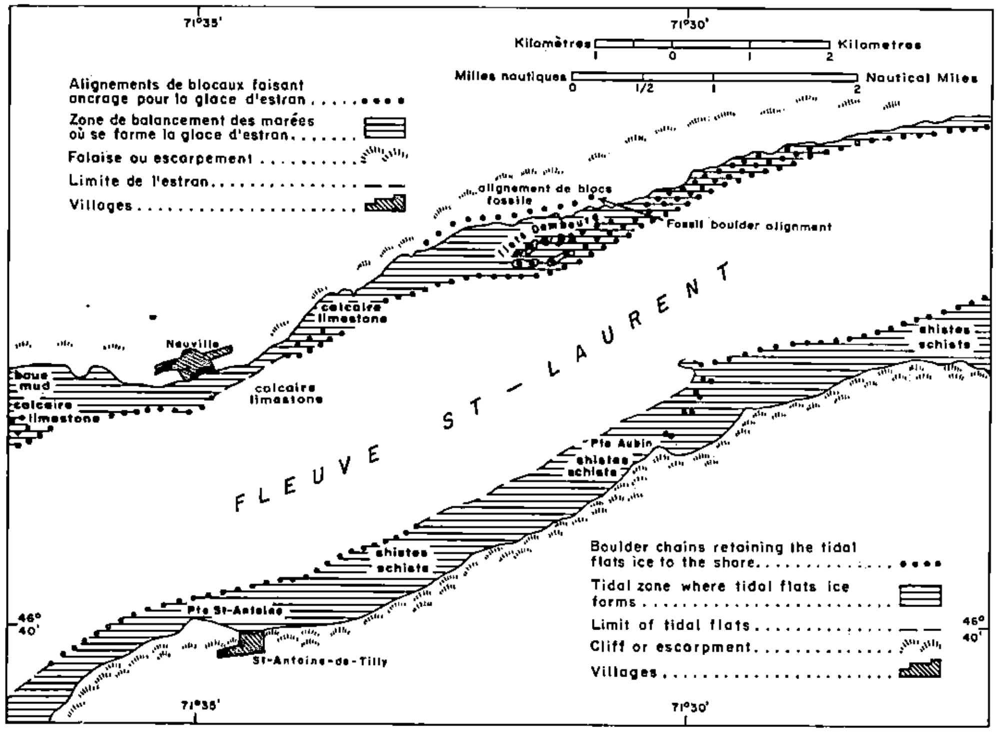

Figure 2. Alignements de blocs sur les estrans du Saint-Laurent dans les régions de Neuville (rive nord) et de St-Antoine-de-Tilly (rive sud).

Alignment of boulders on the tidal flats of the St. Lawrence River between Neuville (north shore) and St. Antoine-de-Tilly (south shore).

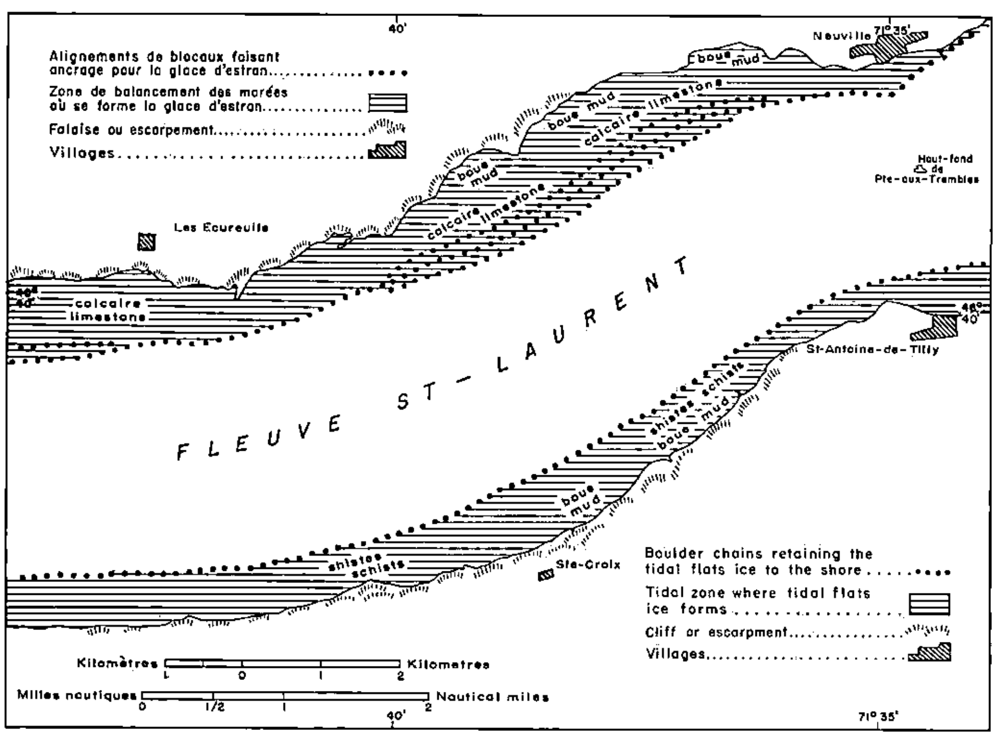

Figure 3. Alignements de blocs sur les estrans du Saint-Laurent entre Les Écureuils et Neuville.

Alignment of boulders on the tidal flats of the St. Lawrence River between Les Ecureuils and Neuville.

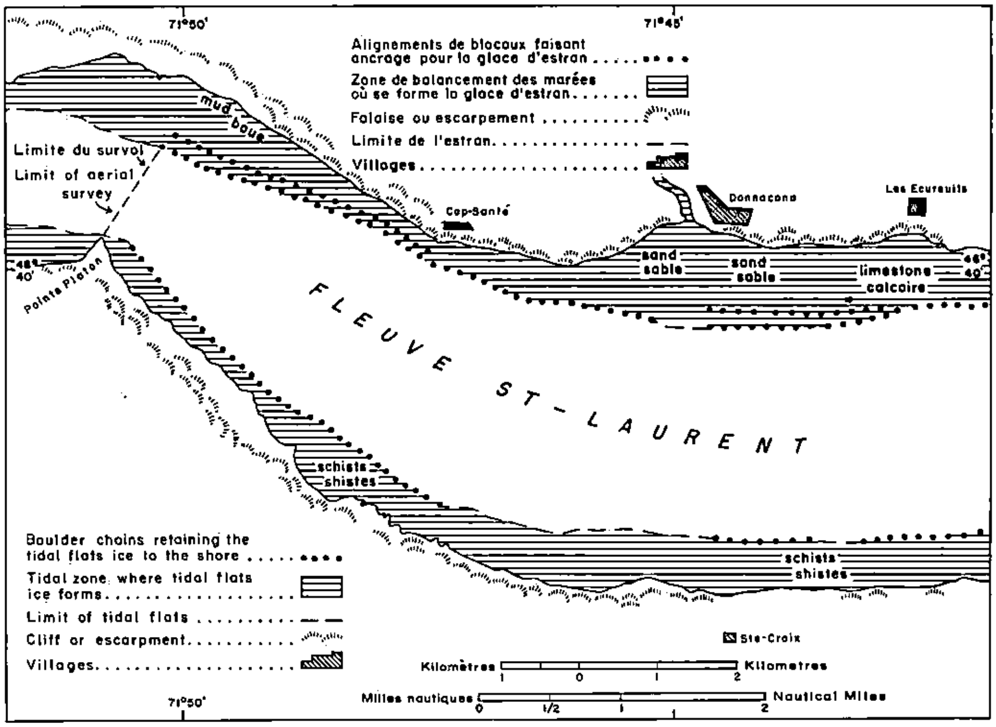

Figure 4. Alignements de blocs sur les estrans du Saint-Laurent entre Pointe Platon et Les Écureuils.

Alignment of boulders on the tidal flats of the St. Lawrence River between Pointe Platon and Les Ecureuils.

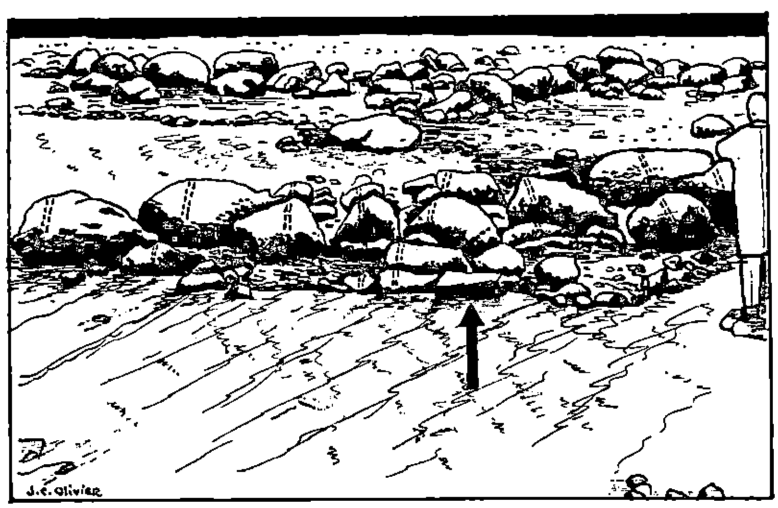

Figure 5. Cap-Rouge, zone inférieure de l'estran. Au premier plan, limite inférieure de la zone centrale et supérieure de l'estran; l'absence de blocs y est à noter. Au deuxième plan, sur l'alignement secondaire de blocs, on y distingue les traits à la peinture d'aluminium tracés perpendiculairement à la rive. Le bloc de calcaire signalé par une flèche a été apporté par la glace au printemps 1956. A l'arrière-plan, le principal alignement de blocs à la limite extrême de basse mer; il est plus large et plus fourni que l'alignement précité.

Cap-Rouge, lower zone of the tidal flats. In the foreground, the absence of boulders is noticeable on the lower limit of the upper and central zone of the tidal flats. On the secondary alignment of boulders, paint marks parallel to the shore can be seen. The limestone slab, indicated by an arrow, was brought by ice in the spring of 1956. In the background, the principal boulder chain lies at extreme low-tide limit; this chain is wider and has more boulders than the secondary line.

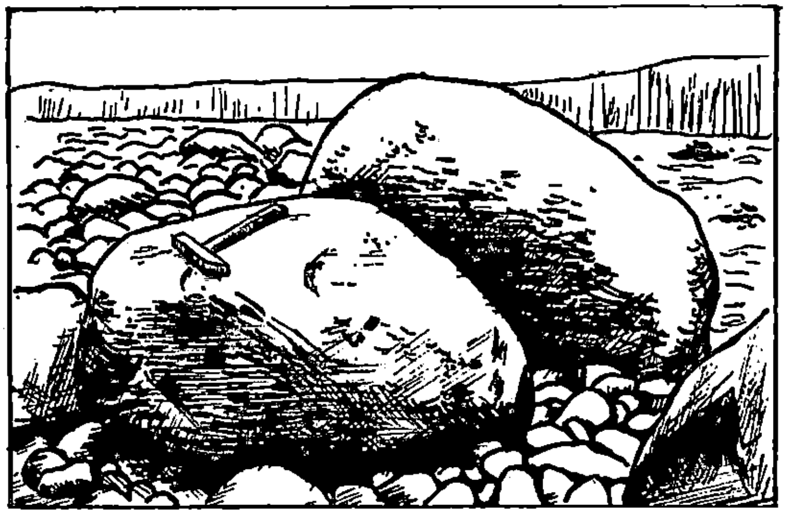

Figure 6. Cap-Rouge, zone inférieure de l'estran. Les blocs, pour la plupart d'origine cristalline, sont généralement de forme ronde ou arrondie. Les fragments de moindre dimension sont plus anguleux.

Cap-Rouge, lower part of the tidal flats. These boulders of crystalline origin have, in general, a rounded or subangular form. The smaller fragments are more angular.

Figure 7. Cap-Rouge. Glace d'estran de 9 à 12 pi. (2,75 à 3,35m) d'épaisseur échouée au milieu de l'estran. L'épaisseur anormale de cette glace est attribuable au chevauchement des glaçons sur la glace d'estran au cours de l'hiver précédent. On remarquera l'absence de blocs dans cette zone de l'estran: le sol est constitué, à cet endroit, de schistes arasés.

Cap-Rouge. Tidal flats ice, 9 to 12 feet (2.75 to 3.35 m) thick, stranded in the central part of the tidal flat. This rather unusual thickness seems to be due to overlapping of floes during the preceding winter. The absence of boulders in this part of the tidal flat is to be noted; the ground consists of a bedrock of eroded schist.

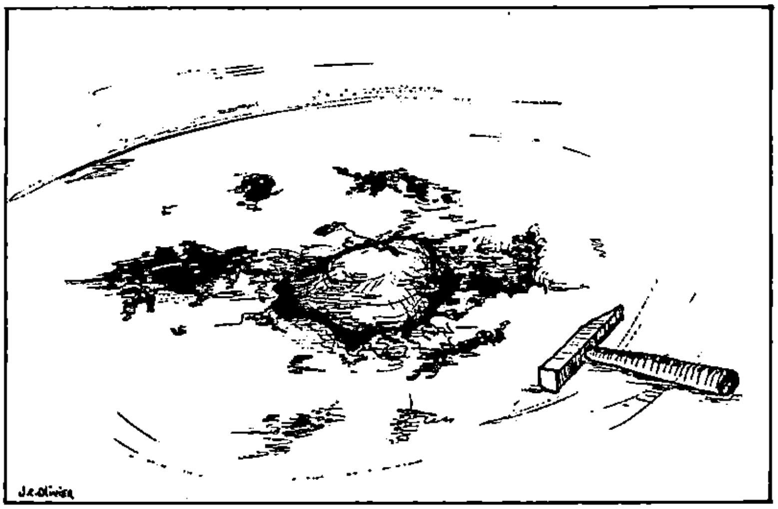

Figure 8. Cap-Rouge. Bloc granitique au sein de la glace entouré de débris terrigènes pris à l'estran sous-jacent.

Cap-Rouge. Tidal flats ice showing a granite boulder and earth debris taken from the shore beneath.

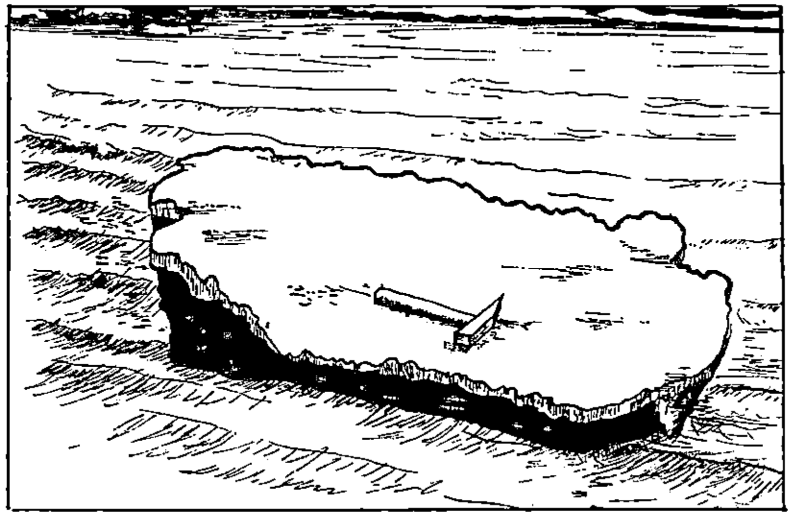

Figure 9. Cap-Rouge. Glaçon fondant sur l'estran (à marée haute); sa partie inférieure est constituée d'une couche terrigène de 10 po. (25 cm) d'épaisseur. Cet exemple permet d'estimer les quantités considérables de sédiments qui peuvent être enlevés par la glace, lorsque celle-ci recouvre de grands estrans. A l'arrière-plan, glaces d'estrans échouées.

Cap-Rouge. A melting floe on the tidal flats (high tide). The lower part of the floe is composed of a 10-in. (25-cm) terrigenous layer which illustrates the considerable quantity of sediments that may be carried by ice when it covers tidal flats. Tidal flats ice, still landfast, appears in the background.

Figure 10. Cap-Rouge, zone supérieure de l'estran. Motte de terre tenue par des débris végétaux, tiges et surtout racines, apportée par la glace au cours du printemps 1956 sur l'estran de Cap-Rouge. A noter la rareté des blocs à la surface de cette partie de l'estran.

Cap-Rouge, upper tidal zone. A mound of sediment held by vegetal debris, stems and roots, brought by ice during the spring of 1956. The scarcity of boulders lying on this part of the tidal flats is to be noted.

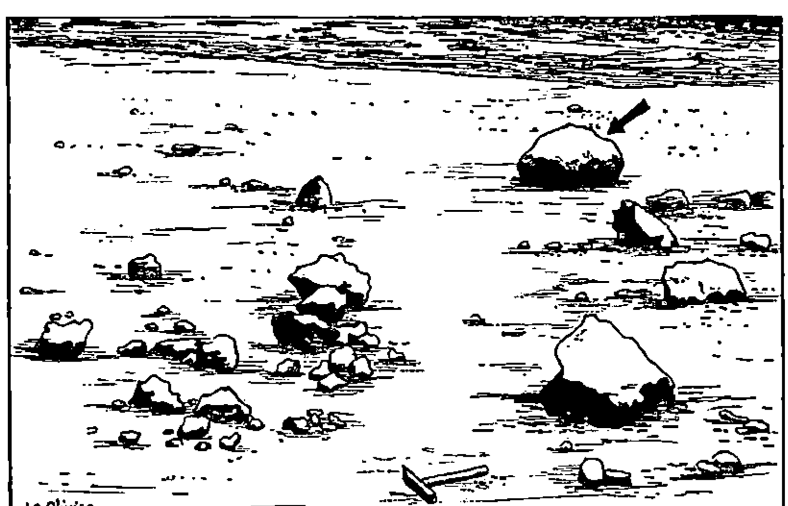

Figure 11. Cap-Rouge, zone supérieure de l'estran. Au premier plan: fragments anguleux de quartzite déplacés par la glace à partir d'un affleurement voisin. Au second plan, à l'endroit de la flèche un bloc de granite apporté par la glace au printemps 1956. A noter à l'arrière-plan, l'estran plat avec de rares blocaux. Le substratum est constitué de schistes arasés, recouverts d'une mince couche de sable ou de boue. On devine au loin le premier des alignements de blocaux à la limite de basse mer.

Cap-Rouge, upper tidal zone in foreground: angular fragments of rock displaced by ice from a nearby outcrop. Behind, a granite boulder (indicated by arrow) was brought by ice in the spring of 1956. Note the level nature of the tidal flats and the scarcity of boulders in the background. The bedrock is composed of an eroded schist surface covered by a thin layer of sand or mud. In the upper part of the photo the first chain of boulders at low-tide limit is shown.