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AN INVESTIGATION OF THE INTERTIDAL SATURATION LEVEL AS IT RELATES TO SHORE PLATFORM DEVELOPMENT

by

© Dennis W. Mercan

A Thesis
submitted to the Faculty of Graduate Studies
through the Department of Geography
in partial fulfillment of the requirements
for the Degree of Master of Arts at The
University of Windsor

Windsor, Ontario, Canada

1982

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ABSTRACT

Saturated or critically saturated intertidal rock has been assumed to be essential for chemical or frost weathering to planate shore platforms in tropical or cold environments. Experimental results revealed that the saturation of rock within the intertidal zone varies with the submergence period, tidal head pressures, and rock type. There is no level of permanent saturation of rock within or above the intertidal zone. Field evidence has confirmed the conclusions of laboratory experimentation. The gradual transition of low saturation values at high tide to nearly saturated rock at the low tidal elevation is contrary to the assumption that there is a distinct break between weathered and unweathered rock within the intertidal zone. Therefore, the theory that shore platforms develop at the level of permanent seawater saturation, below which subaerial weathering cannot proceed, is untenable.

DEDICATION

There is a tide in the affairs of men,
which, taken at the flood, leads on to fortune;
Omitted, all the voyage of their life
Is bound in shallows and in miseries .

- Shakespeare, Julius Caesar, iv,iii

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CHAPTER 1

INTRODUCTION

1.1 Nature of the Problem

Shore platforms are gently sloping erosion surfaces extending seaward from a marine cliff. Although they are the fundamental erosion forms of coastal geomorphology (Fairbridge, 1968), there is no agreement as to their formative processes. This is because of the fact that they exist in a myriad of coastal environments, where different processes operate to varying degrees. It has been estimated that shore platforms occupy 20-30% of the world's shorelines (Trenhaile, personal communication), yet these features have been studied in less than a dozen countries.

'Shore platform' is a morphological term which is genetically neutral, unlike the term 'wave cut platform' which it has generally replaced. Whenever the feature is being discussed, controversy arises over which processes are responsible for its formation. This controversy can be represented by the wave cut and weathering theories. These theories represent the two extremes of a spectrum of platforms, on which both wave erosion and weathering have operated to varying degrees (Trenhaile, 1980).

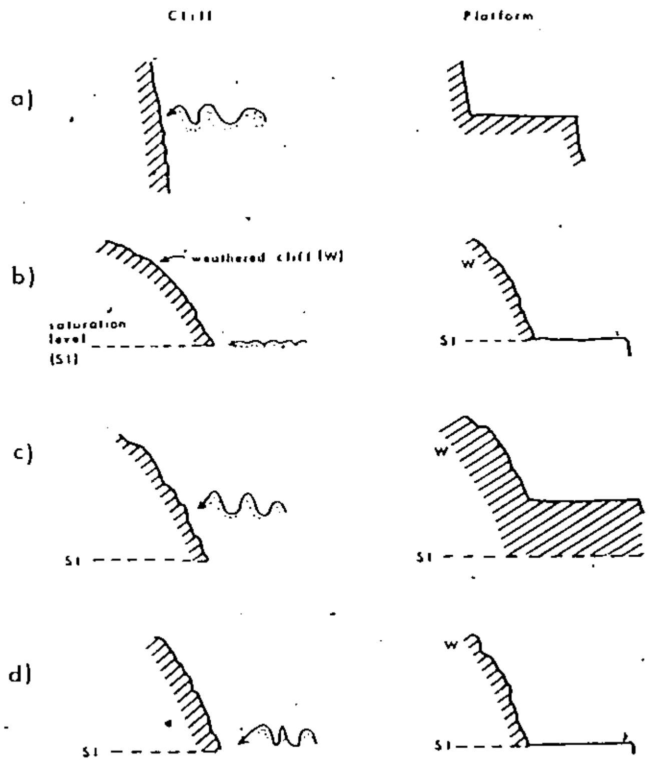
Proponents of the weathering theory believe that horizontal platforms cannot be cut by waves, which, because of tidal and weather variations, operate over a large vertical range. They considered that weathering, which acts down to the level of permanent saturation, is the process involved. Proponents of the wave cut theory, however, maintain that shore platforms are related to the concentration of wave energy, as determined by the level of the tides.

1.2 Previous Research

Shore platforms have been studied for more than a century. Two schools of thought have dominated the research conducted on shore platforms (Trenhaile, 1980). One group has considered that storm waves are capable of eroding sub-horizontal surfaces (Bartrum, 1924, 1935, 1938; Johnson, 1933; Jutson, 1931, 1939; Edwards, 1941, 1951), while the other group has insisted that subaerial weathering is essential for the development of horizontal surfaces (Wentworth, 1938, 1939; Hills, 1949, 1971; Gill, 1967, 1972; Bird, 1968; Davies, 1972) (Fig. 1). As a result, platforms in the tropics and in warm temperate regions were believed to be the result of a variety of chemical and organic weathering processes, whereas those in the cool temperate latitudes were believed to be formed by vigorous wave action. In high latitude and polar regions, shore platforms were usually ascribed to either physical weathering by frost, or a combination of frost and wave action (Nansen, 1922; Moign, 1974ab; **Guilcher**, 1974).

Early coastal work in the northern hemisphere, particularly in environments where storm wave activity is vigorous, has concentrated on mechanical wave erosion as the

FIG. 1 Shore Platform Formation Theories



a) Wave cut - no significant cliff weathering. Platform at level of greatest wear (Bartrum 1924).

b) Bartrum's (1916) Old Hat platform. Platform is at the saturation level. Weak waves wash away weathered debris.

c) Platform cut by waves in weathered material at the level of greatest wear (Dana 1849).

d) Differential wave erosion. Platform at saturation level. Waves erode weathered debris (Edwards 1958).

Source:
Trenhaile
(in preparation-a)

process which develops shore platforms (Dela Beche, 1839; Ramsey, 1846; Davis, 1896; Fenneman, 1902). Although there were early workers who believed that effective wave erosion of coastal cliffs is aided by subaerial weathering, or that subaerial weathering is a necessary condition of platform development (Jukes-Browne, 1893; Geikie, 1903), more recent research in the northern hemisphere has mainly continued to support mechanical wave erosion.

However, in the Pacific, and particularly in Australasia, many workers have held that subaerial weathering is the major process responsible for the formation of shore platforms (Bell and Clarke, 1909; Wentworth, 1938, 1939; Hills, 1949, 1971; Gill, 1967, 1972; Bird, 1968, Davies, 1972). Frost, and possibly ice, is important in the storm wave areas of the northern hemisphere. Particularly in the more northern latitudes, frost shattering was believed to have rapidly eroded cliffs and formed coastal benches, with the weathered debris removed by wave and ice action (Nansen, 1922; Andersen, 1968; Sollid et al., 1973). Gray (1977) accounted for a late glacial platform in the southern Scottish highlands by rapid frost shattering, and it is certainly active on the cliffs and shore platforms of eastern Canada (Dionne, 1972; Trenhaile, 1978; Guilcher, 1981; Trenhaile and Rudakas, 1981).

1.2.1 Wave Erosion

Several workers since Dana (1849) and Bartrum (1924) have maintained that **horizontal** shore platforms are the direct product of wave erosion (Johnson, 1933, 1938; Jutson, 1931, 1939; Edwards, 1941, 1951). Some workers have briefly mentioned the possible relationship between platform gradient and width and tidal range (Davies, 1972; Edwards, 1958; King, 1959), and recent work in storm wave environments of the northern hemisphere has established the occurrence of these relationships (Trenhaile, 1971, 1972, 1974a, 1978). Trenhaile (1974a) believed that this might be suggestive of the fact that the horizontal platforms of Australasia are the product of wave erosion in microtidal and mesotidal environments rather than the product of weathering. This possibility is further supported by the presence of horizontal platforms in the cool, mesotidal environments of Gaspé (Trenhaile, 1978) and western Newfoundland where chemical weathering of the cliff is negligible, and steeply sloping platforms (3.5°) in the macrotidal Bay of Fundy. It finds further support in mathematical models which attempt to simulate the development of platform profiles (Trenhaile and Layzell, 1980, 1981; Trenhaile, in press-a). Furthermore, in the only investigation of an Australasian environment where chemical weathering of the cliffs is an important process, but in a macrotidal environment (Edwards, 1958), the platforms of Yampi Sound were found to "slope uncharacteristically" (Davies, 1972) relative to those elsewhere in Australia, where it should be noted, mesotidal or microtidal ranges dominate.

1.2.2 Chemical Weathering

Le Chatelier's principle has been used to provide the basis for explaining chemical reactions in the weathering of minerals. The principle states that any system in equilibrium will react to restore equilibrium if any force is applied to the system. Rocks which were formed under conditions of high temperature and pressure within the earth are in disequilibrium when located on or near the earth's surface. The adjustment of these rocks to more stable mineral phases under the existing conditions in which they are found results in the weathering of these rocks (Loughnan, 1969).

All chemical weathering begins with the interaction of water on the mineral surface, resulting in a chemical alteration of the mineral. The fundamental process of the weathering environment is leaching by water at low temperatures (30°C) relative to their formative temperatures, in atmospheric pressures ranging from that at sea level to that of the highest mountains (Carroll, 1970). Leaching is the selective removal of chemical constituents which are soluble or which form stable hydrophilic colloid solutions from rocks through the action of percolating water (Yariv and Cross, 1979).

Some of the more important weathering processes are: hydrolysis, solution, ion exchange, oxidation and reduction, and hydration. For the purpose of this study, a brief synopsis will suffice.

Hydrolysis: Hydrolysis in the weathering process refers to the reaction between H^+ and OH^- ions of water and the elements (or ions) of a rock or mineral. Water, with its content of cations and anions is the reagent that causes hydrolysis (Carroll, 1970). Hydrolysis occurs in the **stage when the** H^+ ions with their high **ionic potential readily** penetrate the mineral surface and breakdown the silicate structure (Loughnan, 1969). For rocks to weather by hydrolysis requires water, but the complete weathering of a body of rock by hydrolysis requires more than a single saturation of the rock with water. Therefore, hydrolysis is implemented not by saturation of the rock with water that is immobile, but rather by the repeated renewal of fresh water which leaches away the soluble products of the hydrolysis reaction as the water passes through the rock. The volume of water that is available for leaching tends to condition the pH of the weathering system and thereby influences the kinds and amounts of the weathered products (Keller, 1957).

Solution: In nature water is never "chemically pure," but is always a solution, however weak, of other substances. All substances occurring in the atmosphere and lithosphere are soluble to some degree in water, although their relative susceptibilities to solution differ widely (Reiche, 1950). When water comes into contact with minerals, dissolution of the minerals begins and continues until equilibrium concentrations are attained in the water, or until all the minerals are consumed. The solubility of a mineral is defined as the mass of the mineral that will dissolve in a unit volume of solution under specified conditions (Freeze and Cherry, 1979). Solution may be active on any lithology which has a significant carbonate content, or a carbonate cement (Trenhaile, 1980), despite the fact that seawater is normally saturated or super-satured with bicarbonates (Wentworth, 1939).

Ion exchange: This is the reaction between H^+ AND OH^- ions of water with ions of the mineral, to form soluble products. Many solid minerals, when placed in contact with water, display a marked tendency to replace certain loosely held ions with ions of the same sign from solution, without changing the structure of the substance. Cation exchange refers to the loss and gain of positively charged ions, while with negatively charged ions, anion exchange is obtained. The continual leaching of the soluble products facilitates this process, as opposed to saturation with nonmoving water (Keller, 1957). Reiche (1950) stated that the more common chemical weathering is a matter of piecemeal ion exchange, and Carroll (1970) agreed, adding that it is the most important process in the chemical weathering of rocks.

Oxidation and reduction: This is the process of the losing of an electron and the gaining of a positive charge in the atomic structure of a substance. Although O_2 is involved with the weathered material, oxidation may also occur via dissolved O_2 in water. This process generally operates in the zone of aeration, proceeding more readily in more alkaline solutions (Ollier, 1969), and is extremely slow in strongly acid solutions (Stumm and Lee, 1961). Reduction cannot be separated from oxidation, for both reactions are governed by the redox potential of the system. One reaction will occur in conditions which have changed from those which were favourable to the other reaction. Many silicate minerals contain cations that are easily converted into another oxidation state. A change in the redox potential in the environment of such minerals may cause oxidation or reduction of these cations (Ollier, 1969).

Hydration: This occurs when a clay mineral adsorbs water, thereby incorporating an H+ ion into its structure, albeit weakly. This process results in pressures due to the swelling of the mineral surface, and is the deterioration of a rock due to temperature dependent wetting and drying, producing the same effect as freezing and thawing (Hudec, 1980).

Carroll (1970) stated that the effect of the various processes of weathering reacting with rocks is shown by mineralogical, chemical, and grain size changes in the weathered material compared with the unweathered rock. The weathering processes proceed simultaneously; they are interrelated and therefore the chemical weathering of rock is a complex occurrence. For weathering to continue, an open system must exist, i.e. removal of some weathered products from their point of origin, which then receives an infusion of renewed weathering agents. The end goal is the development of a dynamic equilibrium for that particular weathering environment.

1.2.3 Subaerial Weathering in Low Latitudes

Because low latitude coasts are dominated by swell wave environments (Davies, 1972), most workers in this region have concentrated upon other processes which may be active in producing shore platforms. Dana (1849) believed that the rapid weathering of cliffs in hot, wet climates resulted in the formation of shore platforms. The level at which the rock is permanently saturated with seawater marks the lowest intertidal elevation to which the coastal rock is weathered. Rather than suggesting that shore platforms develop at this saturation level, however, he postulated that waves cut platforms into the weathered cliff at the 'level of greatest wear.' The first workers to propose that platforms developed at the saturation level were Bell and Clarke (1909); however, the waves were not responsible for cutting the platform out of the coastal cliff, as their function was only to remove the debris which collected on the platform surface. This kind of platform was termed 'Old Hat' by Hochstetter in 1864 (see Trenhaile, 1980). Yet it was Bartrum (1916) who first asserted that subaerial weathering of the coastal rock down to the saturation level was the fundamental process which produced Old Hat platforms. He stated that Old Hat platforms were located 'slightly below high water level' (1924). Since Bartrum believed that the unweathered and hence more resistant rock below the saturation level was protected from wave erosion, and that waves were only capable of washing away the weathered material above the saturation level, it follows that he concluded that the permanent saturation level of coastal rock to be just beneath the high tide elevation. He qualified his theory, however, by stating that these platforms develop only in impermeable rocks which are free of joints, and in locations which are sheltered from strong wave activity. He therefore considered the Old Hat platform to be 'abnormal,' and rather rare (1916, 1926). In spite of the fact that these platforms were said to be highly uncommon, many workers have reported their occurrence, often in quite exposed environments (Edwards, 1958; Bird and Dent, 1966; Healy, 1968; Russell, 1971).

Although others have referred to the Old Hat platforms, not all of these workers have agreed with Bartrum as to the precise formative processes. Bartrum had not received full support for his contention that waves are incapable of producing Old Hat platforms, nor that they develop just below the high tide elevation. Hii (1962, 1963) proposed that platforms develop intertidally, where wave abrasion removes the weathered covering of rock; Fairbridge (1952) argued that the saturation level, and the platforms which it controls, are close to low tidal level. Most Australian workers have asserted that subaerial weathering is necessary for the development of horizontal platforms, because even though they concede the ability of waves to erode cliffs in exposed areas, the elevation at which waves operate and their intensity are too variable to produce Old Hat platforms (Wentworth, 1938, 1939; Hills, 1949, 1971; Hawley, 1965; Gill, 1967; Sanders 1968a; Bird, 1968; Davies, 1972).

Trenhaile (1980) remarked on the inconsistency of weathering theorists who applied the Old Hat classification to shore platforms which did not meet all the criteria which Bartrum carefully enunciated. These subsequent workers often inferred that the existence of a sheltered location or weathered cliffs were sufficient evidence of the occurrence of Old Hat platforms. Trenhaile further stated, in opposition to Bartrum, that the original Old Hat platform, along with other horizontal platforms on adjacent islands, are too resistant, despite being weathered, to attribute their formation to weak waves merely removing the debris. He maintained that a platform is not necessarily of the Old Hat type because of the presence of a weathered cliff; rather, the fact that the platform surfaces are wider on the more exposed seaward sides of the islands indicates that wave erosion is vital to their development. Because he had distinguished between Old Hat platforms produced by weathering in sheltered environments and platforms cut by waves in more exposed areas, Bartrum (1935) implicitly related platform morphology to the wave energy of the environment (Trenhaile, 1980). Bartrum had stipulated that weak waves only remove the weathered debris from the platform surface, whereas later workers have argued that waves cut the platform out of the weathered cliff face. The difference between these two positions is crucial, because the question of whether or not the cliff is weathered is irrelevant to understanding platform morphology, if wave erosion is significant in such situations. For example, rather than developing at the saturation level of coastal rock, as theorized by the weathering school adherents, the platform will develop at the level of maximum wear as a result of wave activity, as hypothesized by Dana (1849)(Trenhaile, 1980).

Various physical and chemical weathering processes undoubtedly operate on the cliffs and in the intertidal zones of low latitude coastlines (Pricart, 1972; Consentius, 1975). There is little reliable evidence to support the suggestion that waves either wash away or erode the weathered debris from above the saturation level (Trenhaile, in preparation-b). It appears then, that the only element held in common by the various Old Hat theories for shore platform development is the necessary existence of a coastal cliff which has been weathered down to the elevation at which the rock is permanently saturated with seawater. This saturation level acts as a control to determine the vertical position within the intertidal zone at which the platform will develop. This level of permanent saturation of coastal rock is the crucial premise of the weathering theorists' different arguments for shore platform development.

Although there is no agreement as to the development of horizontal platforms via weathering, all weathering theorists agree that the saturation level distinctly separates the weathered rock above it from the unweathered rock below. It has long been thought that acidic environments are essential for weathering, which is restricted to the zone of aeration, i.e., the zone above the water table (see, for example, Cotton, 1942; Reiche, 1950). Although ~~Reiche~~ (1950) believed that the lower limit of effective alteration of minerals is the water table, Ollier (1969) stated that in the saturation zone the pores in rock are water filled, possibly resulting in the alteration of some minerals by anaerobic bacteria, reduction, hydrolysis, and ionic exchange. Although the flow of water in the discharge belt towards the top of the water table is probably sluggish, so that chemical reactions would proceed slowly and tend to attain equilibrium conditions, it nevertheless allows for the removal of solutes. The rate of weathering above the water table is therefore thought to be as much as 20-30 times greater than weathering below it (Birot, 1968).

Although much work has been conducted with respect to deep weathering of the regolith (Campbell, 1917; Nye, 1955; Ollier, 1965; Watson, 1964; Thomas, 1965; Lelong and Millot, 1966), the relationship between the depth of weathering and water movement and availability may be complex (DeSwardt and Casey, 1963; Thomas, 1974). The interface between weathered and unweathered rock is gradual, and poorly defined. Although the transition may be distinct in basic rocks in the tropics (Chorley, 1969), very little work has concentrated on the capillary fringe in rock, and so the nature of this weathered/unweathered interface is poorly understood. The position of the base of the groundwater zone, rather than that of its surface, determines abrupt changes in the weathering front, and even in such circumstances, the boundary is usually irregular, rather than being a horizontal plane (Ollier, 1969).

The water table may be accurately located in rocks which contain a large amount of water, either because of their high porosity or because they are very fissile. In rocks which are nonporous water is found only in existing fractures, making it very difficult to locate the water table, as some cracks may be dry while others are full of water. The ground water, in such cases, is discontinuous, resulting in an irregular weathering front, with projections of impermeable rock found above adjoining weathered rock (Trenhaile, in preparation-b).

Within the intertidal capillary fringe, which is an extension of the saturation zone into the vadose zone (Bear, 1972), oxidation and reduction alternate in response to tidal oscillations (Carr and Van der Kamp, 1969; Thomson, 1979). The resultant weathering, because of the total effect of these processes, may be greatest near the low tidal level, based upon the findings of Mercan (1980). In his preliminary study of the relationship between tidal oscillations and the intertidal water level, the low tidal level was found to have the highest degree of saturation; this was not unexpected, since rock near the low tidal elevation is water covered for the longest time during a tidal cycle. However, Trenhaile (in preparation-b) stated that it is possible that even just above the low tidal elevation rock may not be submerged for the length of time necessary for permanent saturation to occur within the intertidal zone. He asserted that there is a lack of firm support for the contentions that weak waves removing the weathered debris from coastal cliffs form shore platforms, or that stronger waves carve these features at the elevation of the weathering front on coastal cliffs. Both of these propositions are based on the unfounded assumptions that: there is an intertidal saturation level; that it separates weathered from unweathered rock; and that the water table is smooth and horizontal.

1.2.4 Subaerial Weathering in High Latitudes

Many of the chemical and mechanical weathering processes operative on coastlines in the mid and low latitudes occur in high latitude regions also. Because chemical weathering is usually believed to be retarded by the coldness of the high latitudes (Kelly and Zumberge, 1961), mechanical weathering processes, more suited to the environmental conditions, may dominate shoreline modification. The coastal landforms of cold regions might be distinguished from those which have developed in warmer climates because of the zonal peculiarities resulting from frost shattering and other related processes. Although the climatic conditions of very high latitudes are not optimum for effective frost action, it may be of greater importance in sculpting the coastline than wave activity. This is because of the fact that not only are the waves weaker, but also that the coastline is protected by ice for most of the year (Trenhaile, in press-b).

With respect to shore platform development in polar regions, there are those, on the one hand, who believed it to be slow (Bird, 1967; Zenkovitch, 1967; Davies, 1972; French, 1976) and those on the other who believed it to be quite rapid, as evidenced by recently eroded platforms (Jahn, 1961; Araya and Herve, 1972; Galkin and Nichols, 1972; Sollid et al., 1973; Moign, 1973, 1974ab).

Frost action is most likely to be of greatest importance in the following areas: the northern United States, southern Canada, Ireland, Scandinavia, around the shores of the Japan Sea, and southern South America (Trenhaile, in press-b). Scandinavian researchers have long recognised the relationship between frost action and coastline modification (Rekstad, 1915; Vogt, 1917). Contemporary workers have likewise used Younger Dryas frost shattering to account for intertidal shore platforms in resistant rocks located in sheltered environments in western Scotland (Sissons, 1974; Gray, 1977; Dawson, 1980), and in northern Norway (Andersen, 1968; Sollid et al., 1973). Even shore platforms which were cut into chalk by waves in southern England, which generally has a mild climate, were recently reported to have been damaged when they froze during an especially severe winter (Williams and Robinson, 1981).

The severity of frost shattering within the intertidal zone has been recognised by coastal engineers (Cook, 1952; Kennedy and Mather, 1953; Gjorv, 1965; Gjorv et al., 1965; Seki, 1975; ACI 1980). Kennedy and Mather (1953), working in Maine, recorded 30-40 freeze thaw cycles in one year for an inland location, compared with over 200 frost cycles in the intertidal zone. Since the upper portion of the intertidal zone experiences freeze-thaw cycles related to air temperatures as well as those caused by the rise and fall of the tides, the high tidal elevation may be subjected to the greatest number of freeze-thaw cycles. It is not really known, however, how the duration, freezing or thawing rates, or range of temperature fluctuations about the freezing point of freeze-thaw cycles affects rock disintegration (Trenhaile, in press-b).

The operation of frost shattering within the intertidal zone is a complex phenomenon. Critical saturation of the rock and retention of the water during freezing are essential for effective frost action (Lewis, et al., 1953). The absorption period is longest at the low tidal elevation, and the rate at which rocks take up water is also probably greatest here. This is because of the pressure exerted by the tidal head. It is also necessary for the water within the critically saturated rock to freeze, so that destructive pressures will be generated which will damage the rock. Under ideal conditions, water which freezes within a rock may generate enormous tensile pressures against the confining rock walls (Winkler, 1973). The tensile strength of even the most resistant rocks are less than 10% of the theoretical maximum ice pressures which could be generated (Rzhersky and Novik, 1971; Trenhaile, in press-b), although maximum pressures are probably unattainable in the field.

The degree of saturation of the rock at the time of freezing is a major factor in determining the efficacy of frost shattering within the intertidal zone. Because of the expansion which occurs as water freezes, if the degree of saturation of a rock is $<91.7\%$, assuming uniform distribution of water within the rock, then the crystal growth may be contained without it generating damaging pressures. Fagerlund (1975) stated that because water is rarely equally distributed within a rock, some rocks may have degrees of critical saturation much less than 91.7%. Each porous material has its own well defined critical saturation level, so that the values are different for different materials; there is, therefore, no general critical degree of saturation. Fagerlund argued that frost damage does not occur, even after many frost cycles, if the actual degree of saturation does not at any point within the structure exceed the critical degree of saturation. However, he found that the degree of saturation changes all the time, as it normally increases with the number of freeze-thaw cycles. Full consideration of the principle of critical degrees of saturation requires knowledge of the moisture distribution within a rock, as well as either the critical degree of saturation itself or the rock properties which determine the critical degree of saturation, in all parts of the rock; unfortunately these data are extremely difficult to attain.

Critical saturation may be very difficult to realize under natural conditions (Ver beck and Landgren, 1960).

Saturation is controlled by the rock's permeability and porosity, as rocks with higher porosities take longer to critically saturate, given the same permeability. Pore size and pore size distribution are also involved. A rock with a fine pore structure reaches critical saturation more rapidly than a rock with a coarse pore structure, even if the rocks have the same porosity. For rocks with similar pore size distributions, the one with the higher porosity requires more time to attain critical saturation than the one with the lower porosity (Ver beck and Landgren, 1960). Although rocks with large capillaries may be the first to absorb water, they are also the first to lose it when they are no longer immersed (Fagerlund, 1975).

This basic mechanism of nonuniform distribution of water within a rock has led many workers to report frost damage to rocks with saturation levels below the absolute critical level of 91.7%. Kreuger (1923) found the critical degree of saturation to be on the order of 85%. MacInnis and Lau (1971) also ascribed frost damage to critical saturation levels below 91.7%, but did not provide any value for this lower level; Hudec and Rigbey (1976) believed it to be as low as 80%. Other workers not only correlated frost damage with the degree of saturation, but also found that frost shattering is more damaging in saltwater solutions. This is because saline waters not only increase the osmotic pressures which are involved in frost shattering, but also because higher degrees of saturation are attained and retained by the material during freezing (Powers, 1975; Litvan, 1976; MacInnis and Whiting, 1979). Therefore, the freezing of saline solutions is more deleterious to rock than is freshwater (Cook, 1952; Goudie, 1974; Williams and Robinson, 1981; Trenhaile and Rudakas, 1981). The salinity levels of solutions which have been found to result in the most damage range from 50% to 150% of the normal salinity of seawater (Arnfeld, 1943; Ver beck and Klieger, 1957; Browne and Cady, 1975; Litvan, 1976; MacInnes and Whiting, 1979; Trenhaile and Rudakas, 1981). In coastal situations where porous, fine-grained rocks of low tensile strength may achieve high levels of saturation, frost shattering appears to be most deleterious (Trenhaile, in press-b).

The central issue to be focused upon in high and mid latitude coastal regions, is whether or not frost shattering, acting alone, can produce shore platforms. Although the mechanics of frost action in modifying coastal landforms are not completely understood, several workers consider that frost shattering and planation may produce shore platforms in sheltered environments, where wave action is weak (Andersen, 1968; Sollid et al., 1973; Sissons, 1974; Gray, 1977; Dawson, 1980). As the coastal cliff recedes as a result of frost action, a platform or rough intertidal ramp may result, but moderately smooth horizontal surfaces which occur throughout a variety of rock types cannot necessarily be ascribed to frost action (Trenhaile, in press-b). It is ne[illegible]sary to distinguish, however, between those processes which are responsible for cliff recession, and those which are responsible for the planation of the residual surface; they are not necessarily the same. Physical weathering of coastlines may be dominant in sheltered locations, but if the waves are not capable of removing the resultant debris, the process cannot operate efficiently (Bird, 1967; Howarth and Bones, 1972; John and Sugden, 1975; Trenhaile, in press-b). This debris apron is probably the result of intensive frost shattering, as it is quite pronounced on such cliffs which are frequently wetted (Taber, 1950; MacKay, 1963). This has convinced many workers of the important role which frost shattering plays in the modification of coastal cliffs in cold environments. There are, still, other workers who have downplayed the effectiveness of frost action in these environments because of the pattern of freeze-thaw cycles (Cook and Raiche, 1962; Gardner, 1969; Thorn, 1979).

The formation of strandflats, particularly where they occur in sheltered locations and hence have not been exposed to vigorous wave activity, are believed to be the result of freeze-thaw activity (Rekstad, 1915; Vogt, 1917; Nansen, 1922; Grønlie, 1924; Nordenskjold, 1928; Holtedahl, 1960). Nevertheless, strandflats are widest and best developed on capes and in other exposed areas, where frost and wave action can operate together (Nansen, 1922). In other high latitude coastal environments, strandflats and recently developed shore platforms have been ascribed to the combination of wave action and frost shattering, as in Spitsbergen

(Moign, 1973, 1974ab; Guilcher, 1974). In the St. Lawrence Estuary of eastern Canada, the icefoot removes the debris which has resulted from both solution and frost action working on the cliff (Corbel, 1958). In the latter area, however, especially where a variety of rock types exist, there is no evidence to suggest that physical weathering actually planates intertidal shore platforms, even though such processes may assume an important role in the retreat of cliffs which are saturated (Trenhaile and Rudakas, 1981).

Although Nansen (1904) originally believed that the combination of wave and frost action was responsible for the development of the strandflat, he later proposed that frost-action associated with the icefoot produced shore platforms from coastal cliffs (1922). However, it seems that his revised theory is partly based on the false premise that frost action resulting from the freezing of freshwater is more deleterious to coastal cliffs than the freezing of seawater. Although this position was supported by others (Guilcher,1958; Davies, 1972), it was previously noted (p.21) that experimental work has shown that saltwater solutions are actually more damaging.

If frost is capable of planating subhorizontal surfaces, it must be shown that its efficiency markedly deteriorates rock above a fixed datum within, or slightly above the intertidal zone. Nansen (1922) thought that because the rock underwater is protected against frost action, and because of the location of an icefoot at the high water level, frost action may have its greatest effect on coastal rock above mean sea level. Trenhaille (in press-b), however, maintained that there is a lack of convincing evidence to support the claim that frost shattering operates down to a specific datum, and many geological and engineering experiments suggest that it does not. He asserted that the formation of planated surfaces at the cliff base is not sufficient evidence to accept the claim that frost action is the formative process involved, even though he conceded that the recession of coastal cliffs in sheltered high latitude areas may be largely the result of frost shattering. Rather, he stated that frost in high latitudes does essentially the same thing as chemical weathering in low latitudes -- it helps to weaken rocks sufficiently to permit platform erosion by waves in areas, or in rocks, which would not otherwise be suitable for platform development. In more exposed areas or weaker rock, frost shattering is not essential (Trenhaile, in press-b).

1.2.5 Rock Saturation

It is evident that much of the previous research into shore platforms has been concerned with the intertidal elevation at which coastal rocks are saturated. However, this has usually involved assumptions, rather than direct investigation. It is necessary, therefore, to also consider laboratory research into the saturation of porous media, so that a better understanding of the relevant properties will be achieved. This will then benefit a later discussion of the intertidal saturation elevation of coastal rock, as the resistance of rock to weathering processes in many environments is determined by the degree of water saturation within the rock. Additional factors which complicate matters are the presence of salts and the temperature induced phase change from the liquid to the solid state. These factors vary between environments, producing weathering rates dependent upon the conditions at each location.

Studies of mechanical weathering of rocks (i.e. frost action) have revealed the same kinds of phenomena as those observed with concrete and cement paste. The results of work on the durability of concrete to frost, which is also relevant to the consideration of the efficacy of chemical weathering processes, can therefore be applied to rocks.

1.2.51 Porosity and Permeability

The effective porosity of a rock is its volume of interconnected pore space expressed as a percentage of the total volume of the rock. The permeability of a rock is its capacity as a porous medium to transmit fluid, and indicates the rate of fluid flow under pressure. Porosity determines the amount of water that can be contained within a rock, whereas permeability controls the movement of water within the rock.

Corey (1977) identified six factors which affect the porosity of a rock. They are: 1) structure - porous media with structure have larger porosities than media without structure 2) grain shape - flat platelets can be packed so that porosity is lower than for spheres; it is also possible to stack platelets so that porosity would be greater than that for spheres 3) grain-size distribution - rock with spheres of varying sizes has a smaller porosity than one consisting of spheres of a single size 4) mixing - rock with spheres of two different sizes but with each segregated into different regions will have the same porosity as a rock with a single size of spheres; however, if the two sizes are mixed, the porosity will be reduced 5) packing - individual grains may be tightly packed, resulting in low porosity, or loosely packed, resulting in higher porosity 6) cementation - the volume of cementing material reduces the porosity; consequently consolidated rocks typically have smaller porosities than unconsolidated deposits.

A given porosity can be the result of either a small number of large pores or a larger number of small pores. In the former case, the internal surface area is small, whereas in the latter case it is large. The response of carbonate rocks to weathering has been found to be directly related to the internal surface area and the average pore size (Hudec, 1978).

Hudec (1973) stated that the finer the grain size the larger the porosity, but the smaller the pore size; since pores are interconnected via a large number of capillary openings, pore size and pore size distribution become critical when considering rock as a capillary system. The properties of grain-size, porosity, and permeability are relevant to an explanation of rock weathering based upon saturation, as they determine a rock's ability to sorb water, the movement of that water within the rock, and also the rate of water desorption from the rock (Lewis, et al., 1953).

Materials that contain no water will not be damaged by disruptive pressures which require water in order to be generated (e.g. frost action); for damage to occur, critical conditions of water content and lack of drainage must be present. The size and continuity of the pores control the rate of sorption and, similarly, the rate at which water can escape from the material (Lewis, et al., 1953). The rates of water sorption and desorption will determine in part the type and also the intensity of the disruptive pressures generated within the rock.

The freeze-thaw durability of rock depends mainly upon the rock's ability to achieve a high degree of saturation in the environmental situation, and to maintain this saturation level during freezing. The harmful pore size is large enough to permit water readily to enter a high percentage of the pore space but not so large as to permit easy drainage (Lewis, et al., 1953).

Test results of pore size determinations on building stone were reported by Schaffer (1932); he found the critical pore size to be $<5\mu$, i.e., water was sorbed into these pores, but not easily desorbed. The volume of pores having diameters $<5\mu$ was correlated with the resistance of the stone to freezing and thawing. Sweet (1948) and Fears (1950) also correlated the volume of pores $<5\mu$ in diameter with freeze-thaw susceptibility, and found that they were not as durable to frost action as rocks with the larger pores.

On the other hand, some rocks seem to have 'built in' escape boundaries, which are naturally occurring macroscopic voids that seldom, if ever, become water filled (Powers, 1955). Willman (1944) found a good correlation between resistance to freeze-thaw damage and macroscopic porosity for dolomite. If the number of macroscopic voids per unit volume absorptive rock is right for the permeability, porosity, and strength of the rock substance around the macroscopic voids, the rock cannot be damaged by freezing (Powers, 1955). Lewis, et al., (1953) also found a poor correlation between frost resistance and total porosity. These results support Howe's finding (1910) that the type of porosity is more important than the total pore volume.

1.3 'a priori' model

The relationship between processes responsible for shore platform development and platform morphometry has been studied extensively (Everard, et al., 1964; Sanders, 1968ab; Wood, 1968; Phillips,1970; Wright, 1967, 1969, 1970; Suzuki et al., 1970; Takahashi and Koba, 1975). Trenhaile (1972, 1974ab, 1978) has related the platform gradient and the height of the cliff-platform junction to wave fetch, tidal range, and tidal levels. He proposed a storm wave shore platform model (1978) which indicated that the platform slope is dependent upon the tidal range, and that the mean platform elevation is dependent upon the mean tidal elevation. Mathematical modelling has confirmed the validity of these relationships (Trenhaile and Layzell, 1980, 1981; Trenhaile, in press-a).

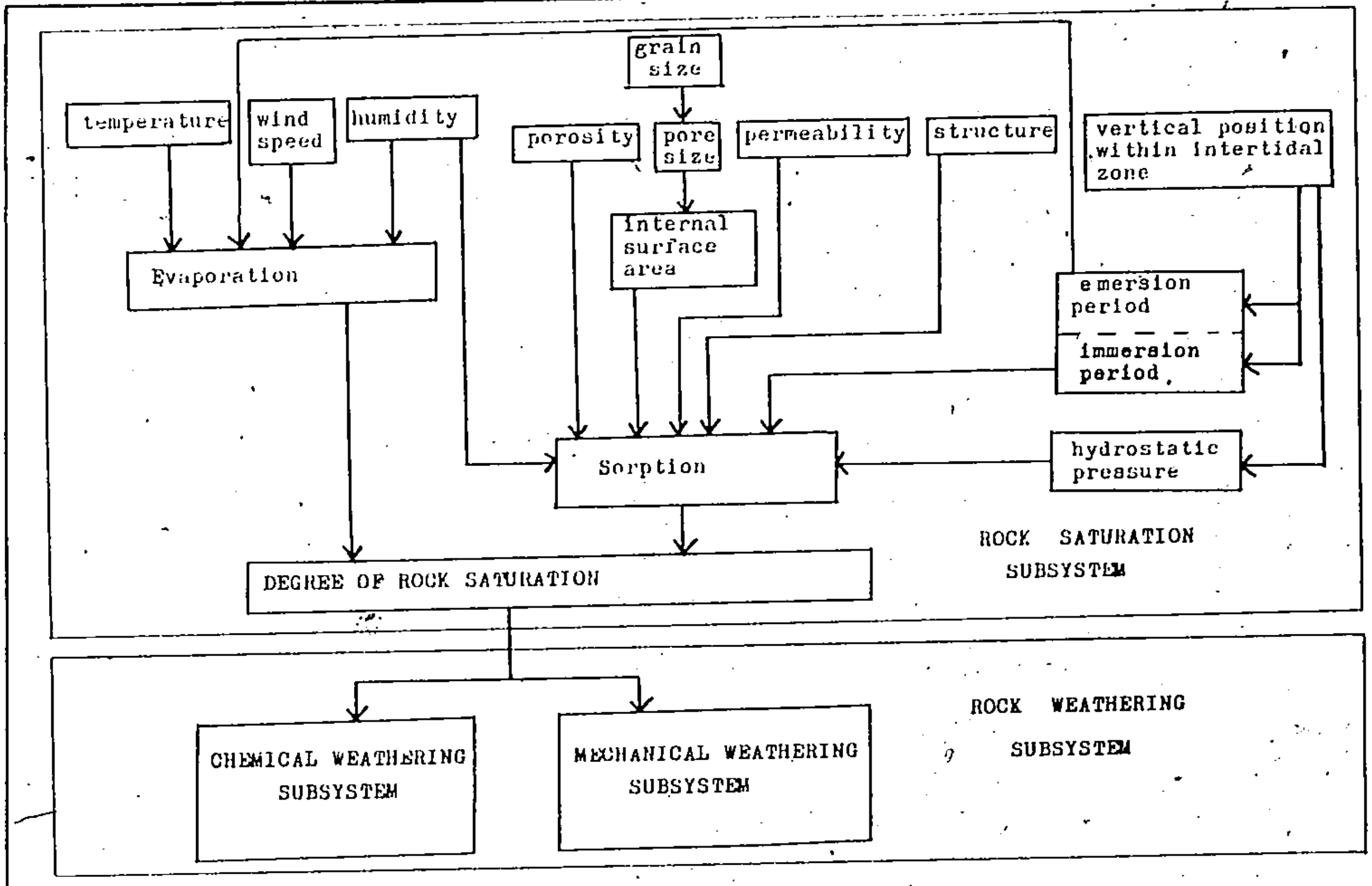


FIG. 2 WATER DEPENDENT ROCK WEATHERING SYSTEM

A model is a formal representation of the researcher's image of the real world, which portrays those relationships that are of greatest interest to the investigator. Not all possible or known relationships are portrayed, as the level of complexity would be too great, thus hindering the understanding sought of the real world situation. The level of abstraction from the real world will determine the scope of the study. However, a careful examination of the selected environmental aspects will provide a more complete understanding of the environmental system's functioning, thus approaching a 'white-box' situation (Harvey, 1973).

Previous research on the nature of the saturation of porous materials is extensive, and has resulted in the generation of rock saturation models (e.g. Hudec, 1980). These relationships have been integrated with others to produce an '*a priori*' model (Fig. 2) of rock weathering, which is dependent upon water saturation for the attendant processes to disintegrate the rock. This study is concerned with the saturation subsystem, as the output of this subsystem acts as an input to the rock weathering subsystem.

Within the saturation subsystem, the degree of saturation is mainly determined by sorption. The influence of the tides has been investigated by Mercan (1980), who found that the degree of saturation in intertidal rock varied inversely with height above the low tidal level. It is well known that pressure beneath the water's surface increases with depth, so that when the tide submerges coastal rock, greater hydrostatic pressure will be exerted upon rock at the low tidal elevation than upon rock at the high tidal elevation. Because rock is a porous medium capable of sorbing water, when the water is under pressure, it will be forced into the porous rock. Therefore, the greater the hydrostatic pressure, the greater will be the amount of water which is forced into and taken up by the rock. The length of the submergence period will depend upon the intertidal elevation of the coastal rock. Rock at the high tidal elevation is submerged for the shortest period of time, while that at the low tidal elevation is submerged the longest. Rock which is submerged for a longer period will have a greater opportunity to sorb water than coastal rock which is submerged for a much shorter time period. Hence, differences in the degree of saturation will exist within the intertidal zone.

The absorption of water is related to lithological and structural variations; fractures increase the amount of water a rock can hold, whereas porosity affects the amount of water absorbed and permeability affects the depth of absorption. The position of the water table (saturation level) is lower down in permeable than in impermeable rocks (Penck, 1953). These properties influence the amount of water a rock can hold, and they vary between the different types of rock.

Hudec (1978) has determined that sorption sensitive rocks (fine-grained argillaceous rocks which critically saturate with mainly adsorbed water) can saturate under conditions of high relative humidity. These rocks do not have to be submerged in order to be in a critically saturated state. In this case, when the rock is exposed to the atmosphere with a high relative humidity, then water will be retained within the rock and a saturated state may occur, or be maintained.

The aforementioned relationships constitute the sorption aspect of saturation. The evaporation aspect of saturation for intertidal rocks occurs during the emersion period, and involves reducing the amount of water retained by the coastal rock. The wind, air temperature and relative humidity determine the rate of evaporation from an exposed surface. Although these variables are important in determining the water retention capability of coastal rock, they will not be studied in the laboratory but will be studied in the field. They are presented here in order to more fully illustrate the environmental situation, so that the determined scope of the study (saturation of coastal rock because of tidal factors) can be adequately related to the larger picture of coastal rock saturation.

Therefore, the tidal factors which are believed to influence rock saturation within coastal environments will be examined to determine the extent of their relationship to saturation levels within the intertidal zone.

1.4 Hypotheses

Based upon the '*a priori*' model, the following hypotheses will be evaluated:

Hypothesis 1) the intertidal degree of saturation of coastal rock varies according to: a) elevation (position) within the intertidal zone. This is composed of two elements - immersion period and tidal head; b) rock type. Hypothesis 2) there is no level of permanent saturation of coastal rock within the intertidal zone or within the supratidal zone.

1.5 Purpose of the study

Although chemical and mechanical weathering of rock requires saturated or critically saturated states for these processes to operate (within the context of shore platform development), previous research has merely assumed this to be the environmental reality. The purpose of this study then, is to indirectly investigate the saturation of coastal rock within the intertidal zone.

An attempt has been made to develop a tentative saturation model of intertidal rock using the relevant aspects of tides. These include: tidal range, tidal type, intertidal elevation of the shore platform surface, and the salinity level. This model facilitated the attempt to determine degrees of saturation in coastal rocks, and the determination of whether there is an absolute saturation level within the intertidal zone. The intertidal level of permanent saturation of coastal rock is essential to theories of shore platform development based upon weathering. The merits of such an argument will be assessed in this study. The scope of this study will be restricted to a preliminary determination of the static degrees of saturation of coastal rock resulting from the tides, i.e., water flow within rock because of pressure, gravity, etc. will be disregarded.

Most of the study is concerned with a laboratory determination of the degrees of saturation of intertidal rock. Field work was also conducted, however, so that the laboratory results could be compared and supplemented with the results from the field. Although desorption was not studied in the laboratory, this phenomenon was investigated in the field, so that a more realistic conception of the environmental conditions could be developed. This feedback mechanism allows for the improvement of the 'a priori' model, with the intent of facilitating future work in this area.

CHAPTER 2

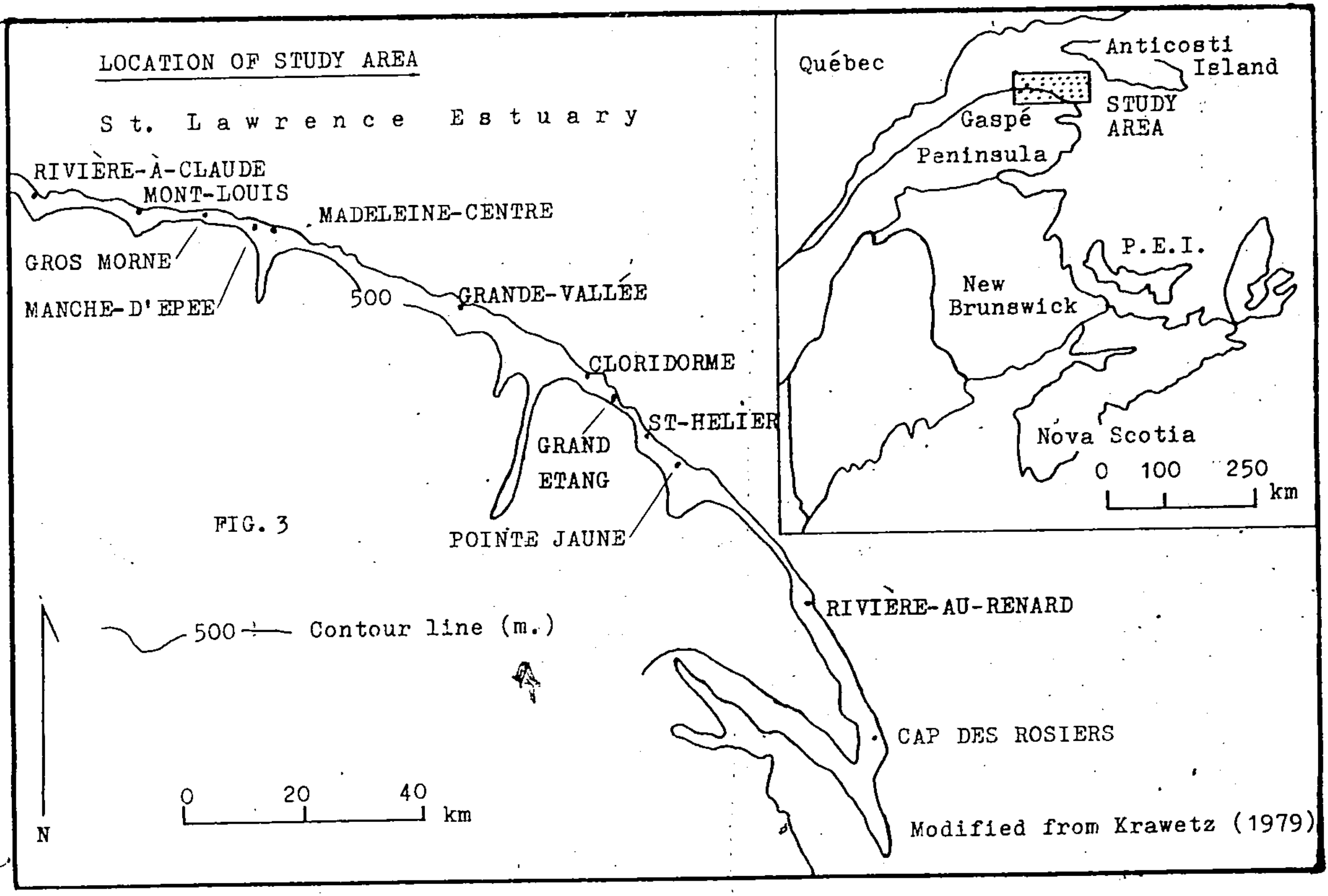
THE STUDY AREA

2-1 Location

Shore platforms occur sporadically for 600 km along the southern shoreline of the St. Lawrence Estuary, between Québec City and Cap-des-Rosiers. The eastern part of this region is the Gaspé Peninsula. The study area is contained within the eastern most 140 km (Rivière-à-Claude to Cap-des-Rosiers) of the Gaspé Peninsula (Fig. 3). The St. Lawrence Passage, which separates the peninsula from Anticosti Island, represents the northern boundary of this region. The coastal cliffs of the Notre Dame Mountains (the northeastern limit of the Appalachian Mountain system) mark the southern boundary of this region.

2-2 Geology

The mid-Ordovician Norman Skill Formation extends northeastward from Virginia to the Gaspé peninsula. North of the St. Lawrence River, the rock formations consist of thin, flat lying limestones and shales overlying the Precambrian basement (Canadian Shield). On Anticosti Island outcrops of upper Ordovician rock occur, while on Mingan Island rock outcrops of lower to lower-middle Ordovician occur (Twenhofel, 1938). Beneath the Jacques Cartier Passage, between Anticosti and Mingan Islands, temporal equivalents of the 'Cloridorme' Middle Ordovician flysch sequence can be found.



LOCATION OF STUDY AREA

FIG. 3

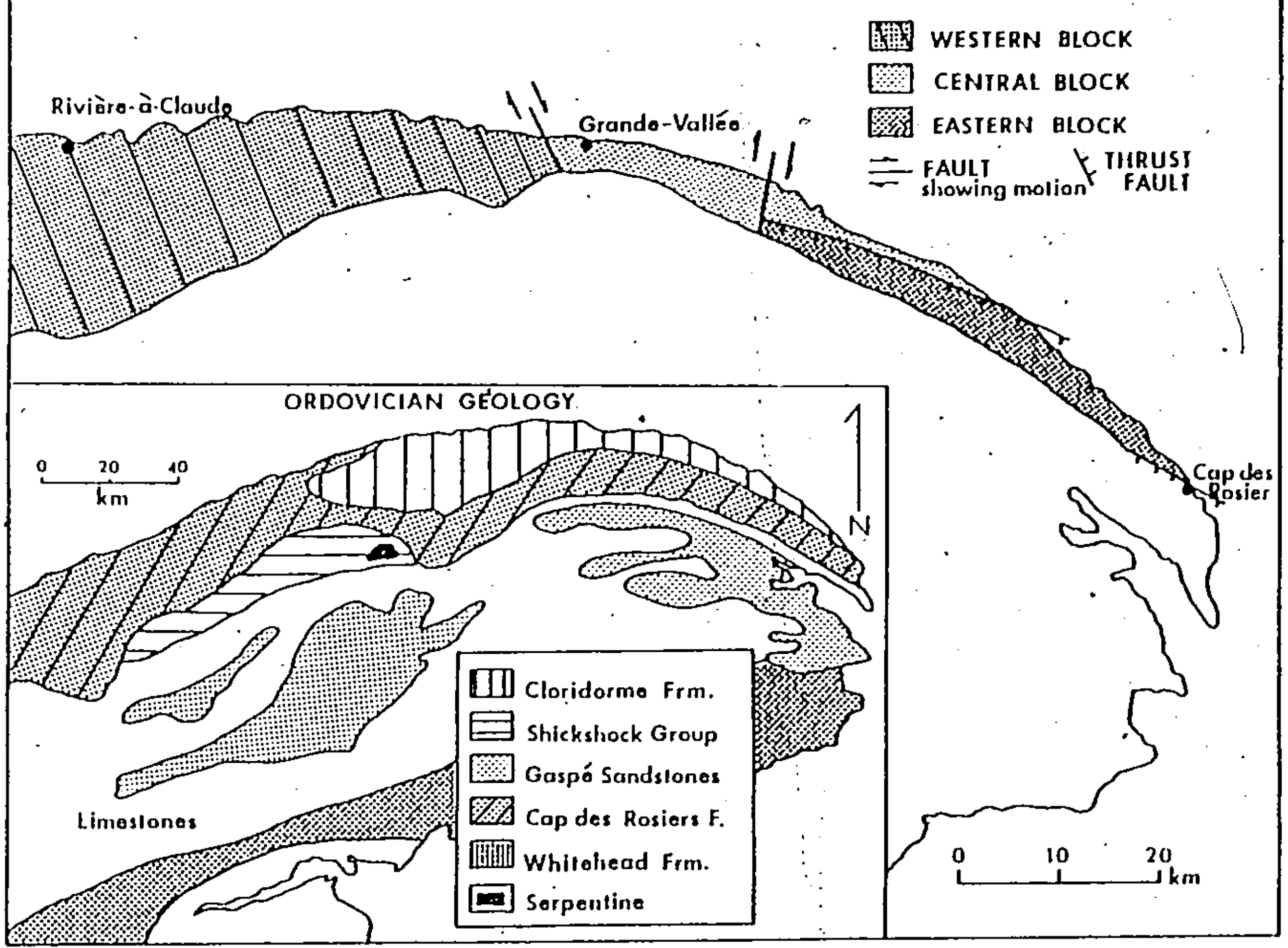
Modified from Krawetz (1979)

Although similarities between the New York and the Gaspésian rocks exist, the apparent lack of continuity in the intervening 500 km of rock makes the use of the term 'Norman Skill' unsuitable, and so the preferred reference to the Gaspé Ordovician flysch is as the 'Cloridorme Formation' (Enos,1969a).

The middle Ordovician and other older formations which were tightly folded during the Taconic Orogency (Neal, 1961), were later covered by the middle Silurian and lower Devonian miogeosynclinal limestones and shales of the central Gaspé synclinorium with angular unconformities (Cummings, 1939). The deposition of terrigenous clastics (Gaspésian sandstones) in the eastern peninsular region occurred later, in the early Devonian period, and spread throughout the area by the middle Devonian period (Logan, 1863; McGerrigle, 1950). During the Acadian Orogency open folds developed before the Carboniferous deposition in the basin underlying the Gulf of St. Lawrence (Alcock, 1924).

The structural configuration of large amplitudinal, assymmetrical folds with some thrust faulting of the middle Ordovician flysch is typical of the Appalachian Valley and Ridge Province. Although the flysch is of low metamorphic grade, the slatey cleavage is well developed in argillaceous rocks (Enos, 1969b). The middle Ordovician rocks of the Gaspé peninsula are divided into three distinct blocks (Fig. 4). The Eastern block (extending from Jersey Cove to Pointe Jaune), consists of only one major fold. It is located at Anse-au-Griffon, and is a steep-limbed, open syncline plunging 5°E with a

GEOLOGY OF STUDY AREA FIG. 4



Source: Enos, 1969ab; as modified from Krawetz, 1979.

wavelength in excess of 3 km. Coastal exposures consist of several southwest dipping homoclines. Near the contact with the Cap-des-Rosiers Formation at St. Helier, L'anse-a-Valleau, Rivière-au-Renard and Jersey Cove, minor folds occur. The Central block is separated from the Eastern block by a thrust fault extending west from Pointe Jaune. It is composed of three large folds overturned to the north and two smaller folds plunging 4°E. Extending for approximately 900 m from Pointe de Cloridorme westward are minor folds with plunges up to 45°E and W. The Western block, which is separated from the Central block by a transverse fault 5 km west of Grand Vallee, is defined by an anticlinal fold extending eastward towards the Central block and plunging from 20°W at Manche-D'Epee to 3°E at Madeleine-Centre.

The thickness of the Cloridorme Formation is estimated to be 7700 m, consisting of dark, slaty argillite (about 60% of the total rock), interbedded with coarse graywackes (15%), calcareous wackes (3%), calcisiltites (20%), and a few beds of pelagic rock (dolostone, limestone, volcanic ash, and silty dolomitic argillite) (Enos, 1969b).

The occurrence of: thin beds of terrigenous and carbonate clastics interbedded with pelagic argillite; distinctive sedimentary structures such as flutes, grooves, tool marks, ripple and convoluted laminations, graded beds; and fragmented benthonic fossils in the coarser clastic beds are the three factors which indicate that turbidity currents deposited the graywackes, calcareous wackes, and calcisiltites (Enos, 1969a).

The argillites, which are 50% pelagic in origin, exhibit a dark gray colour in either the weathered or unweathered state, and are very susceptible to weathering processes. Beds have been found to be up to 4.3 m thick (Enos, 1969b).

According to Enos (1969b), the Cloridorme Formation can be subdivided into 14 stratigraphic units grouped into three sequences. Each sequence is confined to one structural block -- the 'α' sequence with 3 members is confined to the Eastern block, the 'β' sequence with 7 members is confined to the Central block, and the 'γ' sequence with 4 members is confined to the Western block.

2.3 Oceanographic Characteristics

The Gaspé peninsula has been classified as a meso-tidal storm wave environment (Davies, 1964, 1972; Trenhaile, 1980). The area experiences semi-diurnal tides with two complete tidal oscillations daily, the tides being somewhat mixed in height (Canadian Tide and Current Tables: Canada, 1975). The tidal range in this area is between 2.25 and 3.4 m (Trenhaile and Rudakas, 1981). The enclosed shape of the Gulf of St. Lawrence shelters the coastline from oceanic swell and in most cases eliminates the swell effects altogether. This is because the short fetch distances limit the development of whatever locally induced swell waves are generated. The wave environment is dominated by storm generated waves, although their effectiveness is reduced by the short fetch distances of 80-170 km, which are determined by the location of the coastline on the St. Lawrence Estuary and the nearness of Anticosti Island. The storm waves are limited in height and efficacy because of the variable wind direction, which does not favour the generation of waves over a preferred fetch direction for long periods of time. Significant wave heights greater than 1.4 m with wavelengths of 20 m occur only 10% of the time during the summer months. The presence of littoral and sea ice during the winter also inhibits wave activity. Sea ice limits wave activity by preventing wave generation or dampening existing waves for four months of every year along the Gaspé coast, from as early as mid December to as late as early May (Owens, 1974).

2-4 Shore Platform Morphology

The coastline of Gaspé runs parallel to the main geological structures which influence the genesis and form of the 600 km of shore platforms located along the southern St. Lawrence Estuary, between Québec City and Cap-des-Rosiers. The continuity of these platforms along the coastline is occasionally disrupted, especially in embayments. These platforms have elevations which are close to that of mid tide, and are characterized by the following elements: a) the platform surfaces are quasihorizontal and usually display wash-board like relief; b) a steeper sloping ramp is located at the cliff-platform junction; and c) an abrupt terminus marks the seaward end of the platform (Trenhaile, 1978).

A steeper sloping ramp marks the junction of the platform surface with the cliff base. This junction is close to the elevation of the high tide, which also marks the upper level of marine planation.

Platform slopes, which are generally less than 0.75^{o}, are determined by the tidal range. Surface drainage reflects the degree of planation of the platform. Those with steeper surface slopes drain rapidly and more completely than platforms which are more horizontal. However, geological surface conditions exert an important influence upon drainage. The direction of the rock dip determines drainage direction, as platforms which are better drained have seaward dipping strata, compared to the drainage of platforms with landward dipping strata. Rivière-à-Claude marks the boundary between well and poorly drained platforms. The seaward dipping (18^{o}) platforms to the west are well drained while the landward dipping (25^{o}) platforms to the east are poorly drained. Platforms with steeper dipping beds allow much of the free water to collect in depressions, making them drain slowly. This is particularly evident at Mont-Louis and Gros Morne (Trenhaile, 1978).

Changes in lithology are reflected by changes in platform width and steepness. At Gros Morne, Grand Etang, and St. Maurice, the combination of resistant graywackes and argillites give rise to the shortest and steepest platforms in Gaspé. At Grand Vallee and Cloridorme, the widest and most horizontal platforms have developed in thick shales interbedded with thinner graywackes and argillites. Platform width varies between 30 and 100 m, with high cliff areas usually associated with narrow platforms. The rate of cliff retreat is also related to platform width, as the widest platforms were observed on headlands (e.g. Cloridorme) and where cliff recession was inactive, as evidenced by the growth of vegetation on the cliff face (Trenhaile, 1978).

Many platforms in Gaspé end in steep, lithologically and structurally controlled cliffs or ramps at their seaward margin. Although this is a characteristic feature of platforms in microtidal and mesotidal environments, it is generally absent in macrotidal regimes. Trenhaile (1978) described four categories of shore platform termini: a) gently sloping ramps where well planated platforms had developed; b) step-like low tide ramps which are structurally controlled; c) low tide cliffs which are also structurally controlled; and d) low, structurally controlled scarps.

CHAPTER 3

METHODOLOGY

3.1 Introduction

The method of study used involves two aspects: laboratory experimentation and field work. The purpose of the laboratory work was to use the salient parameters as defined in the scope of the study in order to simulate selected environmental conditions. The purpose of the field work was to compare the corresponding results of the laboratory work with the actual conditions which were found to exist in Gaspé. This acted as a guide in the assessment of the a priori model and the laboratory experiments which were derived from it.

3.2 Laboratory Experimentation

3.2.1 Sample Collection and Preparation

Five rock types were used in the laboratory experiments. The limestone was obtained from along the banks of the Detroit River. The other four rock types were obtained from the Muskoka Lakes region of Ontario. Only samples large enough to permit many rock cores to be extracted were selected for use in the study. This allowed for the experimental effects to be averaged between the cores for that particular rock type.

Before the rock samples could be used in any experiments, initial preparations were made. The first procedure dealt with the extraction and preparation of the rock cores. The cores were extracted from each rock sample, using a diamond-studded drill bit (2.54 cm diameter). The top and bottom of each core were cut horizontally using a diamond-studded circular saw, so that the length of the final core sample was 3.8 cm. The top and bottom of each core were removed so that the effects of pre-weathering would be minimal. The cores were next placed in an oven so that their dry weight could be determined (according to ASTM 1981, Part 19, C97-47, paragraphs 4-1 and 4-2): "Dry the specimens for 24 hours in a ventilated oven at a temperature of 105± 2° C (221± 3.6°F). After drying, cool the specimens in the room for 30 minutes and weigh. When the specimens cannot be weighed immediately after cooling, store them in a dessicator." The following modification to this procedure was made: after removal from the oven, the rock cores were placed in a dessicator and allowed to cool before being weighed. This prevented the cores from being exposed to any atmospheric moisture while cooling. After this was accomplished, the cores were returned to the dessicator and stored until needed.

Material from each rock type was then used in the identification of the samples. Only a brief mineralogical description of each rock type is given because it is not the intent of this study to look at the effects of water sorption upon the mineral composition of the rocks. The limestone which originated from a nearby quarry, had a very small amount of quartz. When hydrochloric acid was applied to the rock, an immediate and major reaction occurred, indicating that calcite was contained in the rock. This type of limestone is very porous. The remaining four rock types were all identified as having been metamorphosed, and are similar in nature. The quartzo-feldspathic gneiss (referred to hereafter as gneiss-A) was believed to originally have been a granite. It had a fine matrix with a minor component consisting of quartz and feldspar. The next sample was identified as a quartzo-feldspathic schist (schist-A). It was believed to originally have been a sedimentary rock, which had undergone metamorphism as indicated by the biotite, and also what appeared to be a band of darker coloured minerals in the sample. The next sample was identified as a quartzo-feldspathic gneiss (gneiss-B). It was believed to originally have been a sedimentary rock - perhaps a graywacke which had undergone metamorphism. The mineral grains were rather coarse and consisted of quartz, feldspar, micas, and garnet. The last rock sample was identified as a quartzo-feldspathic schist (schist-B) It too was believed to originally have been a sedimentary rock which was metamorphosed. It consisted mostly of quartz and feldspar, with minor components of biotite and hornblende. None of the metamorphic rocks reacted with hydrochloric acid, so no calcite was believed to be contained in these rocks. Also, the porosity of similar dense and unfractured crystalline rocks is estimated to be quite low - $\simeq$5% (Freeze and Cherry, 1979).

3.2.2 Preliminary Experiments

Next, the bulk specific gravity of the cores was measured. This was performed according to ASTM 1981, Part 19, C97-47. The procedure is summarized as follows: Determine the oven weight of the specimen. Immerse the specimen completely in distilled water for 48 hours. Surface dry the specimen and weigh it. Return the specimen to the distilled water and weigh the specimen while suspended in distilled water. Calculate the bulk specific gravity as follows:

Bulk specific gravity = A/(B-C)

where: A = weight of the dried specimen

B = weight of the soaked and surface dried specimen in air

C = weight of the soaked specimen in water

After the bulk specific gravity was determined (Appendix 1) the rock cores were returned to the oven to be dried in the manner previously described.

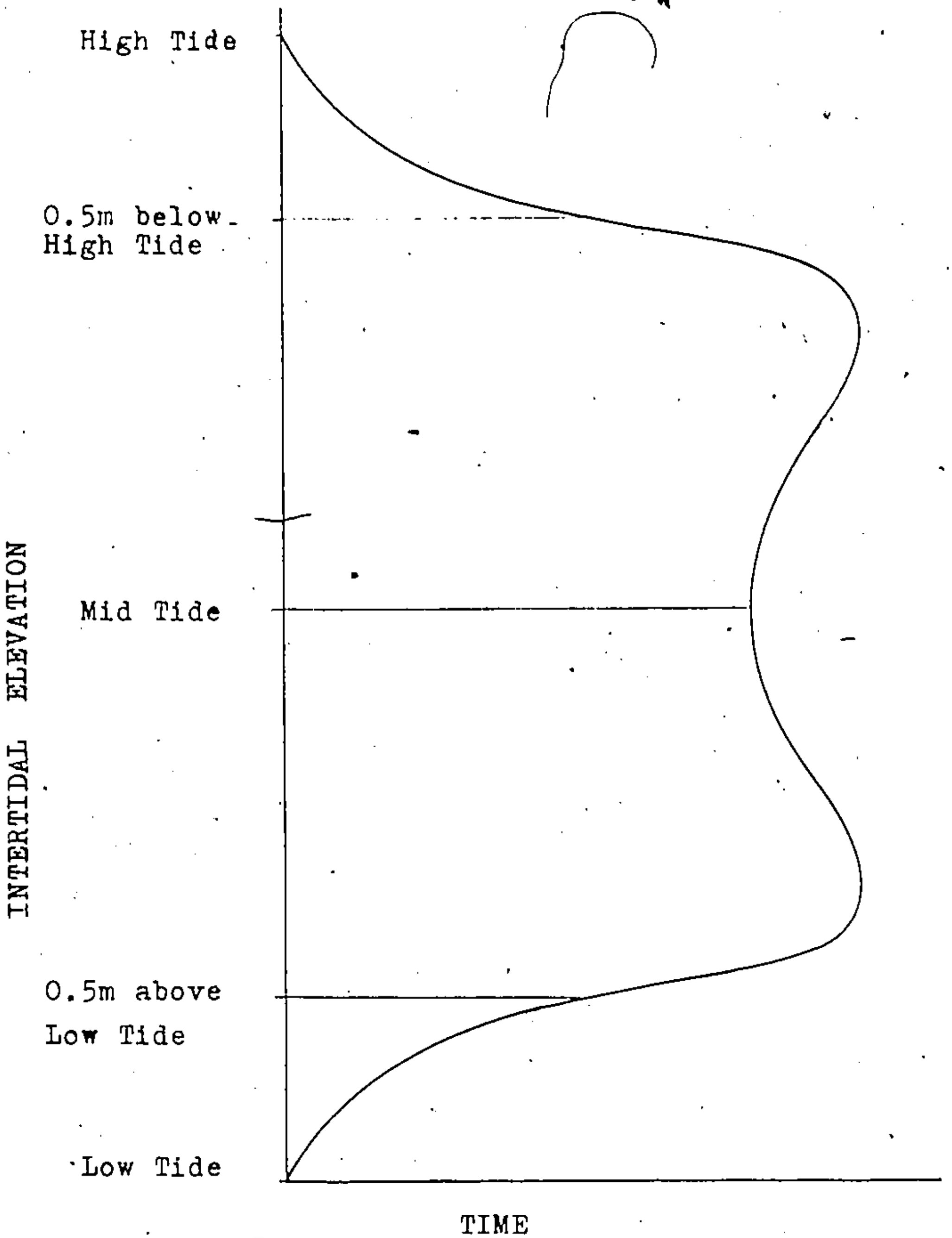
The next property to be determined was the amount of water adsorbed by each rock type during a 12 hour period. A 12 hour period was selected as the exposure time so that the results could be compared with those of other experiments to follow. The procedure was that outlined in ASTM 1981 Part 41 E 104-51, using only section 8-Precautions, which outlined the conditions under which the experiment was to be performed. The solution used to maintain a constant humidity was distilled water (CRC , 1974: see page E 46).

The entire apparatus was set up and distilled water was placed in the container 12 hours prior to the rock cores being placed in the container. This was done to allow the distilled water to saturate the air within the sealed container. The rock cores were next placed in the container, which was then resealed. Twelve hours later, the rocks were weighed and then oven dried in the manner done previously. As well, a temperature probe and hygrometer were placed within the sealed container, so that the relative humidity of the container could be calculated **(Appendix 2 - apparatus set-up).**

3.2.3 Experimental Design

A basic experimental design was constructed using certain key parameters which would allow for the simulation of the desired environmental conditions. These parameters include: tidal range, tidal type, intertidal elevation of the shore platform surface, and salinity level. The first **stage** of the experimental design required the construction of a model tidal duration curve (Fig. 5). The hypothetical curve represents the frequency with which the tides occur at each intertidal elevation, based on very long periods of time (years). On the model curve, the x axis indicates time as a proportion of the period of the tidal cycle. The y axis indicates the range of intertidal elevations, with the ends of the curve representing extreme low and high tide elevations. This hypothetical curve is derived from numerous actual tidal duration curves from each type of tidal range and tidal type. As can be seen, the curve is bimodal.

TIDAL DURATION CURVE (MODEL)



Tidal Range = 3m

FIG. 5

Modified from Carr and Graff (1982)

The peaks of the curve are located at the mean neap high tidal levels.

With respect to this study, the tidal range was chosen as 3.0 m. This represents a tidal range which is in the middle of the mesotidal classification. Most shore platforms in Australasia, which have been the subject of research by weathering theorists into horizontal shore platform development, are located within areas having small tidal ranges (approximately 3m-mesotidal) (Trenhaile, personal communication). Therefore, results of this study could be applied to that region. Also, the tidal range of Gaspé is between 2.25 m and 3.4 m (Trenhaile and Rudakas, 1981), allowing for a comparison between the lab work and the Gaspésian field work. A semi-diurnal tidal type (12 hours) was selected, as Gaspé experiences tidal cycles of this kind.

Returning to the tidal duration curve, it is now possible to determine how long a shore platform might be submerged or exposed, given a particular intertidal elevation. Since Bartrum (1916) Said that the level of permanent saturation is just below the high tide level, such a platform elevation was chosen for this study, one with an elevation 0.5 m below that of high tide. This platform elevation is used to illustrate how the tidal duration curve functions. The first step is as follows:

> let the y axis length between high tide and low tide elevations be L
>
> let the y axis length between high tide and 0.5 m below high tide elevations be l

Now, the position of 1 on the y axis is a proportional distance below the high tide elevation, i.e., 0.5:3.0 = 1:L. In this manner, the appropriate position on the y axis of a shore platform 0.5 m below high tide elevation has been determined.

The second step is as follows:

> draw a perpendicular line from the y axis at 0.5 m below high tide elevation to intersect the curve (call this line 1)
>
> let the entire area beneath the curve be A
>
> let the area beneath the curve which is above line 1 be a

Now, a:A = x:12 hours, where x represents the period of time during which the shore platform located at 0.5 m below high tide elevation is covered by water. The remaining time of a 12 hour period (12 hours - x) represents the period of time during which the same shore platform is exposed, i.e., not covered with water.

The above method can be used to determine the submergence and exposure periods for a shore platform at any elevation within the intertidal area.

The correlative to the submergence/exposure periods is the rate of rise and fall of the tides. Although, using the above method, it was theoretically determined that a shore platform 0.5 m below high tide elevation is water covered for 36 minutes of a 12 hour tidal cycle, the time it takes from first covering the platform surface to reach its greatest height above the platform surface (i.e., at high tide elevation) is a problem of far greater complexity. This is important with regards to the water sorption by the submerged rock. It is believed that the greatest amount of water sorbed by the rock will be associated with the greatest pressure exerted upon the rock by the tidal head. This may be because the most water will be taken up by the rock under the greatest force acting upon it when the pressure associated with the tidal head is greatest. That the greatest pressure is associated with the highest tidal head is easily demonstrated using the equation, $P = po + \rho gh$

where P = total pressure

po = atmospheric pressure (1.013×10^5 N/m^3)

ρ = fluid density (seawater = (1.025×10^3 kg/m^3)

g = gravity (9.80 m/s^2)

h = depth of water in meters.

Since all terms are constant except for h, it is seen that as h increases, P increases as well (Giancoli, 1980). Since the pressure associated with the tidal head forces water into the rock, the greater the pressure the greater the force acting upon the rock, and so the more water will be taken up by the rock. Since the greatest water uptake will occur during periods of greatest pressure, the duration of the period of greatest pressure is important in determining the amount of water taken up by the rock. The rate of rise and fall of the tides to and from the greatest height above the shore platform surface, coupled together with the duration period of the tides at the maximum height, directly influences the amount of pressure exerted upon the rock. This in turn influences the water uptake by the rock. However, it can be seen from a graph showing the rate of the rise and fall of the tides, and verified from field observation, that the tides rise and fall rapidly to and from the vicinity of the extremes of the tidal range, i.e., high and low tide elevations. Once near these extremes, the tides change very slowly, remaining near these levels for hours at a time. It would be extremely complex and beyond the level of this study to attempt to incorporate this phenomenon into the present work. Therefore, a simple compromise was chosen. It was decided that because of the nature of this problem, a linear relationship for the rate of rise and fall of the tides would be used in conjunction with submergence period (as determined by the model tidal duration curve) when simulating environmental conditions.

The next stage in determining the degree of saturation of intertidal rock involved another preliminary experiment. Since coastal rock undergoes cyclic welting and drying, it had to be determined just how many cycles were required before the rock attained its intertidal degree of saturation and maintained it, i.e., how many cycles are required before the degree of saturation is in equilibrium with its particular intertidal elevation? In order to determine this, a tidal simulator was used. Selected rock cores were placed on an elevated screen in one tub of the simulator. Artificial sea water with a salinity of 3.5%, prepared using Kalle's data (see Riley and Skirrow, 1975), then flooded the tub, submerging the cores for 6 hours. Six hours later, the water-filled tub drained, leaving the cores above any water and exposed for the next 6 hours. The cycles were therefore semi-diurnal in nature. The criterion selected for determining when the degree of saturation equilibrium was attained was paragraph 4-2 of ASTM Standard C 642-75, modified to fit this experiment. It reads "Immerse the specimen, after final drying, cooling, and weighing, in water at approximately 70°F (21°C)... until two successive weighings of the surface-dried sample... show an increase in weight of less than 0.5% of the heavier weight." Paragraph 5 of the same Standard outlines the procedure of making the calculations. "By using the weights determined in accordance with the procedures described in Section 4, make the following calculations:

Absorption after immersion, $\% = \left[(B-A)/A\right] \times 100$,

where A = grams of oven dried sample in air,

B = grams of surface-dry sample in air after immersion.

The experiment was conducted over 30 cycles, with measurements taken every 5 cycles. The results (Table 1, Fig. 6) indicated that the degree of saturation equilibrium had been reached after 15 cycles. On this basis, it was decided that the high tide saturation experiment would be conducted for 15 cycles.

3.2.4 High Tide Experiments

It was decided to experimentally determine the degree of saturation of coastal rock just below high tide elevation.

TABLE 1

SATURATION CYCLE TEST

ROCK TYPE	% WEIGHT CHANGE FROM OVEN DRY WEIGHT AT END OF CYCLE #					
	5	10	15	20	25	30
LIMESTONE	5.31	5.74	5.89	5.99	6.10	6.20
GNEISS-A	0.21	0.20	0.21	0.19	0.21	0.20
SCHIST-A	0.21	0.19	0.20	0.21	0.21	0.20
GNEISS-B	0.27	0.22	0.24	0.23	0.25	0.24
	DEGREES OF SATURATION					
LIMESTONE	69.5	75.0	77.1	78.4	79.8	81.3
GNEISS-A	96.7	92.3	95.8	88.6	94.9	91.3
SCHIST-A	88.8	84.2	86.5	85.9	88.6	89.2
GNEISS-B	100	91.3	97.7	95.3	100	99.4

N.B. Because of temporal restraints, the remaining experiments were not performed under the same conditions. If they had been, then higher degrees of saturation than were actually attained, would have been expected.

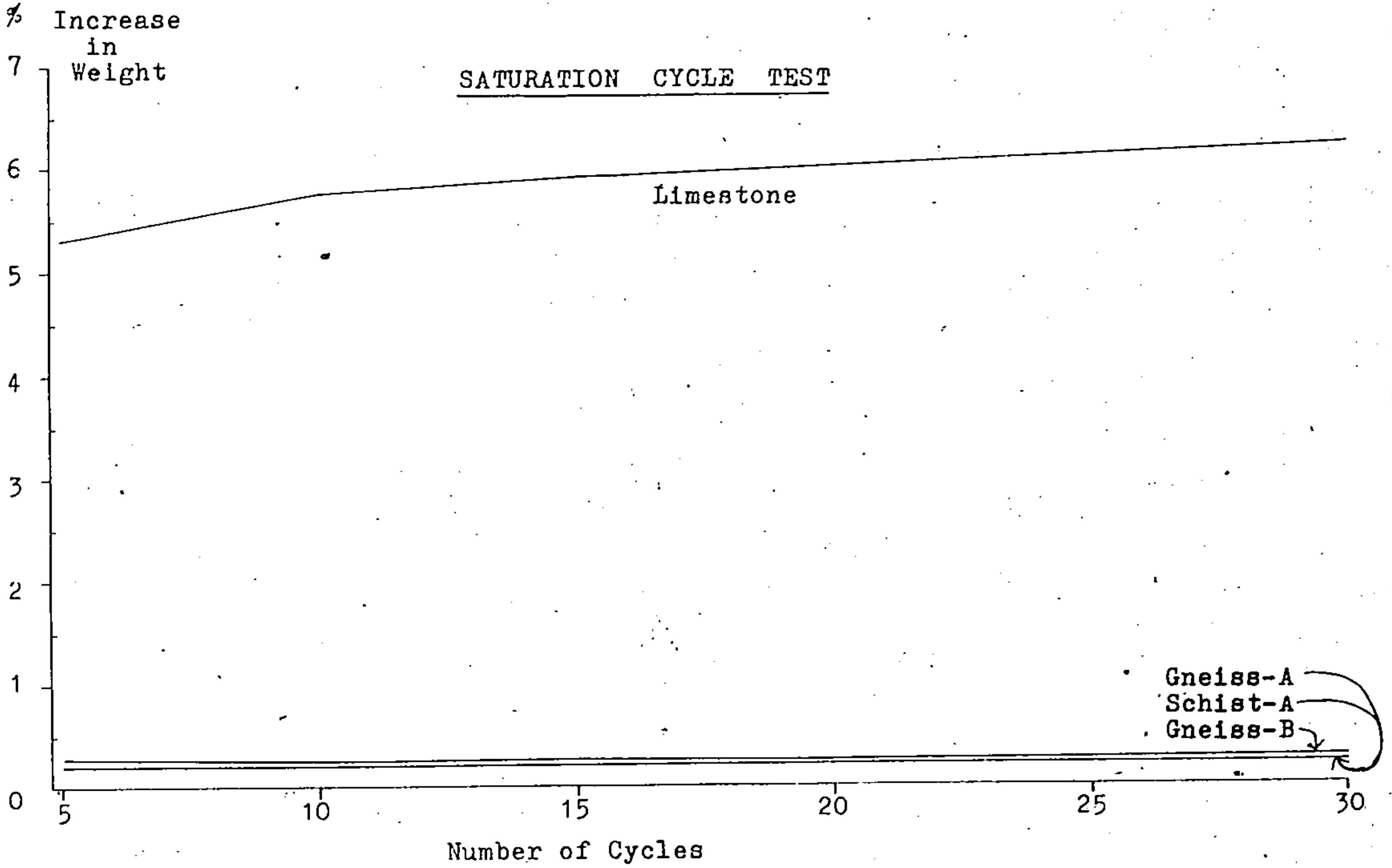

SATURATION CYCLE TEST
% Increase in Weight
7
6
5
4
3
2
1
0
Limestone
Gneiss-A
Schist-A
Gneiss-B
5
10
15
20
25
30
Number of Cycles

FIG. 6

This would allow for evaluation of Bartrum's claim that the level of permanent saturation of coastal rock is slightly below high tide elevation (high-water level). As previously stated, the height selected was 0.5 m below the high tide elevation. Using the model tidal duration curve, the submergence period was calculated as 36 minutes; a previously assumed linear rate of the rise and fall of the tides was also employed. The oven-dried cores were placed in a sufficiently deep plastic container, upon an elevated screen, so that when the water was drained from the container the cores would not be standing in water. The artificial sea water was introduced into the container and allowed to rise over the cores to a depth of 0.5 m over a period of 18 minutes. The water was then drained from the container, requiring another 18 minutes before the cores were exposed to the atmosphere. The cores remained exposed for the remainder of the 12 hour cycle. The experiment was conducted for a total of 15 cycles. Immediately after being exposed to the atmosphere after submergence in the 15th cycle, the cores were surface dried with a damp cloth and weight measurements were taken. When this experiment was completed, the cores were then oven-dried in the previous manner.

3.2.5 Mid and Low Tide Experiments

The experimental design used in the high tide experiment was not used for the current experiments, although theoretically it was possible. Simulation of the actual tidal head of 0.5 m was achieved in the high tide experiment, since this was not an insurmountable obstacle. However, simulating a tidal head of 1.5 m (mid tide elevation), 2.5 m (just above low tide elevation), or 3.0 m (at low tide elevation) would have been difficult to achieve. The problems involved were: finding a suitable container of the desired height which would withstand the generated pressures; ensuring that the container could be adequately drained so that the cores would not be standing in water; filling the container with the artificial sea water; and storing the increased volume of sea water needed when not in the tidal head simulation container.

Instead, the pressure exerted by the tidal head at each of these levels was calculated, using the equation for pressure on p.52. They are as follows:

1.5m = 0.148 atm.
2.5m = 0.248 atm.
3.0m = 0.297 atm.

These pressures were then converted into kilopascals (kPa) using 1 atm = 101.325 kPa, so that the cores could be placed in a pressure vessel and subjected to the same pressure as induced by the height of each tidal head. The converted pressure values are:

1.5m = 15.0 kPa
2.5m = 25.1 kPa
3.0m = 30.1 kPa

These values represent the pressure generated by the tidal head only, i.e., with respect to these tidal head values, atmospheric pressure = 0.

The next step involved determining just how long the cores should be pressurized under water. These pressures represent the maximum pressure exerted by the tidal head at each respective intertidal elevation at the time of high tide. Since high tide remains near the high tide elevation for hours at a time, periods of 1 and 2 hours were selected as the immersion periods. The experiment was conducted as follows: The oven-dried cores were placed on an elevated screen in a container and immersed in artificial seawater for the same length of time which they would be immersed in the pressurized vessel. After the immersion period elapsed, the water was drained and the cores were allowed to sit in the atmosphere for approximately 6 hours. This was performed for a total of 5 cycles. The reason for doing this was to allow the cores to achieve their degree of saturation equilibrium before being placed in the pressure vessel.

The cores were next placed in the pressure vessel and covered with artificial seawater. The vessel was then pressurized so that the total pressure upon the cores was 15.0 kPa. This pressure was maintained for 1 hour, after which the pressure was released and the rock cores weighed. Then the cores were returned to the pressure vessel, covered with water and pressurized so that the total pressure upon the cores was 25.1 kPa. This pressure was maintained for 1 hour, after which the pressure was released and the rock cores weighed. Then the cores were returned to the pressure vessel, covered with water and pressurized so that the total pressure upon the cores was 30.1 kPa. This pressure was maintained for 1 hour, after which the pressure was released and the rock cores weighed. After all the cores had been exposed to the selected pressure levels while immersed for 1 hour, they were oven-dried. The above procedure was repeated for an immersion period of 2 hours. After this series of experiments were conducted, the cores were oven-dried.

3.2.6 Vacuum Saturation Experiments

In order to determine the degrees of saturation for the preceding experiments, the total effective porosity of the rock cores (with respect to water content) had to be determined. The method used was vacuum saturation. The amount of water absorbed by this technique was assumed to be an accurate measure of the total amount of water which could occupy the interconnected pores of the rock cores.

The oven-dried cores were placed in a vacuum dessicator and the air was evacuated for 5 minutes, to a pressure reading of **-99.5 kPa.** This represents 96.6% of a complete vacuum. While the vacuum was maintained, oxygen-free (boiled) seawater was introduced into the vessel, covering the cores to a depth of $\simeq$5 cm. Once the cores were water covered, the vacuum in the chamber was released. Then, using Palm-N-Turn containers, each core was removed from the vacuum dessicator and transferred into the pressure vessel, which contained artificial seawater. At no time since the cores became submerged during the experiment were they exposed to the atmosphere. Once all the cores were in the pressure vessel and covered with artificial seawater, the vessel was pressurized so that the total induced pressure upon the rock cores was 103.4 kPa. This pressure was maintained for 12 hours. At the end of the vacuum saturation period, the vessel was depressurized and the rock cores weighed. The amount of water absorbed by the rock cores using the vacuum saturation technique represents the absolute saturation of the cores.

3.3 Field Work

A field trip to Gaspé was taken when the coastline was icefree so that samples could be collected from the shore platform surface. A mid tidal horizontal platform at Mont-Louis, which had been previously surveyed by Trenhaile (1978), was selected as the first study site. A reconnaissance of the platform was made before samples were taken. The platform was submerged to a depth of 0.76 m during higher high tide. When the platform surface became exposed after the higher high tide, pool samples and platform surface samples were collected. A total of 20 pool samples and 12 platform surface samples representing 10 rock types were collected (Table 2).

As each sample was collected, it was immediately weighed. Pool samples were selected because although on the platform itself, they might have been kept continually submerged if not exposed through drainage or evaporation of the pool. This allows a comparison between samples continually under water and those regularly exposed, at the same intertidal elevation. Thereafter, wet and dry bulb temperature readings were periodically taken using a sling psychrometer, so that the relative humidity could be calculated; at the same time weight measurements were taken throughout the remainder of the tidal cycle, so that the rate of water loss (or alternatively, the amount of water retention) of the rock could be determined. Weight measurements were taken at the following times after the initial platform exposure: 0,2,4,7 and 10.5 hours. Psychrometer readings were taken at the following times after the initial platform exposure: 0.5, 2.75, 4.5, 6.25, 7.75, 9.75, and 11.5 hours.

As well, 5 samples representing 3 rock types from the cliff face at the rear of the platform were collected (see Table 2). At the time of collection psychrometer readings were also taken. These samples were also weighed in the field. When all the measurements were recorded, the samples were placed in plastic bags and stored until needed.

A second mid tidal horizontal platform was also selected for study, at Madeleine-Centre. Again, a reconnaissance of the platform was made before samples were collected. It was determined that the platform was submerged to a depth of 0.76 m during higher high tide. When the platform surface became exposed after higher high tide, samples from the platform surface itself were collected. A total of 12 samples representing 5 rock types were collected. As each sample was collected, it was immediately weighed. Thereafter, psychrometer readings and weight measurements were taken periodically throughout the remainder of the tidal cycle, so that the rate of water loss (or alternatively, the amount of water retention) of the rock could be determined. Weight measurements were taken at the following times after the initial platform exposure: 0,2,4,7.5, and 10.5 hours. Psychrometer readings were taken at the following times after the initial platform exposure: 0, 1.5, 6.0, 7.5, 9.5, and 11.0 hours.

As well, 4 samples representing 2 rock types from the cliff face at the rear of the platform were collected (see Table 2). Psychrometer readings were also taken at the time of sample collection. These samples were also weighed in the field. When all the measurements were recorded, the samples were placed in plastic bags and stored until needed.

When the field work was completed, the samples were transported back to the laboratory to undergo further testing: First, the rocks were oven-dried. Then they were subjected to vacuum saturation (as previously outlined) in order to measure the total effective porosity of the rocks (with respect to water content). However, because of the size and shape of the rocks, they were not removed from the vacuum dessicator as **before**. Instead, they remained in the vacuum chamber, submerged in a free-water saturation situation (no induced pressure) for 12 hours. At the end of the saturation period, the vacuum was released and the rocks weighed. The amount of water absorbed by the rocks using the vacuum saturation technique is assumed to be an accurate measure of the total amount of water which could occupy the interconnected pores of the rocks (100% saturation).

TABLE 2 - MINERALOGICAL IDENTIFICATION OF GASPÉSIAN ROCKS (FIELD STUDY)

Sample # *	Rock Type	Textures and Structures	Mineralogy	Porosity Estimate
11,12,15, 20,25,27, 30,46	Sedimentary (Diagehetic) <u>Black shale</u>	very fine grained and fissile	clay minerals	<10%
4,6,40,43, B1,B2,B4	Sedimentary (Diagenetic) <u>Silty shale</u> (some shaly silts)	very fine grained and laminated, most are fissile	fine quartz and clay grains	<10%
21,29,50,C	Sedimentary (Diagebetic) <u>Silty shale</u>	very fine grained and less fissile	clay minerals and fine quartz grains	<10%
N.B. -many of the above shales contain fractures filled with secondary calcite (#4 contains fine disseminated pyrite as well) -shales generally have low permeabilities				
7	Sedimentary <u>Chert</u>	massive (contains fractures filled with fine pyrite)	10% crystals and granules of quartz set in a cryptocrystalline quartz matrix	<2%
1,9,14,17, 19,26,22, A,B	Sedimentary <u>Greywacke</u> (i.e., dirty sandstones with 15% muddy or clay matrix)	most are fine grained and massive(i.e., no apparent layering)	clay and quartz grains (#17 shows calcite filled fractures)	<30%

TABLE 2 (cont'd)

5,10,23,24, 41,42,44,B3	Sedimentary Sandstone	medium(0.25-0.5) to very fine(1/16-1/8mm) grained, mostly massive(#23 shows laminations)	mostly quartz grain framework with up to 15% muddy matrix	<30%
45,51	Sedimentary Siltstone (i.e., 1/256-1/16 mm grain size)	very fine grained(#51 shows laminations)	mainly very fine clastic quartz grains	<30%
3,D,E	Metamorphic (low regional) Black slate (pelite group)	very fine grained and contains cleavage	micateous minerals (i.e., mostly muscovite)	<5%
13,16,51	Metamorphic (medium grade regional) Marble (calcarious group)	finely laminated(secondary disseminated pyrite concentrated along or adjacent to rock fractures)	mainly calcite and diopside(i.e., a fine green mineral)	<2%
8,47,49	Metamorphic (high grade regional) Gneiss (quartzofeldspathic group)	coarse grained 1mm and foliation showing gneissosity(banding)	light quartz and feldspar and dark biotite and hornblende	<2%
28,32,48	Metamorphic (Dynamic) Fault breccia	drawn out fragments of shale(black) and carbonate(red brown)	fragments set in hydrothermal white quartz	<5%

TABLE 2 (cont'd)

18	Igneous Anorthasite (plutonic rock)	medium grained(1mm 5mm) and hollocrystalline and massive	mainly plagioclase	<2%
2	Igneous Quartz syenite (plutonic rock)	medium grained(1mm 5mm) and hollocrystalline and massive	3% hornblende, 2% phlogopite, 5% quartz, 90% mainly alkali feldspar	<2%

* Sample #	Location	Site
1 - 20	Mont-Louis	platform pools
21 - 32	Mont-Louis	platform surface
A - E	Mont-Louis	cliff face
40 - 51	Madeleine-Centre	platform surface
B1 - B4	Madeleine-Centre	cliff face

6

3.4 Statistical Techniques

The objective of this study was to measure a rock property-degree of saturation. This is the amount of water actually contained within a rock at any given time compared with the maximum amount of water which the same rock could hold. It is therefore a relative, not absolute value, as the degree of saturation can vary. Two different types of rock may each be 50% water saturated, but rock A might contain 40 ml of water while rock B might contain only 10 ml of water. This is because a very porous and permeable rock can contain a greater actual amount of water than a nonporous and impermeable rock, when each is, e.g., 50% water saturated. Hence, the data values of all the experiments were expressed as a proportion of the vacuum saturation values.

A one-tailed t-test for correlated data (repeated measurements upon the same individuals) was used to test the subhypothesis that the **degree of saturation varies according to** the intertidal immersion period. The data used for this test were the 1 hr. and 2 hr. values for the following intertidal elevations: mid tide (M.T.), 0.5 m above low tide (+L.T.) and at low tide (L.T.), for each rock type. Before the t-test was performed, the data were tested for normality using a one sample Kolmogorov-Smirnov test (Table 3).

A oneway analysis of variance test was used to evaluate the subhypothesis that the intertidal **degree of saturation** varies according to the tidal head. The data used were from the high, mid and low tide experiments for each rock type.

The high tide values (0.5 m below high tide =-H.T.), along with the mid tide, just above low tide, and at low tide values for 1 hr. immersion were treated as one data set. Then, the same high tide values along with the mid tide, just above low tide, and at low tide values for the 2 hr. immersion were treated as another data set. First, however, all the data were tested for normality using a one sample Kolmogorov-Smirnov test (Table 3). The data were next tested for homogeneity of variance using Bartlett's test (Table 4). Only the schist-A 1 hr and schist-B 1 hr. data sets had to be $\log_{10}$ transformed in order to meet the homogeneity of variance assumption. These transformed data sets were also retested for normality (Table 5). The oneway analysis of variance was used to test for a difference between the selected tidal head values. Based on the results of the F-test, a posteriori tests were run on the data sets, to determine which particular tidal heads were significantly different from the others. The Scheffe method was selected because it is one of the more rigorous methods, i.e., it reduces the probability of making a Type 1 error (Downie and Heath, 1970).

A oneway analysis of variance was also used to test the subhypothesis that the intertidal degree of saturation varies according to rock type (Appendix 3). The data used were the low tide values of each rock type, as this intertidal elevation would logically have the greatest degree of saturation, since it is immersed for the longest period. First, the data were tested for normality using a one sample Kolmogorov-Smirnov test (Table 3). The data were next tested for homogeneity of variance (Table 4). In order to meet this requirement of the analysis of variance, the data were transformed by $1/\sqrt{\ }$. The transformed data were then retested for normality (Table 5). The analysis of variance tested for a difference in the degree of saturation between rock types. Based on the results of the F-test, a posteriori tests were run on the data to determine which rock types differed significantly from the others. Again, the Scheffe method was used.

A one sample t-test for correlated data was used to test the hypothesis that there is no intertidal nor supratidal permanent saturation level. The low tide data for each rock type were used, with its respective vacuum saturation data, to determine if a significant difference existed between the greatest intertidal degree of saturation and saturated rock. The results from the absorption experiment were used to evaluate whether or not a supratidal permanent saturation level exists. First, however, all the data were tested for normality using a one sample Kolmogorov-Smirnov test (Table 3). It was necessary to $\log_{10}$ transform the limestone adsorption and vacuum saturation data in order to achieve valid t-test results. These transformed data were then retested for normality (Table 5).

The statistical tests were performed using computer programs from S.P.S.S., (Nie et al., 1975).

TABLE 3: NORMALITY VALUES FOR LABORATORY EXPERIMENTS DATA

		-H.T.	M.T. 1 hr.	+L.T. 1 hr.	L.T. 1 hr.	M.T. 2 hr.	+L.T. 2 hr.	L.T. 2 hr.	ADSORPTION
1LIMESTONE	K-S Z:	0.657	0.730	0.602	0.542	0.723	0.430	0.366	1.215
n=38	2 TAILED P:	0.782	0.662	0.862	0.930	0.672	0.993	0.999	0.104
GNEISS-A	K-S Z:	1.050	0.868	0.698	0.548	0.481	0.452	0.478	0.807
n=24	2 TAILED P:	0.220	0.439	0.714	0.924	0.975	0.987	0.976	0.533
SCHIST-A	K-S Z:	0.710	0.624	0.667	0.697	0.671	0.827	0.459	1.200
n=40	2 TAILED P:	0.695	0.831	0.766	0.717	0.759	0.501	0.984	0.112
GNEISS-B	K-S Z:	0.905	0.568	0.492	0.484	0.361	0.782	0.785	0.740
n=32	2 TAILED P:	0.386	0.904	0.969	0.973	0.999	0.574	0.569	0.644
SCHIST-B	K-S Z:	0.935	1.196	1.151	0.574	0.465	0.934	0.823	0.398
n=32	2 TAILED P:	0.346	0.115	0.141	0.897	0.982	0.348	0.508	0.997

ALL THE DATA ARE NORMALLY DISTRIBUTED

-H.T. = 0.5m below the high tidal elevation
M.T. = 1.5m above the low tidal elevation
+L.T. = 0.5m above the low tidal elevation
L.T. = at the low tidal elevation

TABLE 4

RESULTS OF BARTLETT'S TEST FOR HOMOGENEITY OF VARIANCE

TIDAL HEAD TEST DATA:

		x^2_{obs}
LIMESTONE	1 hr.	2.733
GNEISS-A	"	1.319
SCHIST-A	"	3.193
GNEISS-B	"	6.775
SCHIST-B	"	1.489
LIMESTONE	2 hr.	1.387
GNEISS-A	"	2.550
SCHIST-A	"	0.333
GNEISS-B	"	5.025
SCHIST-B	"	5.771

df= g-1, where g= # groups

x^2_{crit} @ .05 = 7.815, df= 3

ALL THE DATA SETS HAVE HOMOGENEITY OF VARIANCE

ROCK TYPE TEST DATA:

x^2_{obs} = 6.547 x^2_{crit} @ .05 = 9.49, df= 4

df= g-1, where g= # groups

THE DATA HAVE HOMOGENEITY OF VARIANCE

TABLE 5

Normality Transformations were performed on the following data:

		-H.T.	1 hr. M.T.	1 hr. +L.T.	1 hr. L.T.	
SCHIST-A						
	K-S Z:	0.582	0.628	0.601	0.632	log$_{10}$ transformed
	2 TAILED P:	0.888	0.825	0.863	0.819	
SCHIST-B						
	K-S Z:	0.810	1.091	1.025	0.475	log$_{10}$ transformed
	2 TAILED P:	0.528	0.185	0.244	0.978	

		ADSORPTION	
LIMESTONE			
	K-S Z:	1.013	log$_{10}$ transformed
	2 TAILED P:	0.257	

			K-S Z:	2 TAILED P:	
LIMESTONE	L.T.	2 hr.	0.433	0.992	
GNEISS-A	L.T.	1 hr.	0.656	0.783	$1/\sqrt{}$ transformed
SCHIST-A	L.T.	1 hr.	0.659	0.778	
GNEISS-B	L.T.	1 hr.	0.596	0.870	
SCHIST-B	L.T.	1 hr.	0.416	0.995	

ALL THE TRANSFORMED DATA ARE NORMALLY DISTRIBUTED

CHAPTER 4

DATA ANALYSIS

4.1 Experimental Results

The results of all the laboratory experiments are reported in summary form as a proportion (%) of their vacuum saturation values. It is evident that the limestone quickly attained its maximum saturation value (≃ 60%) at the high tidal level, and did not vary from this at lower tidal levels. However, the metamorphic rocks generally achieved low initial saturation values (≃ 25%) at the high tidal level, but most attained much higher saturations (> 80%) when they were submerged under greater pressures for longer periods of time at lower elevations. This can be explained by the fact that the limestone is a coarse grained, porous and permeable rock whereas the metamorphics are mostly fine grained nonporous and impermeable. Coarse grained rocks with large capillaries, such as the limestone, usually are the first to absorb large amounts of water, but the rocks with fine grains and fine pore structures, such as the metamorphics, reach critical saturation faster than rocks with coarse pore structures (Fagerlund, 1975; Ver beck and Landgren, 1960). This suggests that frost shattering, when it is efficacious, would weather gneiss and schist rocks rather than limestone.

TABLE 6

LABORATORY EXPERIMENTS: DEGREES OF SATURATION

ROCK TYPE	-H.T.	M.T.	+L.T.	L.T.	ADSORPTION*
LIMESTONE	61.6	57.4	58.1	58.7	0.9
GNEISS-A	27.4	83.0	83.5	88.8	24.2
SCHIST-A	27.1	75.1	82.0	92.8	26.8
GNEISS-B	25.3	66.2	95.1	97.4	20.7
SCHIST-B	25.6	84.1	90.1	96.8	31.4
		1 HOUR IMMERSION			
LIMESTONE		57.4	59.4	59.8	
GNEISS-A		88.3	83.7	86.7	
SCHIST-A		81.5	79.6	76.1	
GNEISS-B		81.0	74.9	82.2	
SCHIST-B		94.1	83.8	89.2	
		2 HOUR IMMERSION			

* Adsorption for 12 hours @ 94% relative humidity

N.B. These degrees of saturation values are expressed as a percentage of the absolute (vacuum) saturation for each rock type.

-H.T. = 0.5m below high tidal elevation
M.T. = 1.5m below high tidal elevation
+L.T. = 0.5m above low tidal elevation
L.T. = at the low tidal elevation

An examination of the saturation values reveals several anomalies, which are also immediately evident from the tidal saturation curves for each rock type (Fig. 7a-11b). The only anomaly with the limestones is that the highest degree of saturation occurs at the high tidal elevation where the tidal head pressure is lowest and submergence the briefest, but the number of experimental cycles is the greatest. When the limestone values are compared, it is noted that all of the experimental results are very close to each other (Table 6). This suggests that the limestone quickly attains its maximum saturation value, with increases in either tidal head or submergence time not increasing the degree of saturation. Since all the experimental values are within a range of 4.2% (57.4-61.6), it is believed that some type of measurement error has been recorded. It is quite possible that water on the surface of the cores was not entirely removed before weighing, thus giving slightly inaccurate results. Since the high tidal values are so close to the remainder of the experimental values, it is likely that the range of the high tidal data values are greater than the range of allowable error.

With the remainder of the rock types, anomalies between certain sets of data values consistently occur. Although with the 1 hour submergence values no anomalies occur (see Figs. 7a-11a), anomalies are found within the 2 hour submergence values for all gneiss and schist rocks (see Figs. 7b-11b). Again, where these anomalies do occur for the

2 hour submergence values, the greatest range is 10.3% for schist-B (83.8-94.1). Measurement errors related to the wetness of the core surface before it was weighed are believed to be responsible for these anomalies. It may be impossible to ensure that the surfaces of all the rock cores are dried to the same degree before they are weighed. Also, the lowest saturation value at which any of the 2 hour submergence ranges began was 74.9% for gneiss-B. This itself represents a high degree of saturation for those rock cores, with all other experimental saturation values higher still. It appears then, that within the context of the experimental design, maximum degree of saturation values are being reached in most cases, and any variability in these values at these percentages exceeds what must be the allowable error for the same percentages.

When the gneiss and schist data values are viewed from a different perspective, different anomalies occur. When the 1 hour and 2 hour submergence values between each individual rock type are examined, it is noted that the 2 hour values are greater than the 1 hour values at the mid tidal elevation, as expected. But at the 0.5 m above low tidal elevation (+L.T.) and also with the at low tidal elevation (L.T.), the 1 hour submergence values are greater than the 2 hour submergence values for all gneiss and schist rocks. Measurement error or a flaw in the procedure of the experimental design might account for these anomalies.

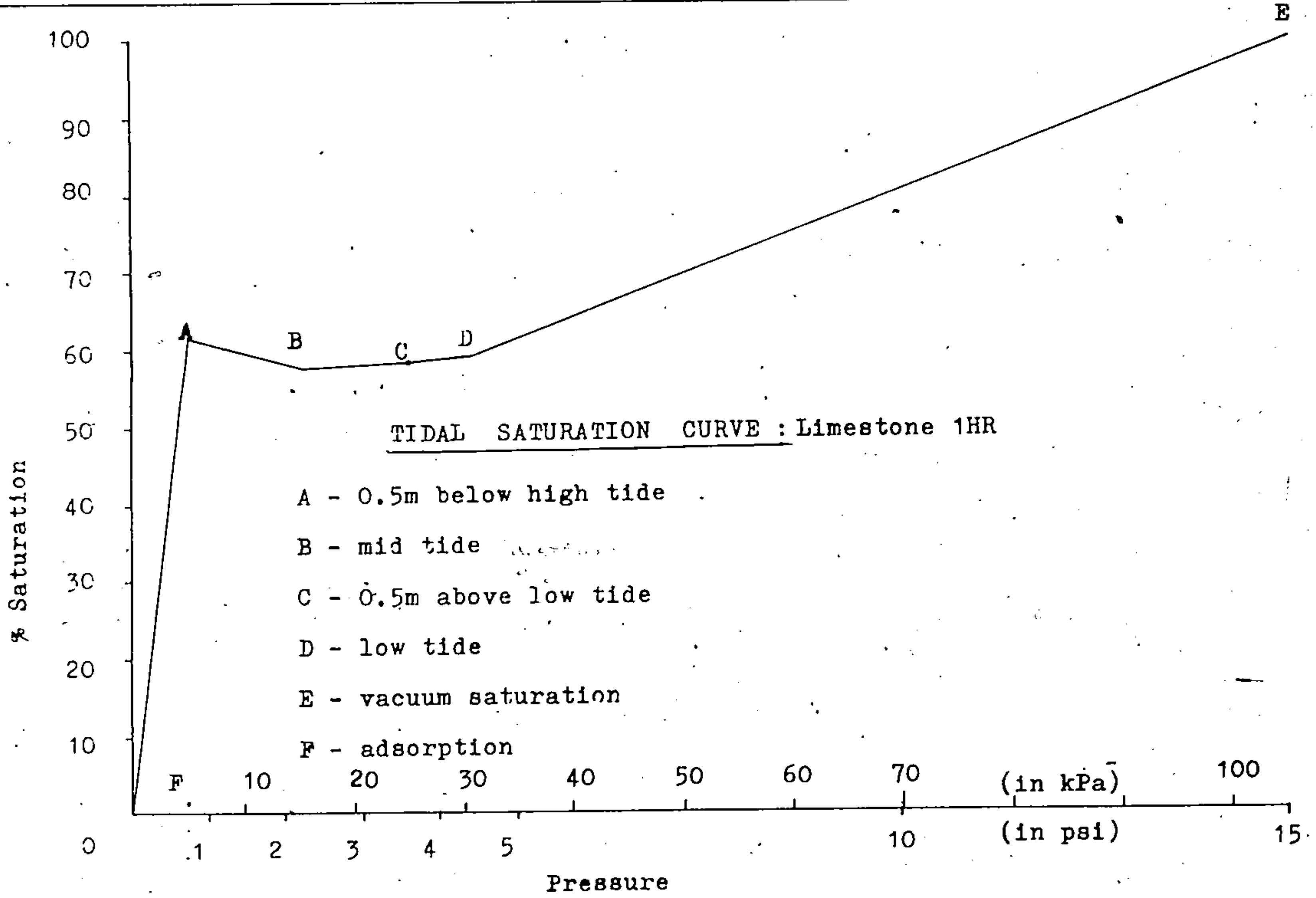

TIDAL SATURATION CURVE : Limestone 1HR
A - 0.5m below high tide
B - mid tide
C - 0.5m above low tide
D - low tide
E - vacuum saturation
F - adsorption
A
B
C
D
E
F
% Saturation
0
10
20
30
40
50
60
70
80
90
100
10
20
30
40
50
60
70
100
(in kPa)
.1
2
3
4
5
10
15
(in psi)
Pressure

FIG. 7a

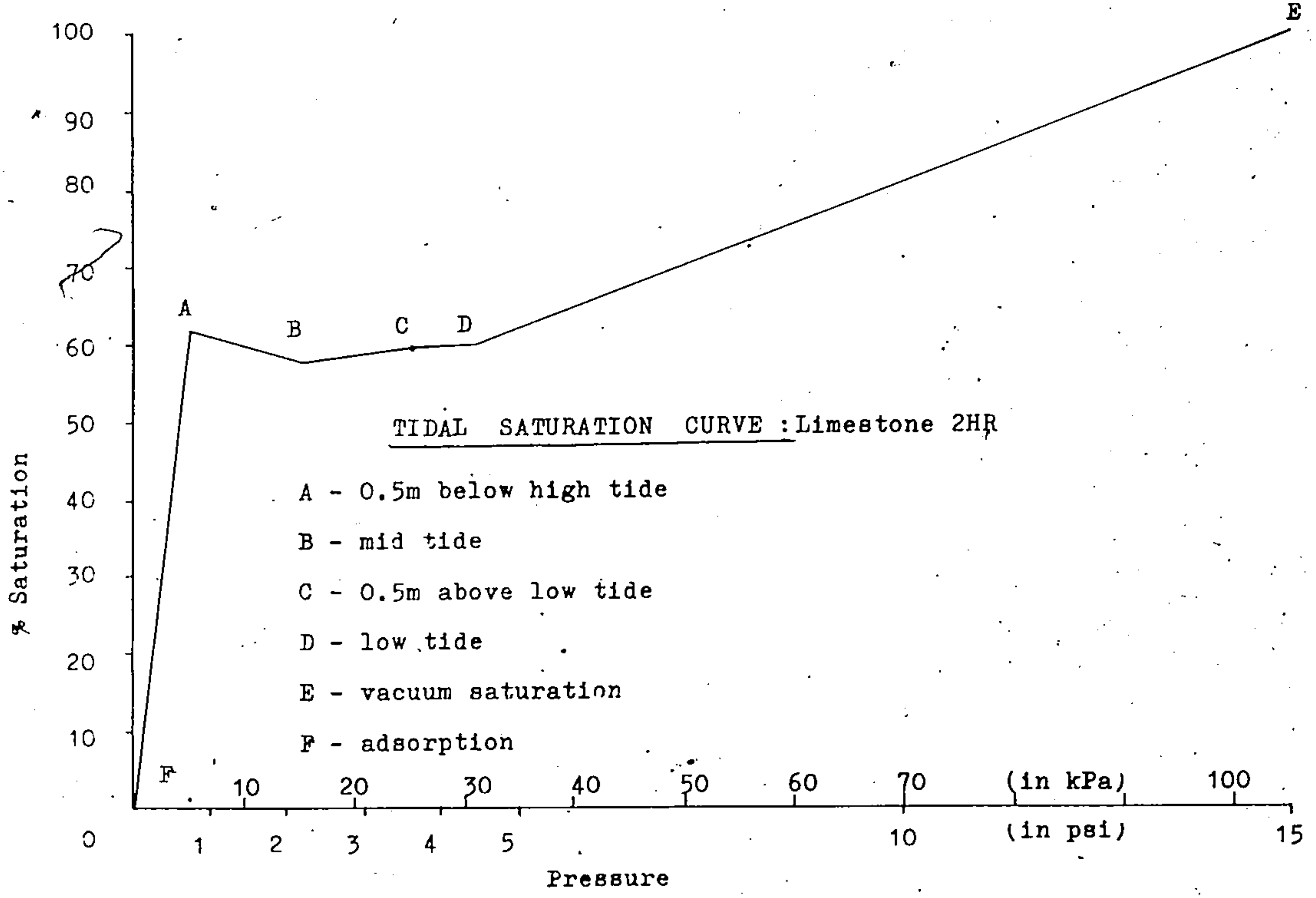
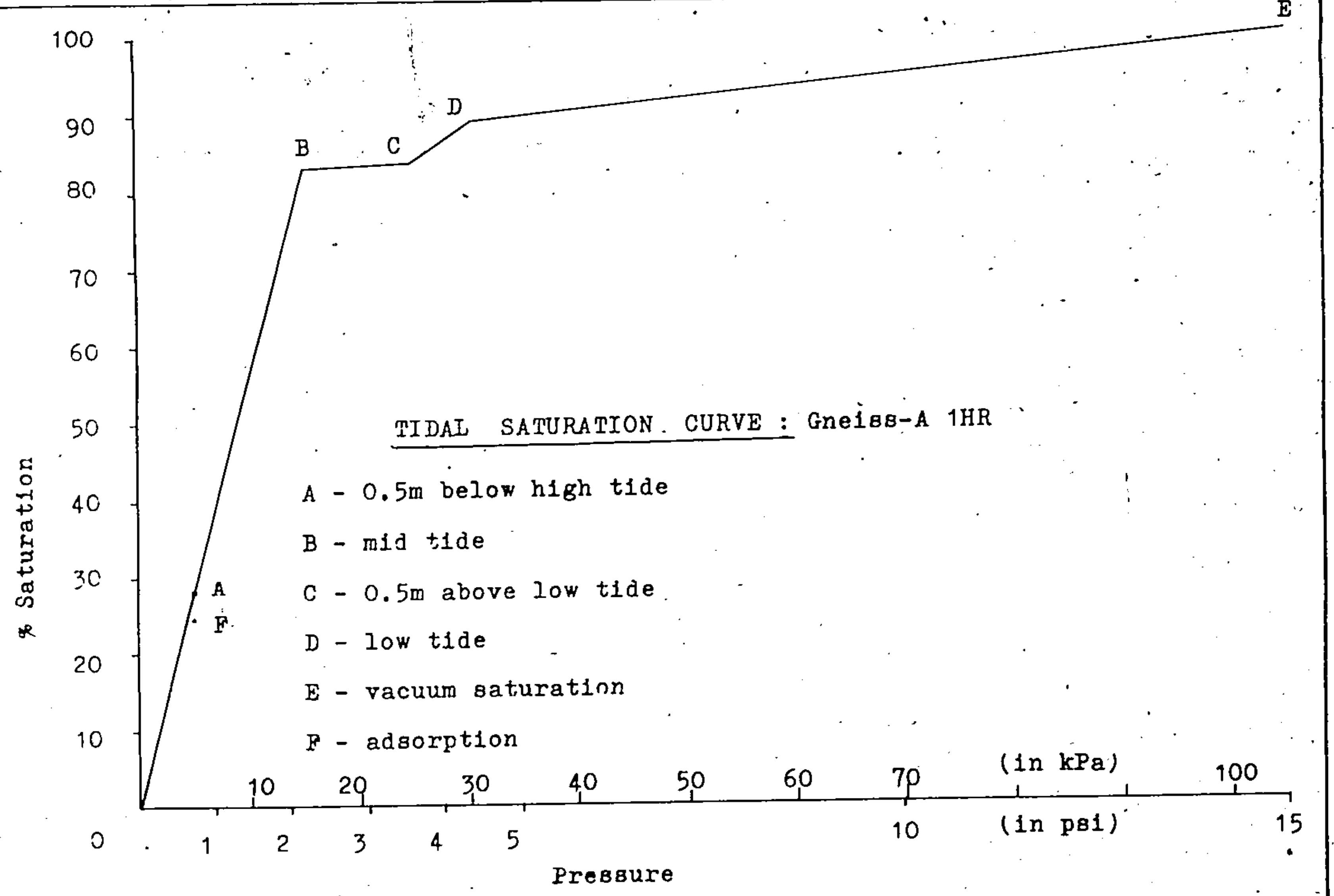

TIDAL SATURATION CURVE :Limestone 2HR
A - 0.5m below high tide
B - mid tide
C - 0.5m above low tide
D - low tide
E - vacuum saturation
F - adsorption
A
B
C
D
E
F
% Saturation
100
90
80
70
60
50
40
30
20
10
0
10
20
30
40
50
60
70
(in kPa)
100
1
2
3
4
5
10
(in psi)
15
Pressure

FIG. 7b


TIDAL SATURATION CURVE : Gneiss-A 1HR
A - 0.5m below high tide
B - mid tide
C - 0.5m above low tide
D - low tide
E - vacuum saturation
F - adsorption
% Saturation
100
90
80
70
60
50
40
30
20
10
0
Pressure
(in kPa)
10
20
30
40
50
60
70
100
(in psi)
1
2
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4
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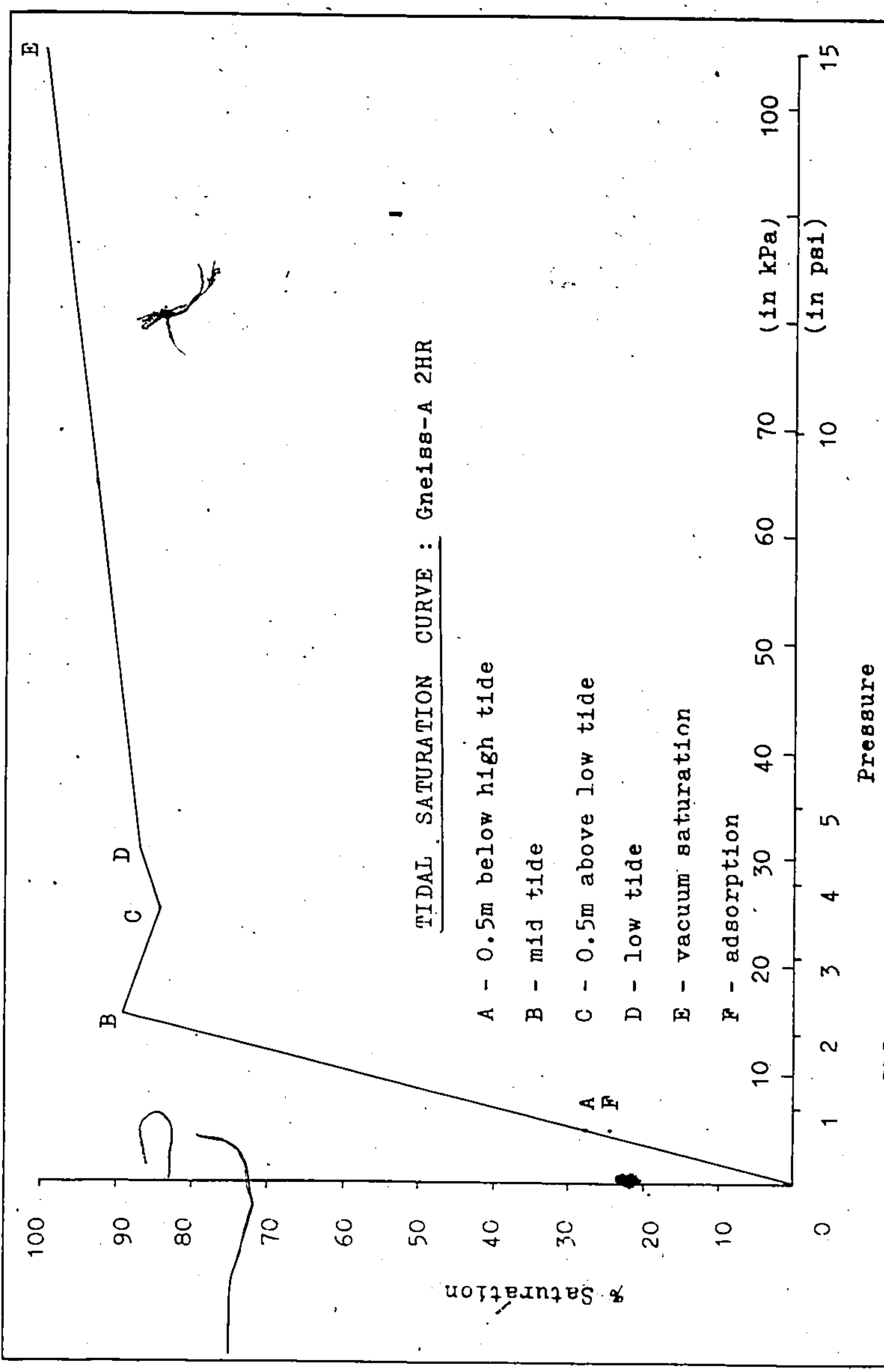
10
15
A
F
B
C
D
E

FIG. 8a


TIDAL SATURATION CURVE : Gneiss-A 2HR
A - 0.5m below high tide
B - mid tide
C - 0.5m above low tide
D - low tide
E - vacuum saturation
F - adsorption
A
F
B
C
D
E
% Saturation
0
10
20
30
40
50
60
70
80
90
100
Pressure
(in kPa)
(in psi)
10
20
30
40
50
60
70
100
1
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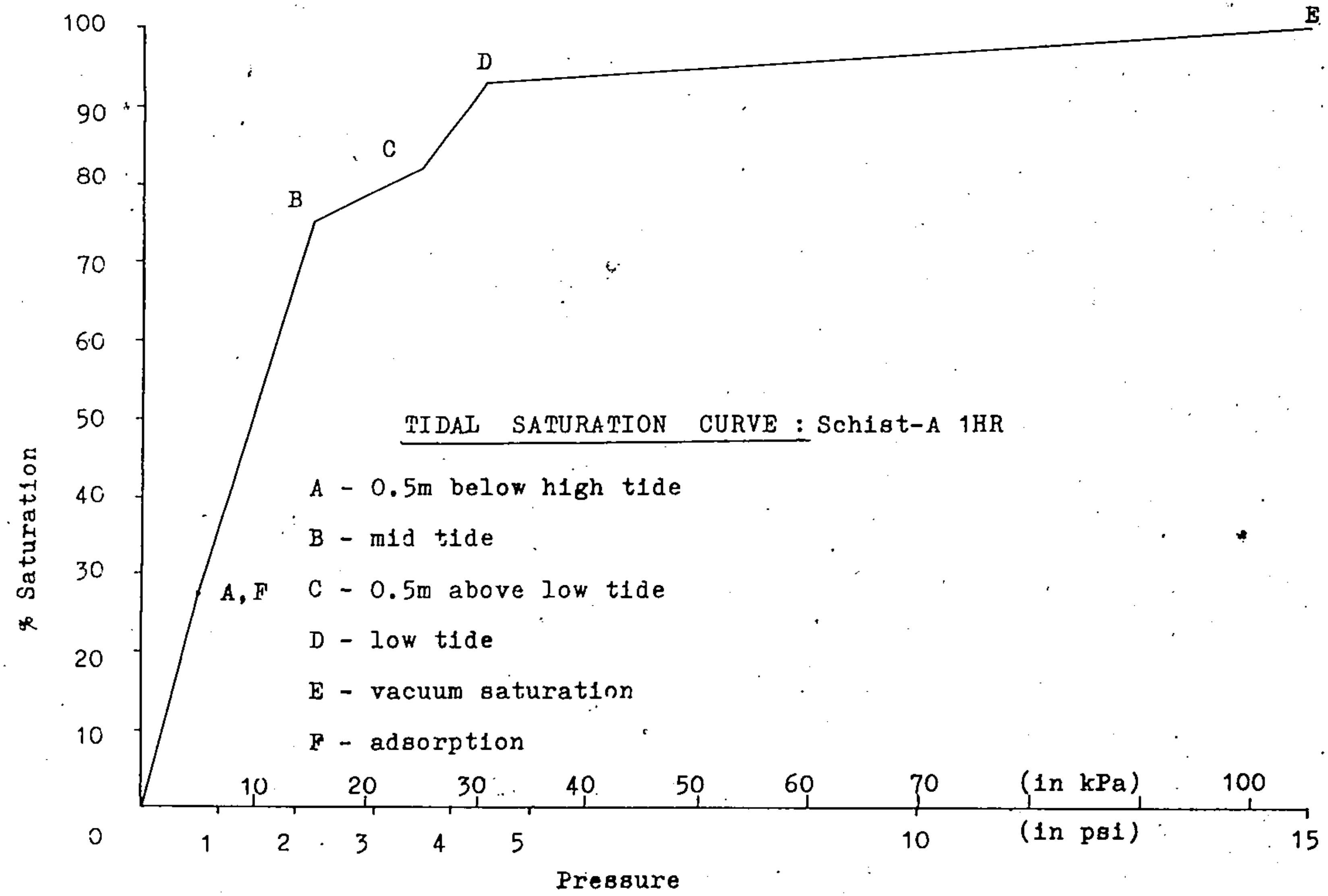
4
5
10
15

FIG. 8b


TIDAL SATURATION CURVE : Schist-A 1HR
A - 0.5m below high tide
B - mid tide
C - 0.5m above low tide
D - low tide
E - vacuum saturation
F - adsorption
A,F
B
C
D
E
% Saturation
100
90
80
70
60
50
40
30
20
10
0
10
20
30
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50
60
70
(in kPa)
100
1
2
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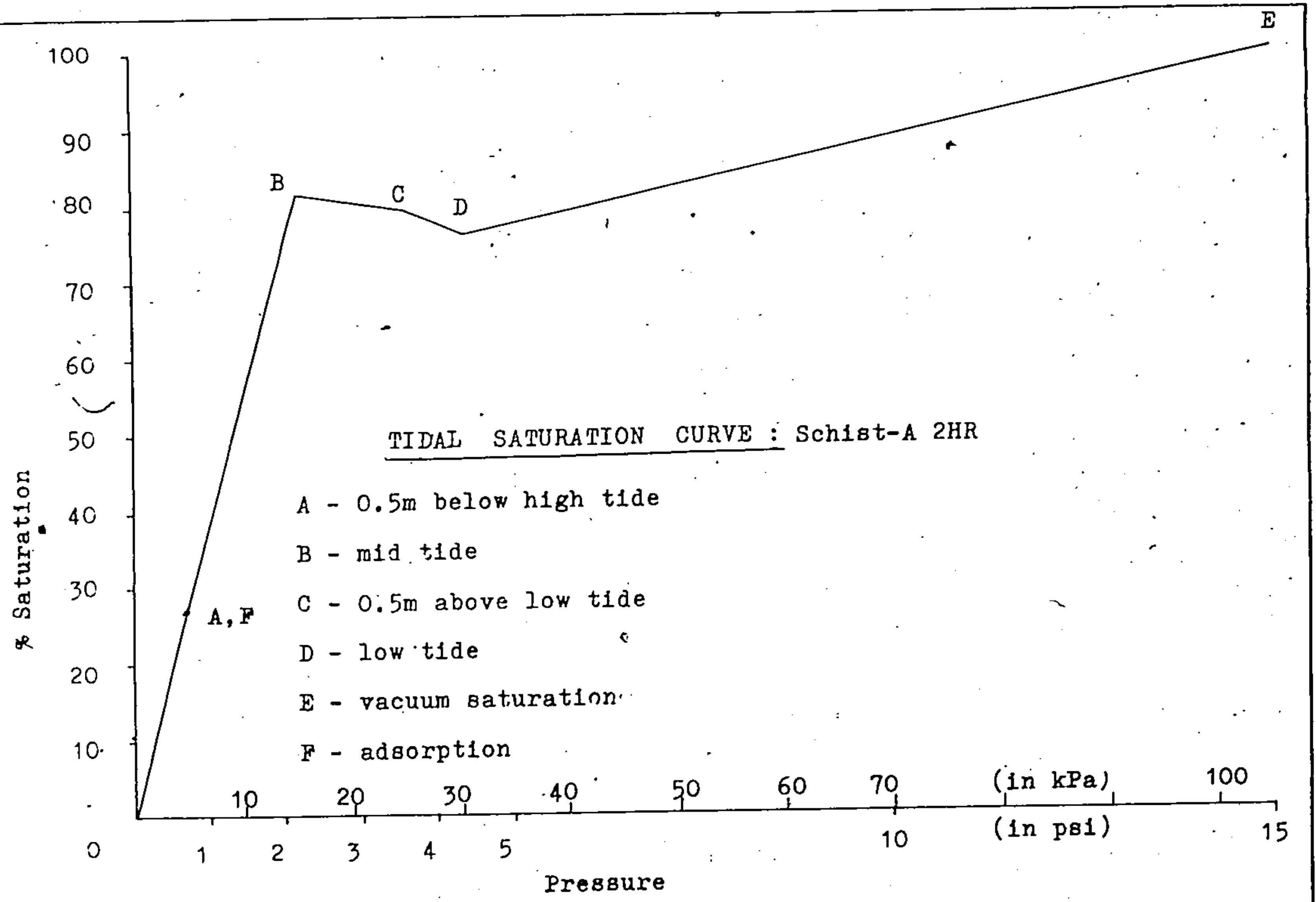
4
5
10
(in psi)
15
Pressure

FIG. 9a


TIDAL SATURATION CURVE : Schist-A 2HR
A - 0.5m below high tide
B - mid tide
C - 0.5m above low tide
D - low tide
E - vacuum saturation
F - adsorption
A,F
B
C
D
E
% Saturation
100
90
80
70
60
50
40
30
20
10
0
10
20
30
40
50
60
70
(in kPa)
100
1
2
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4
5
10
(in psi)
15
Pressure

FIG. 9b

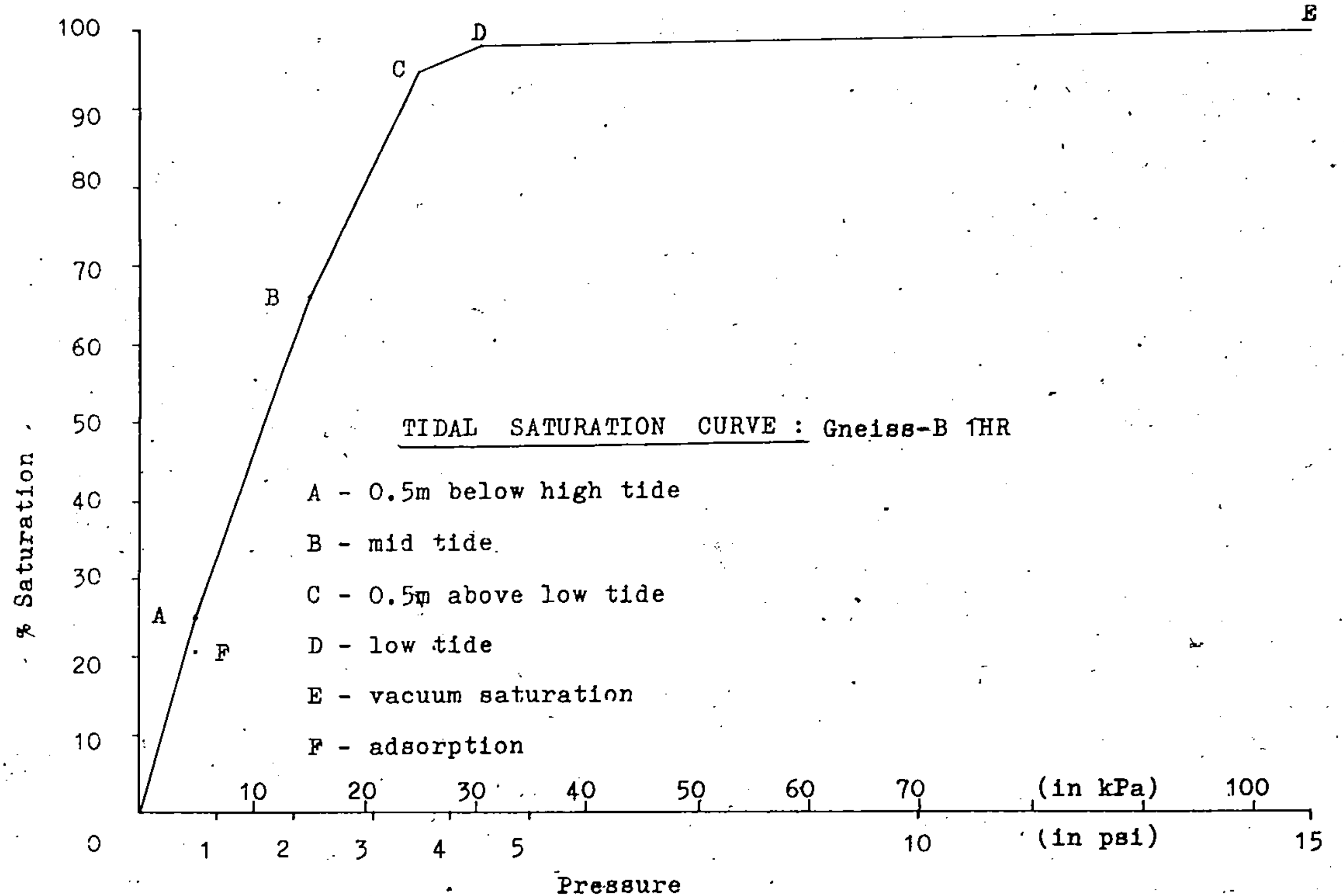
TIDAL SATURATION CURVE : Gneiss-B 1HR
A - 0.5m below high tide
B - mid tide
C - 0.5m above low tide
D - low tide
E - vacuum saturation
F - adsorption
A
B
C
D
E
F
% Saturation
0
10
20
30
40
50
60
70
80
90
100
10
20
30
40
50
60
70
(in kPa)
100
1
2
3
4
5
10
(in psi)
15
Pressure

FIG. 10a

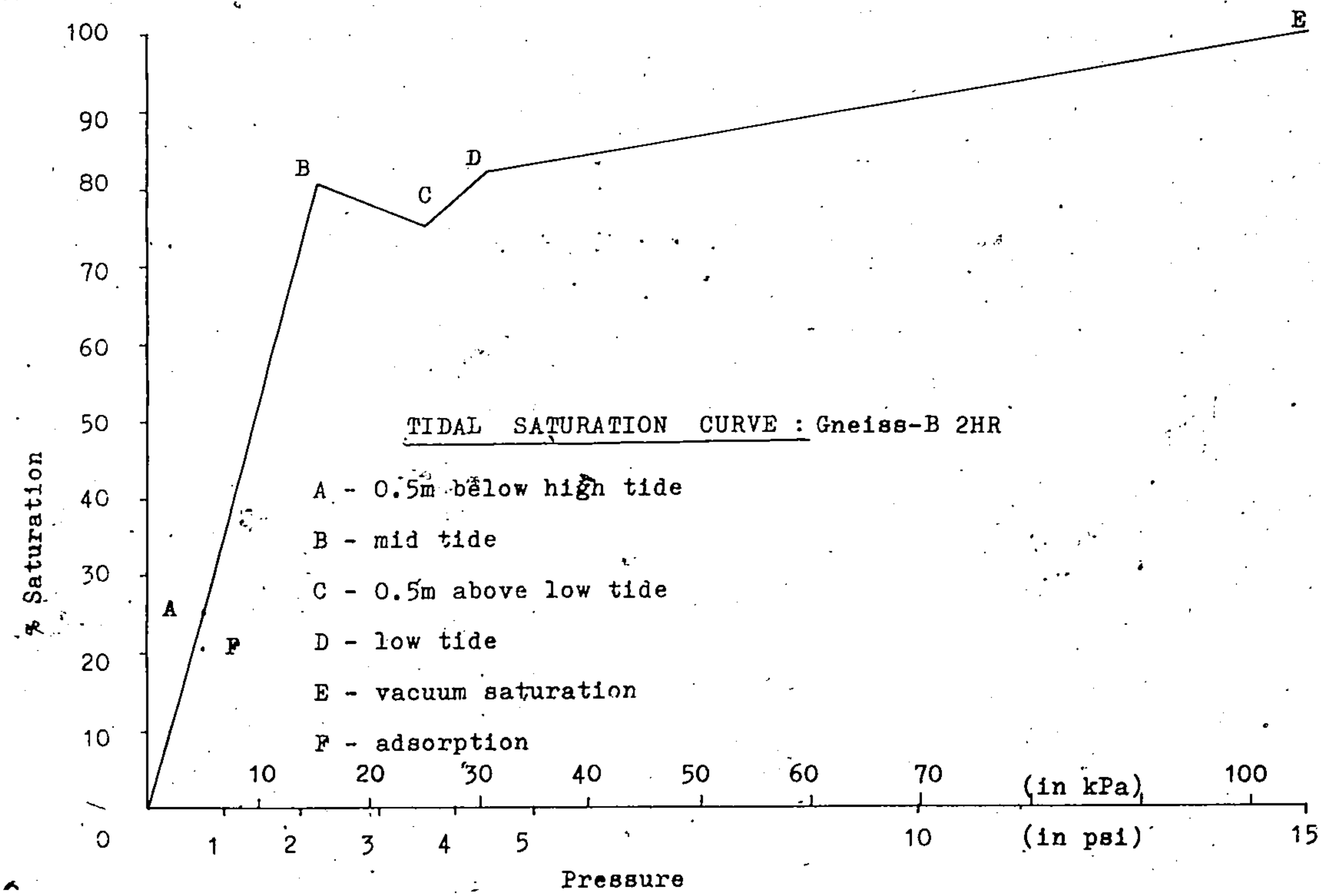
TIDAL SATURATION CURVE : Gneiss-B 2HR
A - 0.5m below high tide
B - mid tide
C - 0.5m above low tide
D - low tide
E - vacuum saturation
F - adsorption
A
B
C
D
E
F
% Saturation
100
90
80
70
60
50
40
30
20
10
0
10
20
30
40
50
60
70
100
(in kPa)
1
2
3
4
5
10
15
(in psi)
Pressure

FIG. 10b.

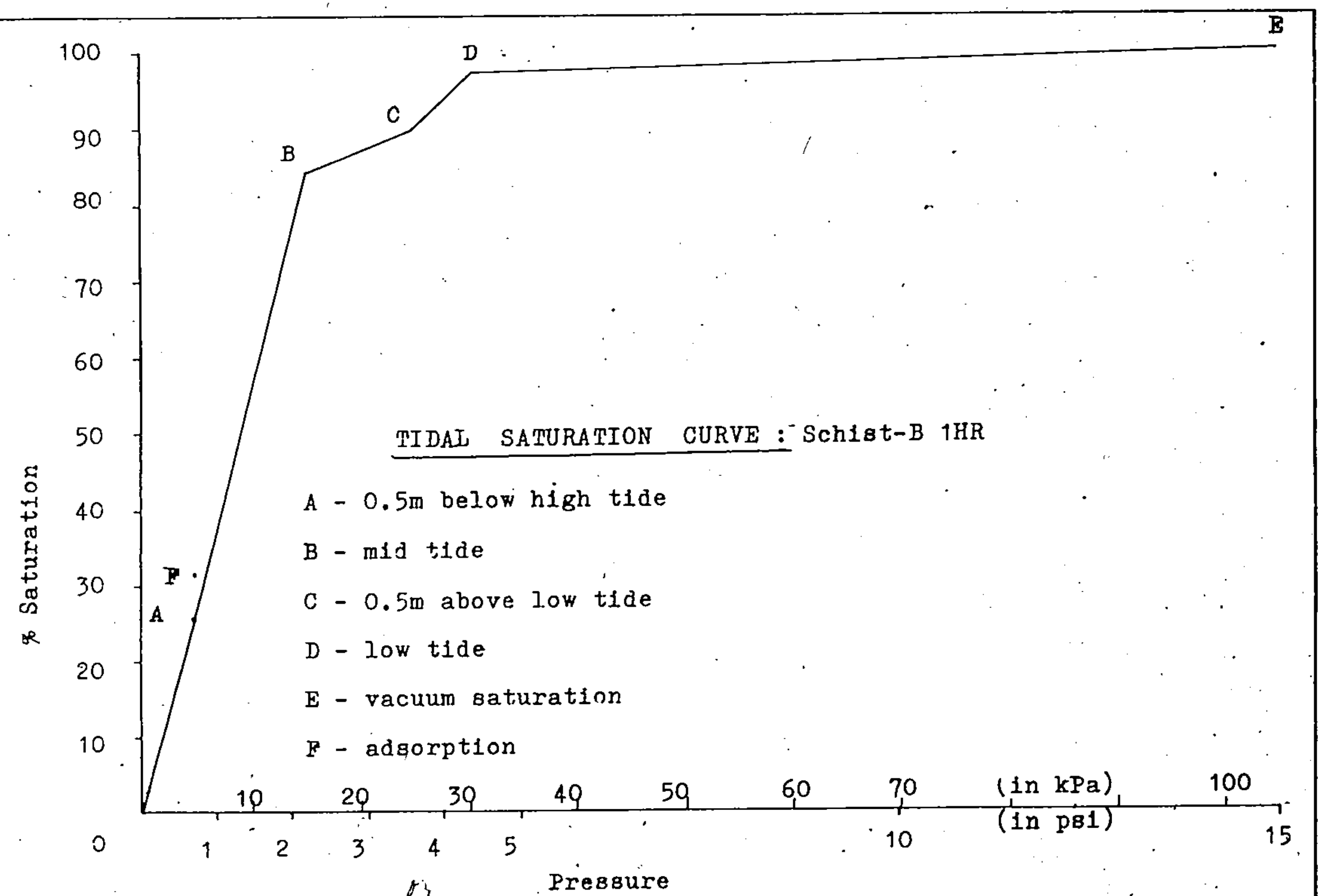
TIDAL SATURATION CURVE : Schist-B 1HR
A - 0.5m below high tide
B - mid tide
C - 0.5m above low tide
D - low tide
E - vacuum saturation
F - adsorption
% Saturation
100
90
80
70
60
50
40
30
20
10
0
10
20
30
40
50
60
70
(in kPa)
100
1
2
3
4
5
10
(in psi)
15
Pressure
A
F
B
C
D
E

FIG. 11a

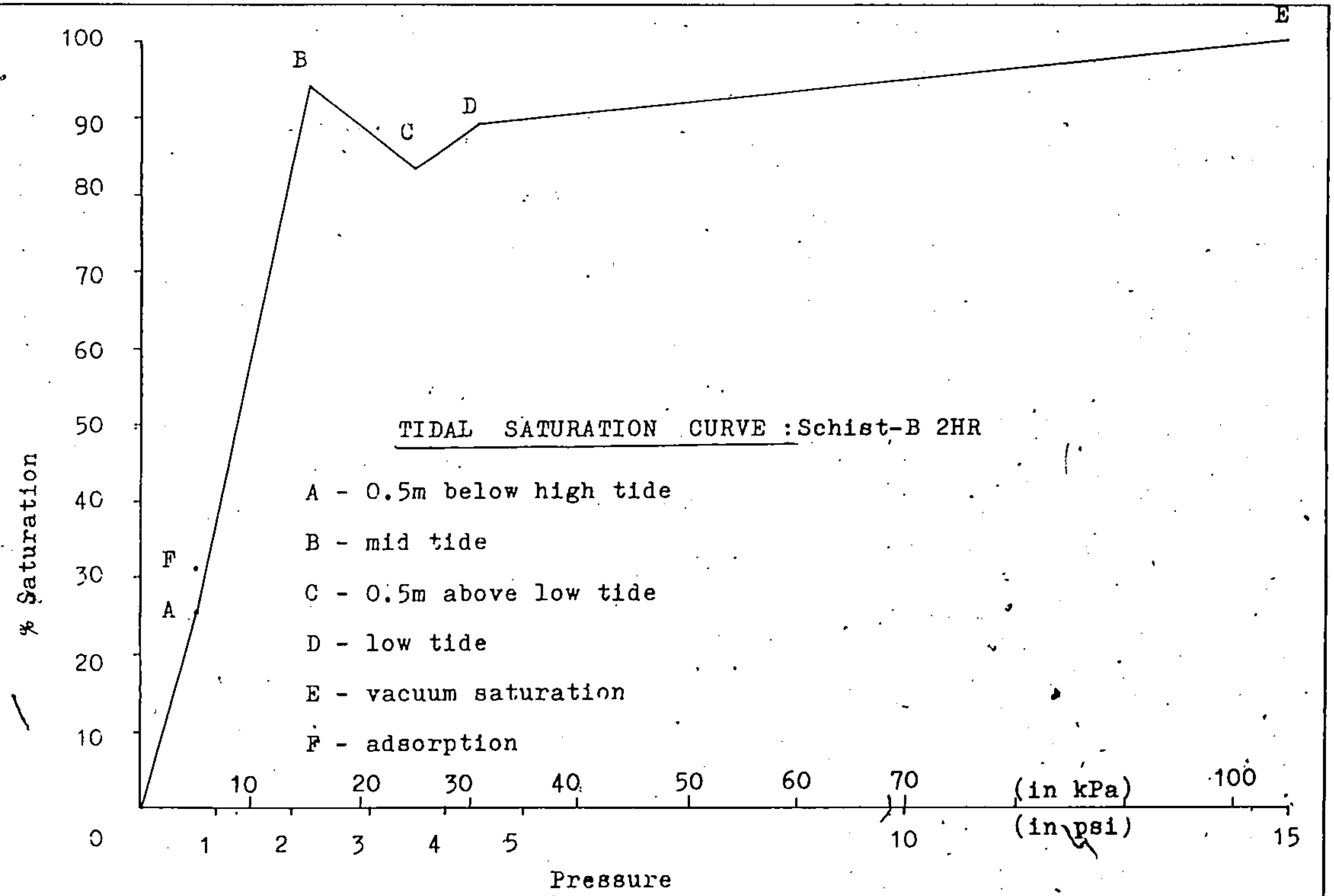
TIDAL SATURATION CURVE :Schist-B 2HR
A - 0.5m below high tide
B - mid tide
C - 0.5m above low tide
D - low tide
E - vacuum saturation
F - adsorption
A
B
C
D
E
F
% Saturation
100
90
80
70
60
50
40
30
20
10
0
10
20
30
40
50
60
70
100
(in kPa)
1
2
3
4
5
10
15
(in psi)
Pressure

FIG. 11b

4.2 Intertidal Elevations

In order to statistically evaluate the subhypothesis that the degree of saturation varies with the elevation of coastal rock within the intertidal zone, a series of one-tailed t-tests between the 1 hour and 2 hour submergence periods was performed, for each applicable intertidal elevation and for each rock type. It was hypothesized that less water would be absorbed for an immersion period of 1 hour than for an immersion period of 2 hours, whatever the intertidal elevation. The results indicate that coastal rock at the mid tidal level only, for the gneiss and schist rocks, absorb more water the longer they are submerged (Table 7). There is no significant difference between submergence periods for either the +L.T. or L.T. elevations. This pattern occurred only with the metamorphic rocks; limestones displayed contrary results. Longer submergence periods do result in greater water absorption, but only at the +L.T. and L.T. elevations for limestone. No significant difference in water absorption, between the one and two hour submergence periods, was found at the mid tidal elevation (M.T.).

Following this, a series of oneway analysis of variance tests between all the intertidal elevations was performed, though these were done separately for the 1 hour and 2 hour submergence periods. The results indicate that there is a significant difference in saturation between the intertidal elevations (Tables 8-17). This is evidenced by the high, and in some cases extremely high F values, for all rock types.

TABLE 7

RESULTS OF T-TEST ON IMMERSION PERIODS(1 & 2 HOURS) FOR INTERTIDAL ELEVATIONS

ROCK TYPE	INTER-TIDAL ELEVATION	df	T_{obs}	T_{crit}	α	df used
LIMESTONE	M.T.	37	-0.14	1.697	.05	30
	+L.T.	37	-7.03*	1.697	.05	30
	L.T.	37	-6.16*	1.697	.05	30
GNEISS-A	M.T.	23	-2.44*	1.714	.05	23
	+L.T.	23	-0.17	1.714	.05	23
	L.T.	23	1.87	1.714	.05	23
SCHIST-A	M.T.	39	-8.27*	1.697	.05	30
	+L.T.	39	2.05	1.697	.05	30
	L.T.	39	13.43	1.697	.05	30
GNEISS-B	M.T.	31	-6.95*	1.697	.05	30
	+L.T.	31	16.76	1.697	.05	30
	L.T.	31	12.42	1.697	.05	30
SCHIST-B	M.T.	31	-7.06*	1.697	.05	30
	+L.T.	31	4.58	1.697	.05	30
	L.T.	31	5.87	1.697	.05	30

df = n-1, where n= number of pairs.

* indicates a significant difference @ α

M.T. = 1.5m above low tidal elevation
+L.T. = 0.5m above low tidal elevation
L.T. = at the low tidal elevation

TABLE 8 : ANALYSIS OF VARIANCE

ONEWAY ON TIDAL HEAD FOR LIMESTONE 1hr

Source of Variation	df	Sum of Squares	Mean Squares	F ratio
Between Groups	3	387.0205	129.0068	42.377
Within Groups	148	450.5529	3.0443	
Total	151	837.5732		F_{crit} @ .05= 3.23

A POSTERIORI SCHEFFE TEST:

	-H.T.	M.T.	+L.T.	L.T.
-H.T.				
M.T.	87.416*			
+L.T.	57.468*	3.129		
L.T.	38.932*	9.677	1.799	

F_{crit} @ .05= 9.69

* indicates a significant difference between groups

TABLE 9 : ANALYSIS OF VARIANCE

ONEWAY ON TIDAL HEAD FOR LIMESTONE 2hr

Source of Variation	df	Sum of Squares	Mean Squares	F ratio
Between Groups	3	331.1614	110.3871	31.674
Within Groups	148	515.7970	3.4851	
Total	151	846.9583		F_{crit} @ .05= 3.23

A POSTERIORI SCHEFFE TEST:

	-H.T.	M.T.	+L.T.	L.T.
-H.T.				
M.T.	94.264*			
+L.T.	25.951*	21.296*		
L.T.	18.134*	29.708*	0.698	

F_{crit} @ .05= 9.69

* indicates a significant difference between groups

TABLE 10 : ANALYSIS OF VARIANCE

ONEWAY ON TIDAL HEAD FOR GNEISS-A 1hr

Source of Variation	df	Sum of Squares	Mean Squares	F ratio
Between Groups	3	60567.1599	20189.0508	208.447
Within Groups	92	8910.6416	96.8548	
Total	95	69477.7500		F_{crit} @ .05= 3.34

A POSTERIORI SCHEFFE TEST:

	-H.T.	M.T.	+L.T.	L.T.
-H.T.				
M.T.	384.04*			
+L.T.	390.62*	0.028		
L.T.	468.29*	4.173	3.518	

F_{crit} @ .05= 10.02

* indicates a significant difference between groups

TABLE 11 : ANALYSIS OF VARIANCE

ONEWAY ON TIDAL HEAD FOR GNEISS-A 2hr

Source of Variation	df	Sum of Squares	Mean Squares	F ratio
Between Groups	3	62672.1462	20890.7148	465.784
Within Groups	92	4126.2539	44.8506	
Total	95	66798.3750		F_{crit} @ .05= 3.34

A POSTERIORI SCHEFFE TEST:

	-H.T.	M.T.	+L.T.	L.T.
-H.T.				
M.T.	993.38*			
+L.T.	850.56*	5.539		
L.T.	942.16*	0.597	2.341	

F_{crit} @ .05= 10.02

* indicates a significant difference between groups

TABLE 12: ANALYSIS OF VARIANCE

ONEWAY ON TIDAL HEAD FOR SCHIST-A 1hr

Source of Variation	df	Sum of Squares	Mean Squares	F ratio
Between Groups	3	7.3277	2.4426	1999.021
Within Groups	156	0.1906	0.0012	
Total	159	7.5183		F_{crit} @ .05= 3.23

A POSTERIORI SCHEFFE TEST:

	-H.T.	M.T.	+L.T.	L.T.
-H.T.				
M.T.	3281.66*			
+L.T.	3873.33*	25.0*		
L.T.	4830.0*	148.33*	53.33*	

F_{crit} @ .05= 9.69

* indicates a significant difference between groups

TABLE 13 : ANALYSIS OF VARIANCE

ONEWAY ON TIDAL HEAD FOR SCHIST-A 2hr

Source of Variation	df	Sum of Squares	Mean Squares	F ratio
Between Groups	3	81473.8095	27157.9336	2893.130
Within Groups	156	1464.3784	9.3870	
Total	159	82938.1875		F_{crit} @ .05= 3.23

A POSTERIORI SCHEFFE TEST:

	-H.T.	M.T.	+L.T.	L.T.
-H.T.				
M.T.	6250.78*			
+L.T.	5904.89*	4.922		
L.T.	5110.34*	57.384*	28.693*	

F_{crit} @ .05= 9.69

* indicates a significant difference between groups

TABLE 14 : ANALYSIS OF VARIANCE

ONEWAY ON TIDAL HEAD FOR GNEISS-B 1hr

Source of Variation	df	Sum of Squares	Mean Squares	F ratio
Between Groups	3	108591.5194	36197.1719	500.361
Within Groups	124	8970.4275	72.3421	
Total	127	117561.9375		F_{crit} @ .05= 3.23

A POSTERIORI SCHEFFE TEST:

	-H.T.	M.T.	+L.T.	L.T.
-H.T.				
M.T.	370.93*			
+L.T.	1079.29*	184.76*		
L.T.	1150.93*	215.07*	1.15	

F_{crit} @ .05= 9.69

* indicates a significant difference between groups

TABLE 15 : ANALYSIS OF VARIANCE

ONEWAY ON TIDAL HEAD FOR GNEISS-B 2hr

Source of Variation	df	Sum of Squares	Mean Squares	F ratio
Between Groups	3	71209.0038	23736.3320	947.565
Within Groups	124	3106.1777	25.0498	
Total	127	74315.1250		F_{crit} @ .05= 3.23

A POSTERIORI SCHEFFE TEST:

	-H.T.	M.T.	+L.T.	L.T.
-H.T.				
M.T.	1981.44*			
+L.T.	1574.16*	23.403*		
L.T.	2071.37*	0.998	34.067*	

F_{crit} @ .05= 9.69

* indicates a significant difference between groups

TABLE 16 : ANALYSIS OF VARIANCE

ONEWAY ON TIDAL HEAD FOR SCHIST-B 1hr

Source of Variation	df	Sum of Squares	Mean Squares	F ~~ratio~~
Between Groups	3	7.2886	2.4295	1118.349
Within Groups	124	0.2694	0.0022	
Total	127	7.5580		F_{crit} @ .05= 3.23

A POSTERIORI SCHEFFE TEST:

	-H.T.	M.T.	+L.T.	L.T.
-H.T.				
M.T.	2685.0*			
+L.T.	3005.0*	9.0		
L.T.	3365.0*	38.0*	10.0*	

F_{crit} @ .05= 9.69

* indicates a significant difference between groups

TABLE 17: ANALYSIS OF VARIANCE

ONEWAY ON TIDAL HEAD FOR SCHIST-B 2hr

Source of Variation	df	Sum of Squares	Mean Squares	F ratio
Between Groups	3	97944.5726	32648.1875	840.081
Within Groups	124	4819.0317	38.8632	
Total	127	102763.5625		F_{crit} @ .05= 3.23

A POSTERIORI SCHEFFE TEST:

	-H.T.	M.T.	+L.T.	L.T.
-H.T.				
M.T.	1918.03*			
+L.T.	1394.49*	41.634*		
L.T.	1665.27*	8.925	12.005*	

F_{crit} @ .05= 9.69

* indicates a significant difference between groups

This is a result of the various tidal pressures exerted upon the coastal rock within the intertidal zone. The *a posteriori* Scheffe tests indicate the particular intertidal elevations which have significantly different saturation values from other elevations (Tables 8-17).

Next, the subhypothesis that the intertidal degree of saturation varies according to rock type was investigated, by using a oneway analysis of variance test. The data for this test were the greatest L.T. saturation values for each rock type. It was logically expected, and experimentation confirmed, that the degree of saturation of coastal rock is greatest at the low tidal elevation because intertidal rock here is under the greatest water pressure for the longest time. The results of the F test indicate a highly significant difference in saturation values between the rock types studied (Table 18). It is not surprising that the results of the Scheffe test reveal limestone to have a significantly different saturation value at the low tidal elevation from the gneiss and schist rocks, because it is a porous and permeable sedimentary rock, whereas the others have all been metamorphosed, resulting in nonporous and impermeable rocks (cf. limestone L.T. 1 hour with gneiss and schist L.T. 2 hour values, Table 6; for explanation see Fagerlund, and Ver beck and Landgren, p.20). It is also possible to explain why the saturation levels of gneiss-A are not significantly different from schist-A, but are significantly different from gneiss B and schist-B. Mineralogical identification

TABLE 18 : ANALYSIS OF VARIANCE

ONEWAY ON ROCK TYPES

Source of Variation	df	Sum of Squares	Mean Squares	F ratio
Between Groups	4	0.0003	0.0001	394.064
Within Groups	161	0.0000	0.0000	
Total	165	0.0003		F_{crit} @ .05= 2.89

A POSTERIORI SCHEFFE TEST:

```
MULTIPLE RANGE TEST


SCHEFFE PROCEDURE
RANGES FOR THE 0.050 LEVEL



  (*) DENOTES PAIRS OF GROUPS SIGNIFICANTLY
      DIFFERENT AT THE 0.050 LEVEL

                                G G G G G
                                R R R R R
                                P P P P P
                                0 0 0 0 0
     MEAN         GROUP         4 5 3 2 1

      .0052       GRP04
      .0052       GRP05
      .0054       GRP03
      .0057       GRP02         * *
      .0084       GRP01         * * * *
1ONEWAY
```

GRP01 = LIMESTONE
GRP02 = GNEISS-A
GRP03 = SCHIST-A
GRP04 = GNEISS-B
GRP05 = SCHIST-B

revealed that all have been metamorphosed; the difference is that gneiss-A was believed to originally have been an igneous rock (granite), whereas the others were sedimentary in origin. Although both the sedimentary and igneous rocks had been metamorphosed, only gneiss-A and schist-A had undergone high grade metamorphism whereas gneiss-B and schist-B had not. Usually, when rocks undergo high grade metamorphism, smaller minerals are formed and the matrix is much finer. This means that the rocks would tend to be more impermeable than the lower grade metamorphosed rocks. The resultant saturation values for gneiss-A and schist-A tended to be similar, and at the same time different from gneiss-B and schist-B (see Table 6, 1 hour L.T. values).

It is now possible to evaluate hypothesis I completely. The hypothesis that the intertidal degree of saturation varies according to elevation within the intertidal zone and according to rock type must be accepted. The degree of saturation of coastal rock within the intertidal zone varies according to the length of the submergence period and the tidal head pressures which act on the rock.

4.3 Intertidal and Supratidal Saturation

In order to statistically evaluate the subhypothesis that there is no level of permanent saturation of coastal rock within the intertidal zone, a series of one sample t-tests were performed using the following L.T. elevation data values: limestone 2 hour submergence, and gneiss and schist 1 hour submergence periods. The mean which these samples were tested against was that of absolute or vacuum saturation. The t-tests were directional because it was hypothesized that the L.T. elevation saturation values would be less than the absolute saturation, for each rock type. The results reveal that there is a statistically significant difference between the degree of saturation at the L.T. elevation and that of absolute saturation, for each rock type (Table 19). The particularly high t_{obs} value for limestone indicates the magnitude of the difference, and this is readily seen by comparing the L.T. elevation saturation values with that of absolute saturation (100%)(see Table 6). Therefore, this subhypothesis was accepted. This is because of the fact that in order for an intertidal level of permanent saturation to exist, the coastal rock within that zone must be saturated. This was not found to be the case. Although extremely high intertidal degrees of saturation exist, the coastal rock is not saturated within the intertidal zone. Although this distinction may seem trite, it nevertheless must be stated because it is precisely upon this intertidal level of saturation which the weathering school of thought bases its various theories of shore platform development.

Next, a series of one sample t-tests were performed using the adsorption data values, so that the subhypothesis that there is no level of permanent saturation of coastal rock within the supratidal zone could be statistically evaluated. Since this subhypothesis stated that the adsorption saturation values would be less than that of absolute saturation the t-tests were directional. The results reveal that there is a statistically significant difference in the saturation values between adsorption and absolute saturation (Table 20). When the means of the experimental data are considered (Table 1), this becomes apparent, especially for the limestone, and is so indicated by the extremely high t_{obs} value (Table 20).

Summing up what has been revealed by the data, it is now known that there is neither an intertidal nor a supratidal level of permanent saturation within coastal rock. The hypothesis which stated this can be accepted. However, there are very high, and in some cases extremely high degrees of saturation within the intertidal zone, but not the supratidal zone. The results imply that there cannot be a distinct break in the efficacy of chemical weathering processes operative on coastal rock above or below the elevation of a saturation zone.

However, with regards to the role of frost action within the intertidal zone, the attainment of critical saturation is very important. It has previously been noted that damaging frost induced pressure can only be exerted if a rock is critically saturated. The critical saturation level, however, varies with each rock type, but values are generally high enough to suggest that frost shattering may be operative within the intertidal zone. This would occur at the low tidal elevation for schist-A &B and gneiss-B, but not for gneiss-A nor limestone. The results of this study have

TABLE 19

T-TEST RESULTS ON INTERTIDAL PERMANENT SATURATION LEVEL

ROCK TYPE	df	T_{obs}	T_{crit}	∝	df used
LIMESTONE	37	-151.07*	1.697	.05	30
GNEISS-A	23	-6.23*	1.714	.05	23
SCHIST-A	39	-5.20*	1.697	.05	30
GNEISS-B	31	-2.19*	1.697	.05	30
SCHIST-B	31	-2.06*	1.697	.05	30

df = n-1, where n= number of pairs

* indicates a significant difference @ ∝

TABLE 20

T-TEST RESULTS ON SUPRATIDAL PERMANENT SATURATION LEVEL

ROCK TYPE	df	T_{obs}	T_{crit}	∝	df used
LIMESTONE	37	-173.75*	1.697	.05	30
GNEISS-A	23	-73.25*	1.714	.05	23
SCHIST-A	39	-38.82*	1.697	.05	30
GNEISS-B	31	-57.89*	1.697	.05	30
SCHIST-A	31	-39.15*	1.697	.05	30

df = n-1, where n= number of pairs

* indicates a significant difference @ ∝

revealed that the degree of saturation near the high tidal level is not even remotely close to the necessary critical saturation levels in any of the rock types for frost shattering to occur. Yet paradoxically, frost shattering may occur at the high tidal level or within the supratidal zone. Pools of standing water or meltwater from the icefoot on the platform surface might tend to provide isolated spots of critically saturated rock. When the tide flows out to sea uncovering the platform, immediate freezing (if the temperature is low enough), might therefore result in a limited amount of surficial damage to the platform by frost shattering. Similarly in the supratidal zone, groundwater flowing out from the cliff face, or meltwater from the icefoot, or from snow and ice on top of the cliff trickling down the cliff face might saturate the exterior of the cliff face. In this situation, when the temperature frequently fluctuates about the freezing point, some frost damage may occur on the cliff face. The magnitude of this event requires further study before it can be incorporated into the overall picture of frost shattering within the intertidal or supratidal zone.

4-4 Field Work

Although the data from the field work were analyzed, they were not subjected to any statistical testing procedures because of insufficient samples. Indeed, it was not the intent to go out into the field and gather data which could be statistically tested, but gather field data which represent the environmental conditions, so that they could be compared with the results of the laboratory work.

The results of the field data were classified according to rock type, location (Mont Louis/Madeleine-Centre), and site (platform pools/platform surface/cliff face)(Table 21). When all the pool samples are compared as a group to all the platform samples as a group, the pool rocks immediately following exposure have a saturation value of 96% and the platform surface rocks have a saturation value of 92%. Therefore, the saturation values are similar, with the pool rocks having slightly higher degrees of saturation than the platform surface rocks, at the time when the shore platform first became exposed. This is because the pool rocks may have been submerged from tens to hundreds of hours, rather than desorbing during tidal ebb. Rocks on the platform surface, on the other hand, undergo cyclic wetting and drying, and are submerged for only about half the tidal cycle. The submergence period clearly then influences the saturation values attained by the rock for its particular site on the shore platform.

When a general analysis of saturation at first exposure by rock group is conducted, the pool rocks have higher saturation values than the platform surface rocks. The igneous rocks are generally saturated if they are found in pools but the metamorphic and sedimentary rocks in pools also have extremely high saturation values. The platform surface rocks which are metamorphic attained only moderately high degrees of saturation as a whole, whereas the sedimentary rocks attained extremely high saturation values, slightly higher than those found in the pools (2% higher).

TABLE 21

GASPÉSIAN SHORE PLATFORMS: DEGREES OF SATURATION

ROCK TYPE	# SAMPLES	WEIGHED AFTER EXPOSURE AT INTERVAL # 1	2	3	4	5
SHALE:A	6	98	91	82	74	71
:B	5	97	84	81	80	81
:C	4	99	93	94	88	91
CHERT:A	1	100	100	96	91	83
GREYWACKE:A	5	100	92	86	81	77
:B	2	100	100	93	100	100
SANDSTONE:A	2	82	89	78	78	75
:B	2	100	82	80	79	78
:C	3	90	81	77	76	72
SILTSTONE:C	2	96	79	86	75	75
SLATE:A	1	100	84	68	68	63
MARBLE:A	2	97	91	84	79	64
GNEISS:A	1	83	67	50	50	33
:C	2	91	64	77	59	64
FAULT BRECCIA:B	2	100	68	60	72	60
:C	1	57	35	35	30	27
ANORTHASITE:A	1	100	100	78	67	67
QUARTZ SYENITE:A	1	100	100	100	100	100

		Temperature range:
A =	Mont Louis shore platform pools	10 - 17°C
B =	Mont Louis shore platform surface	10 - 16°C
C =	Madeleine Centre shore platform surface	11 - 14°C

#1 = as the shore platform was exposed
#2 = 2 hours after exposure
#3 = 4 hours after exposure
#4 = 7.0 hours after exposure for A,B; 7.5 hours for C
#5 = 10.5 hours after exposure

CLIFF SAMPLES: DEGREE OF SATURATION @ RELATIVE HUMIDITY (# SAMPLES)

	Mont Louis	Madeleine Centre
SHALE	100@ 100(1)	79@ 88(3)
GREYWACKE	18@ 100(2)	
SANDSTONE		7@ 88(1)
SLATE	69@ 100(2)	

The desorption curves reveal some interesting patterns when studied by rock grouping (Figs. 12-29). One of the impermeable and nonporous igneous pool rocks remained saturated throughout the entire desorption period while the other desorbed water only after being exposed for a couple of hours. These rocks do not initially desorb easily whatever water they contain. The sedimentary rocks usually have extremely high saturation values at exposure, and thereafter desorb water at a moderate rate, whereas the metamorphic rocks, which have attained very high saturation values, have markedly rapid desorption rates, followed by stabilization. The platform surface rocks, on the other hand, display different desorption patterns. The sedimentary rocks start from high to extremely high degrees of saturation, and initially desorb at a slow to moderate rate and then stabilize. The desorption rates of the metamorphic rocks follow one of two patterns. They rapidly desorb from moderate saturation values to become more stable or start at very high degrees of saturation and desorb, then adsorb, and then desorb again, in response to the changing relative humidity.

It should be noted that these desorption rates have occurred under the environmental conditions encountered during a typical late spring period in the study area. Different weather conditions would undoubtedly influence the desorption rates.

Certain anomalies were noticed when the data from the field samples were analyzed. Particular samples were

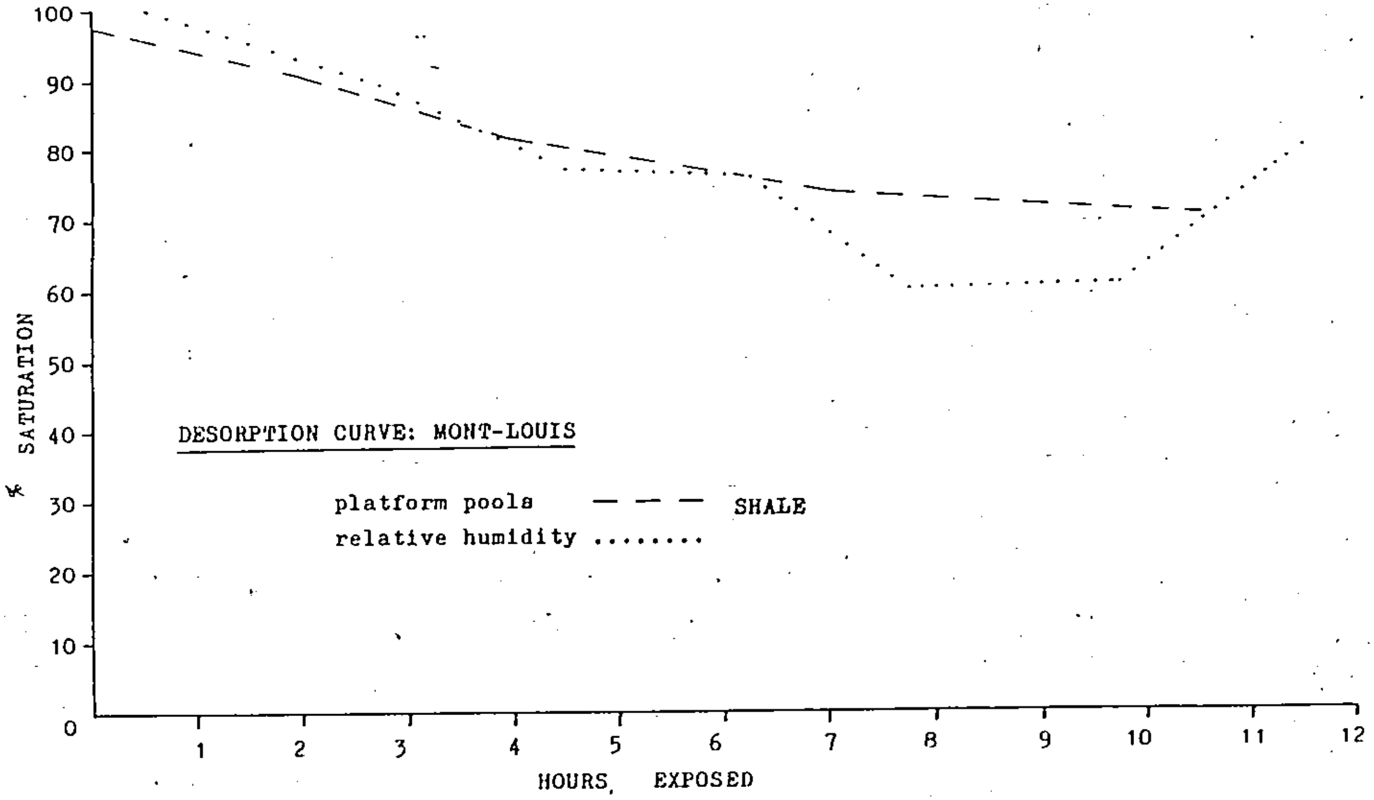
DESORPTION CURVE: MONT-LOUIS
platform pools — — — SHALE
relative humidity ....
% SATURATION
100
90
80
70
60
50
40
30
20
10
0
1
2
3
4
5
6
7
8
9
10
11
12
HOURS, EXPOSED

FIG. 12

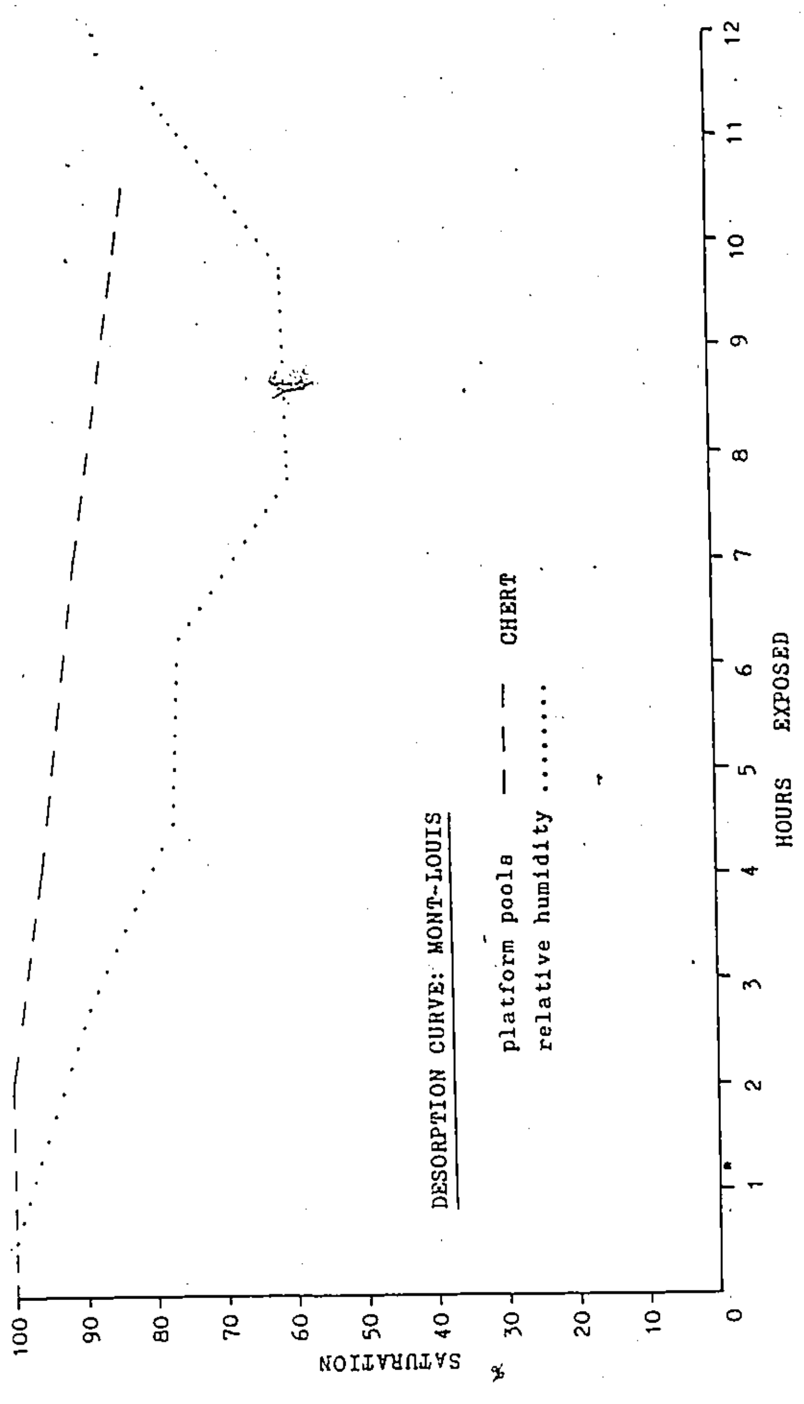
DESORPTION CURVE: MONT-LOUIS
platform pools — — CHERT
relative humidity ....
100
90
80
70
60
50
40
30
20
10
0
% SATURATION
1
2
3
4
5
6
7
8
9
10
11
12
HOURS EXPOSED

FIG. 13

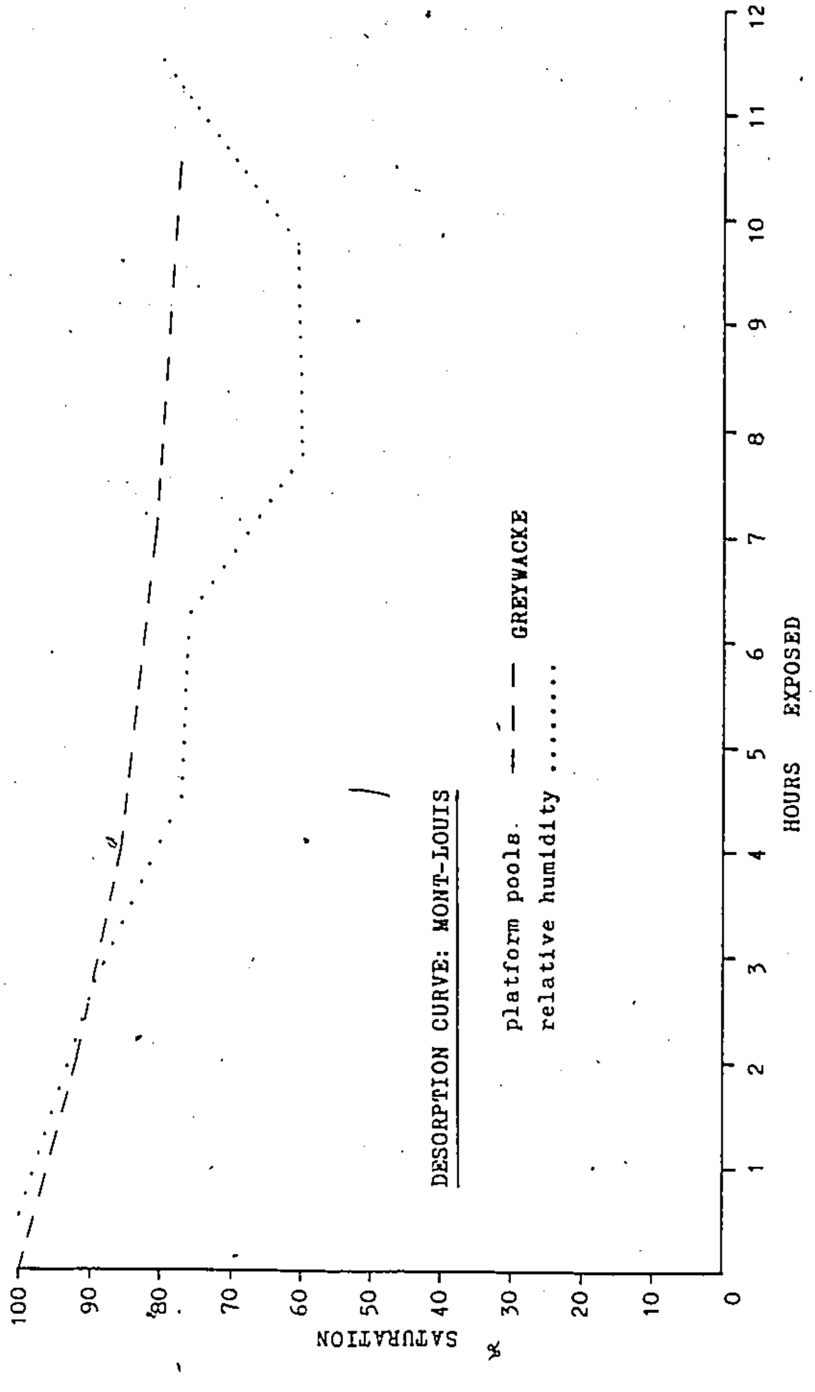
DESORPTION CURVE: MONT-LOUIS
platform pools — — — GREYWACKE
relative humidity ....
% SATURATION
100
90
80
70
60
50
40
30
20
10
0
1
2
3
4
5
6
7
8
9
10
11
12
HOURS EXPOSED

FIG. 14

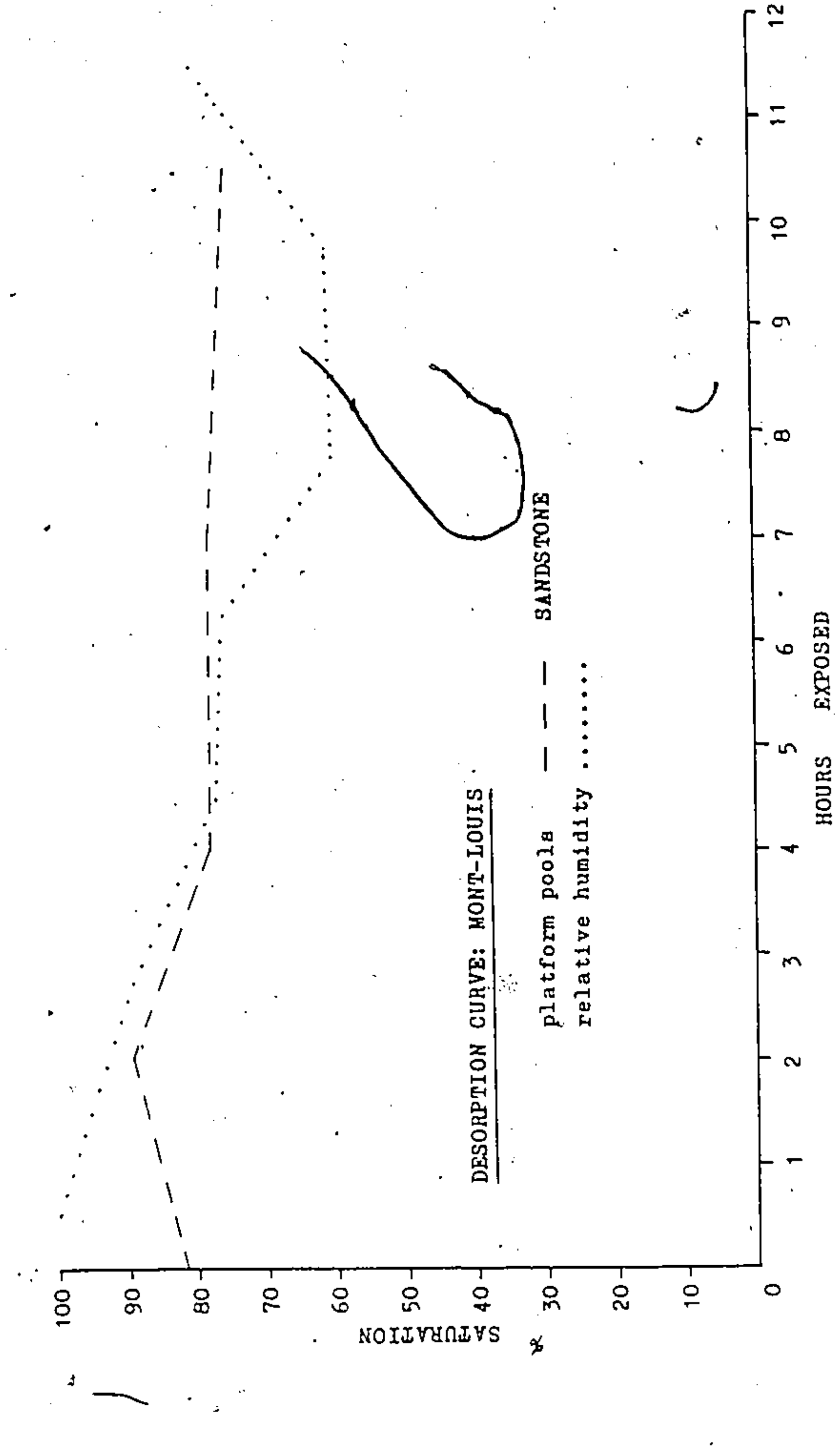
DESORPTION CURVE: MONT-LOUIS
SANDSTONE
platform pools — — —
relative humidity ....
% SATURATION
100
90
80
70
60
50
40
30
20
10
0
1
2
3
4
5
6
7
8
9
10
11
12
HOURS EXPOSED

FIG. 15.

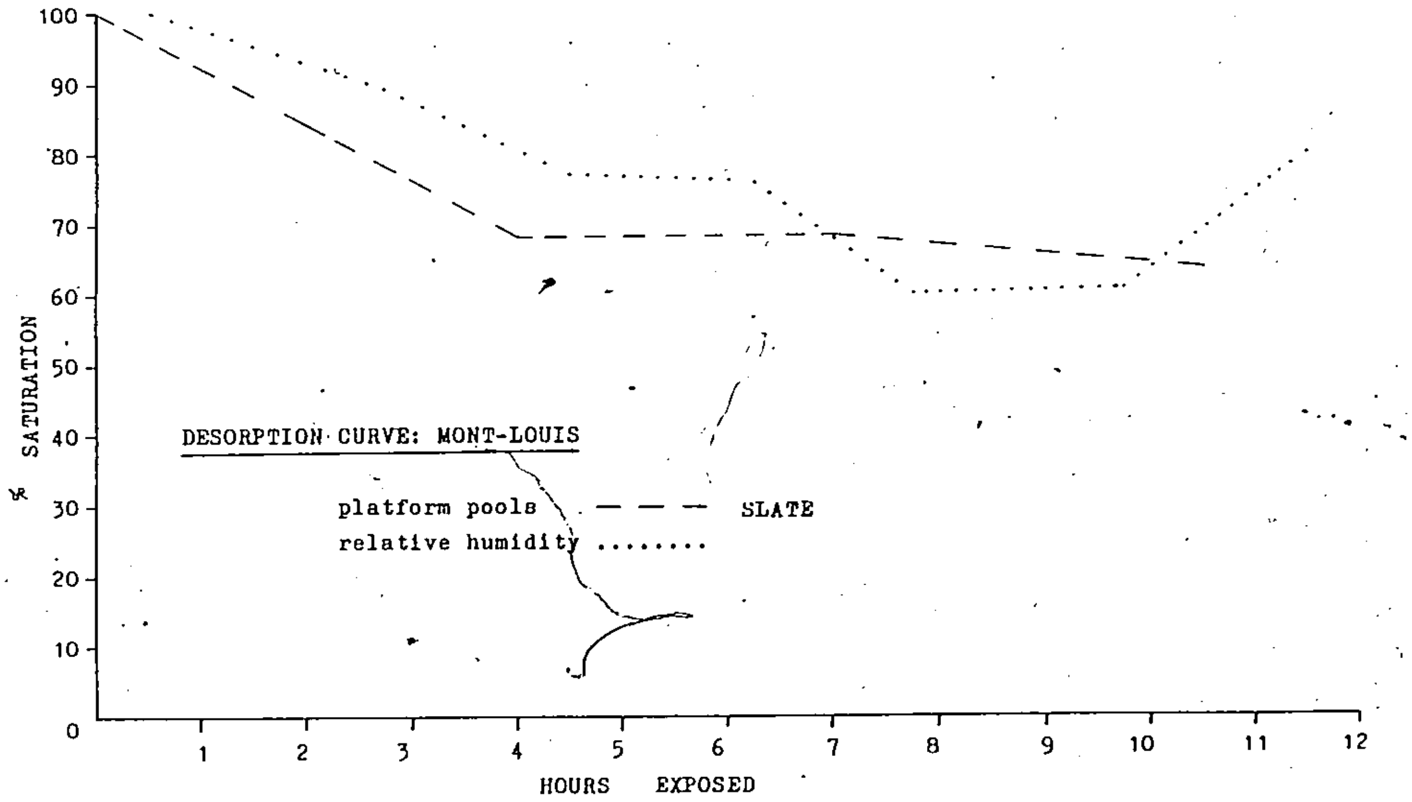
DESORPTION CURVE: MONT-LOUIS
platform pools — — — SLATE
relative humidity ....
% SATURATION
100
90
80
70
60
50
40
30
20
10
0
1
2
3
4
5
6
7
8
9
10
11
12
HOURS EXPOSED

FIG. 16

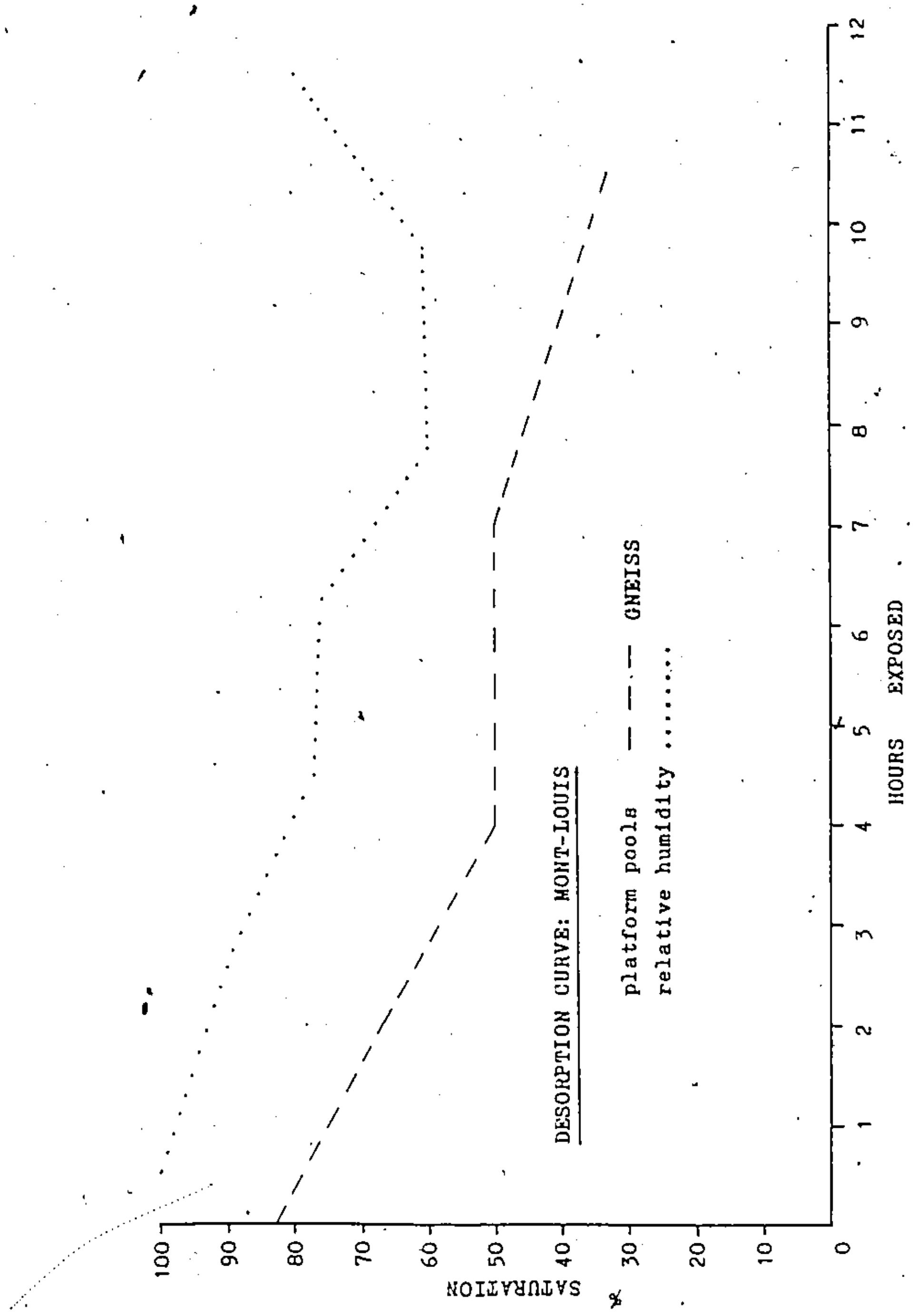
DESORPTION CURVE: MONT-LOUIS
platform pools — — GNEISS
relative humidity ....
% SATURATION
100
90
80
70
60
50
40
30
20
10
0
1
2
3
4
5
6
7
8
9
10
11
12
HOURS EXPOSED

FIG. 17

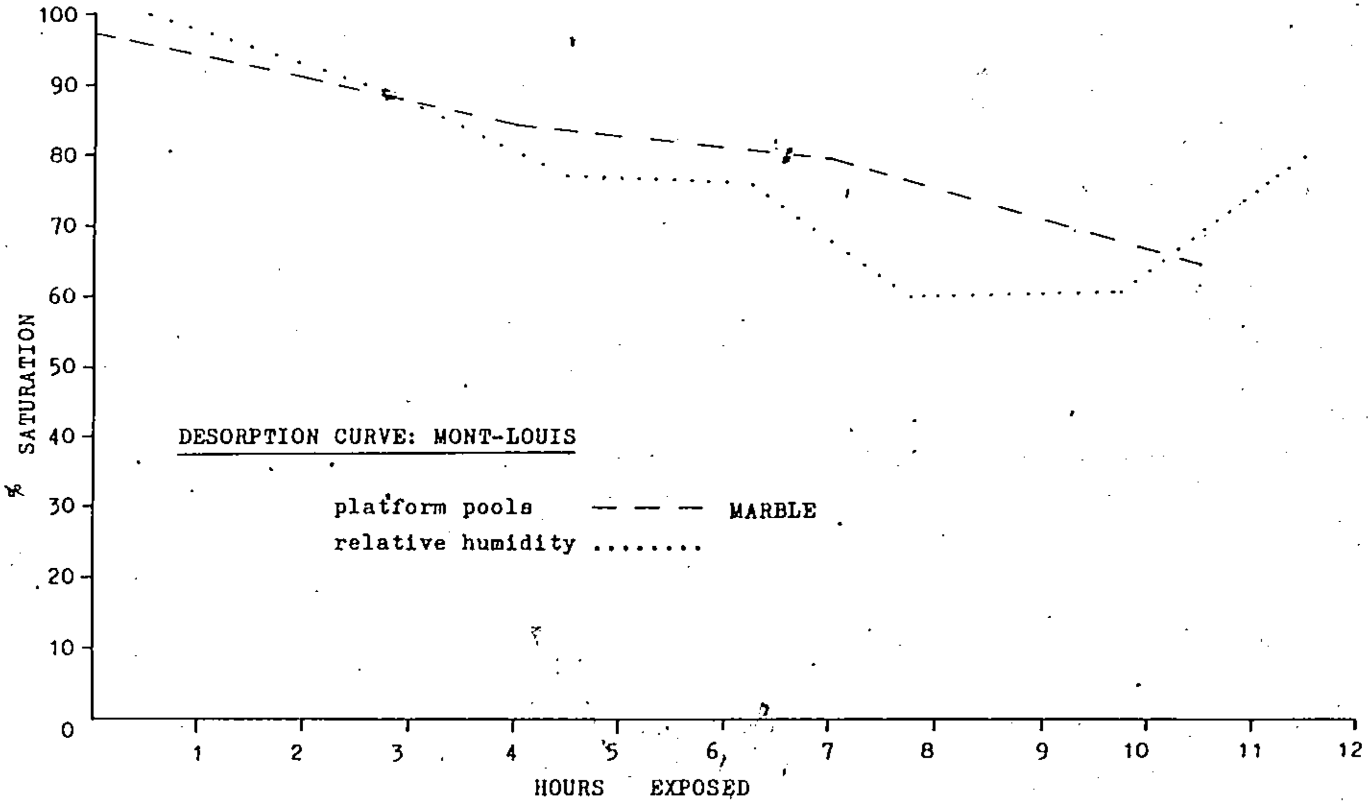
DESORPTION CURVE: MONT-LOUIS
platform pools — — — MARBLE
relative humidity ....
% SATURATION
100
90
80
70
60
50
40
30
20
10
0
1
2
3
4
5
6
7
8
9
10
11
12
HOURS EXPOSED

FIG. 18

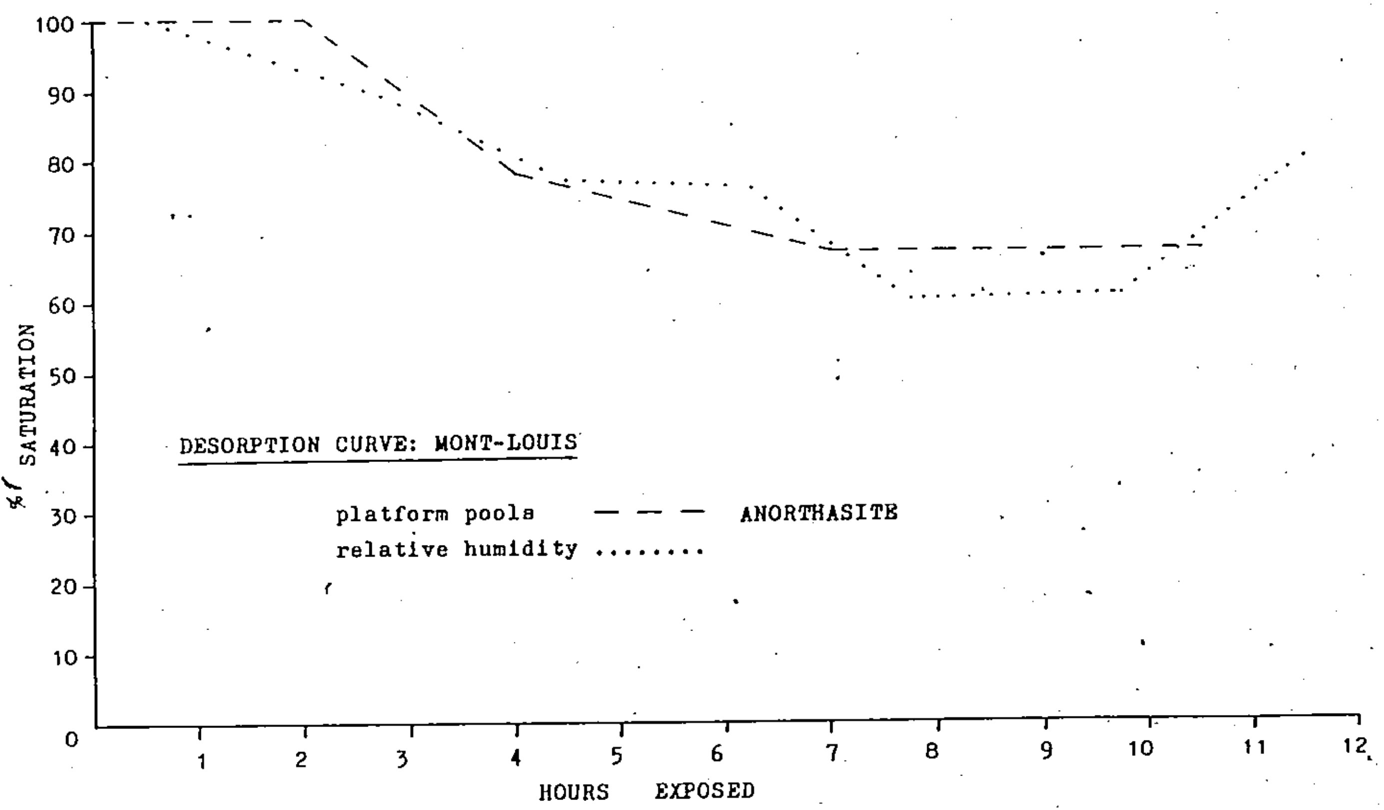
100
90
80
70
60
50
40
30
20
10
0
% SATURATION
1
2
3
4
5
6
7
8
9
10
11
12
HOURS EXPOSED
DESORPTION CURVE: MONT-LOUIS
platform pools — — — ANORTHASITE
relative humidity ....

FIG. 19

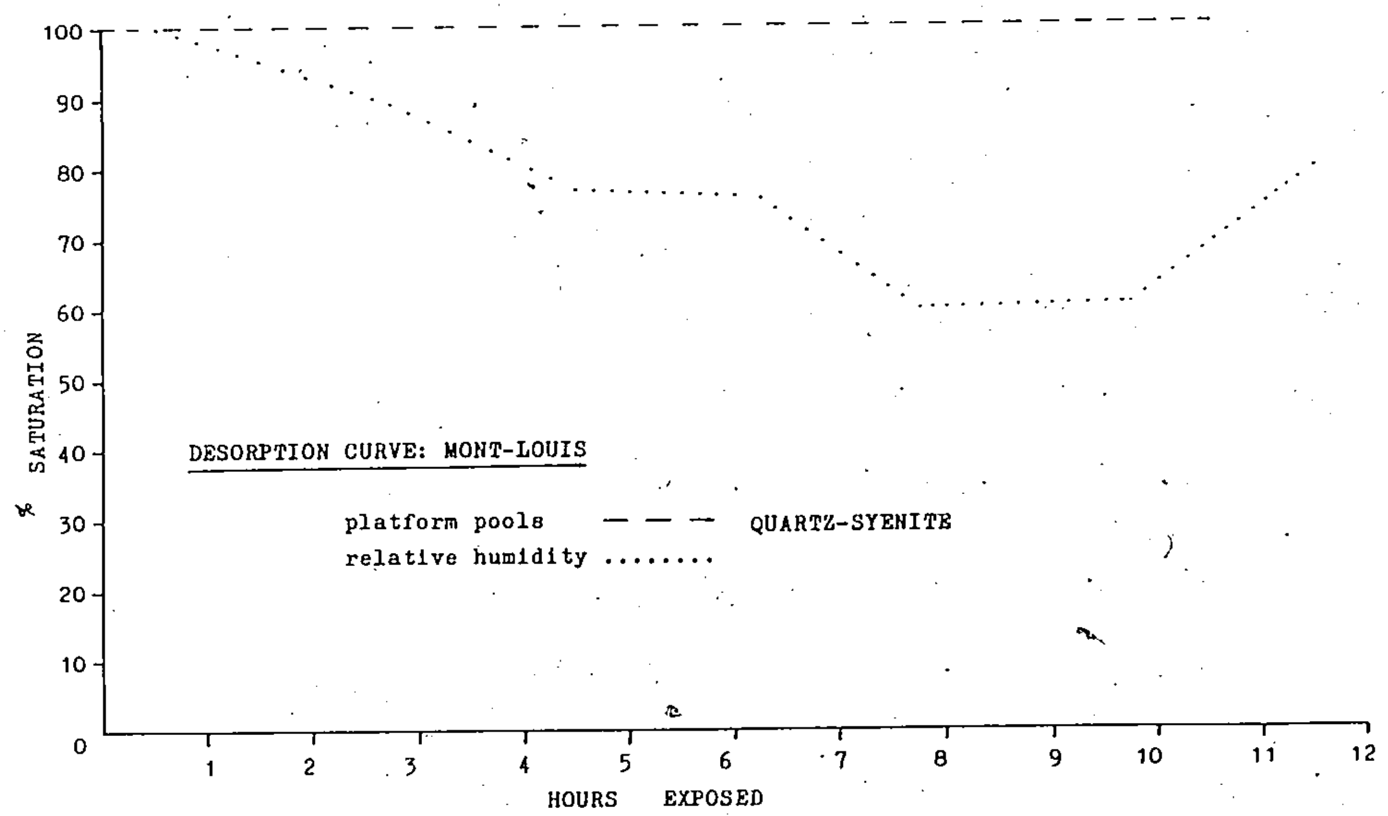
DESORPTION CURVE: MONT-LOUIS
platform pools — — — QUARTZ-SYENITE
relative humidity ....
% SATURATION
100
90
80
70
60
50
40
30
20
10
0
1
2
3
4
5
6
7
8
9
10
11
12
HOURS EXPOSED

FIG. 20

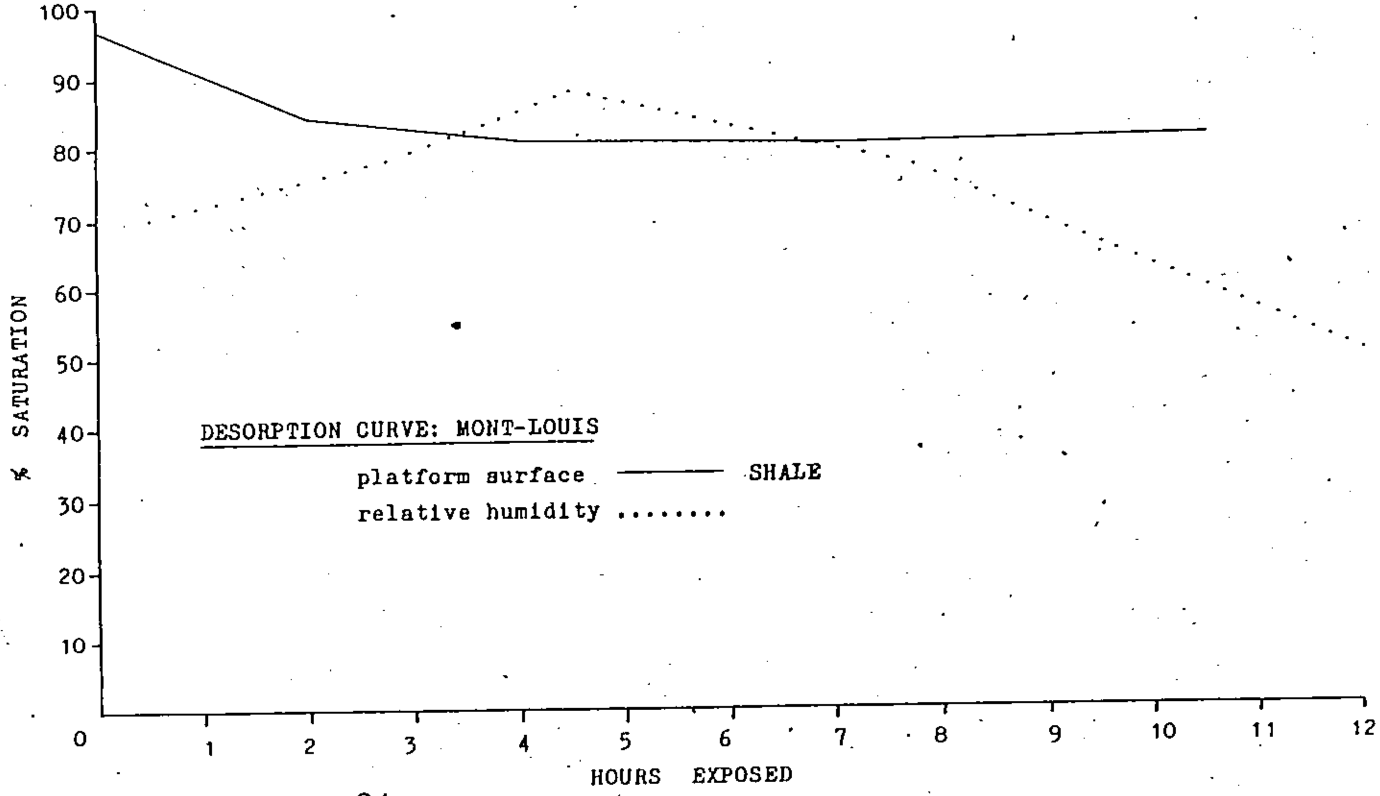
DESORPTION CURVE: MONT-LOUIS
platform surface
SHALE
relative humidity
% SATURATION
100
90
80
70
60
50
40
30
20
10
0
1
2
3
4
5
6
7
8
9
10
11
12
HOURS EXPOSED

FIG. 21

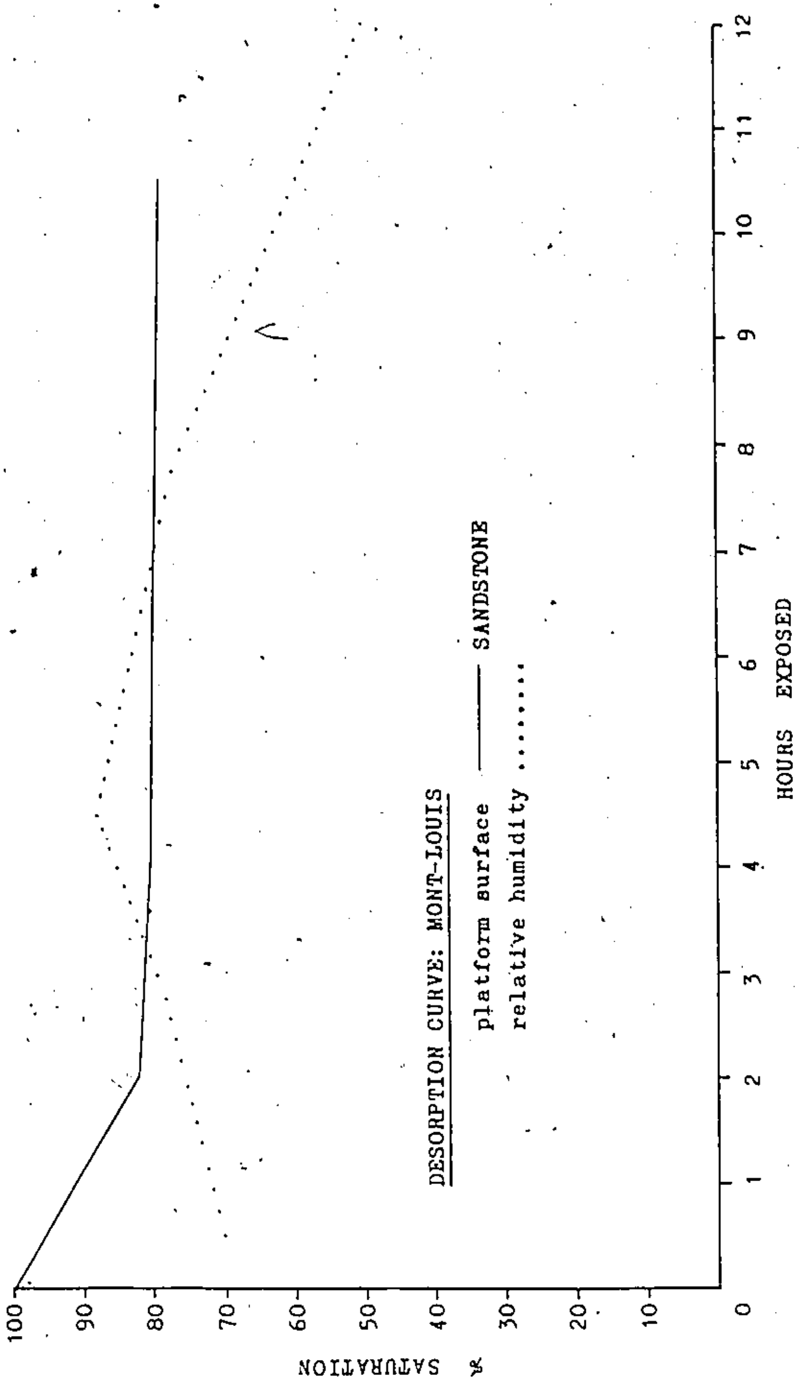
DESORPTION CURVE: MONT-LOUIS
platform surface —— SANDSTONE
relative humidity ....
% SATURATION
100
90
80
70
60
50
40
30
20
10
0
1
2
3
4
5
6
7
8
9
10
11
12
HOURS EXPOSED

FIG. 22

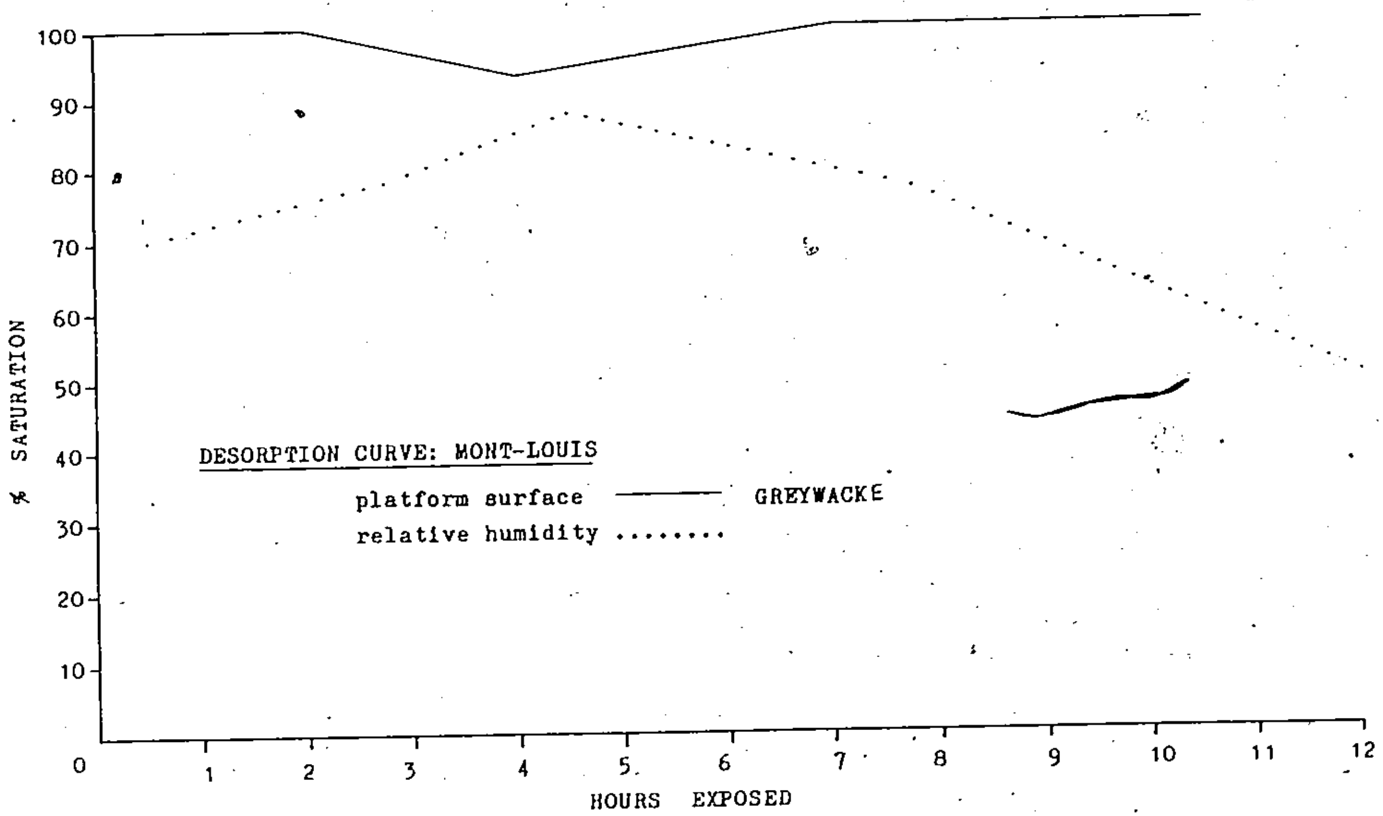
100
90
80
70
60
50
40
30
20
10
% SATURATION
0
1
2
3
4
5
6
7
8
9
10
11
12
HOURS EXPOSED
DESORPTION CURVE: MONT-LOUIS
platform surface
relative humidity ....
GREYWACKE

FIG. 23

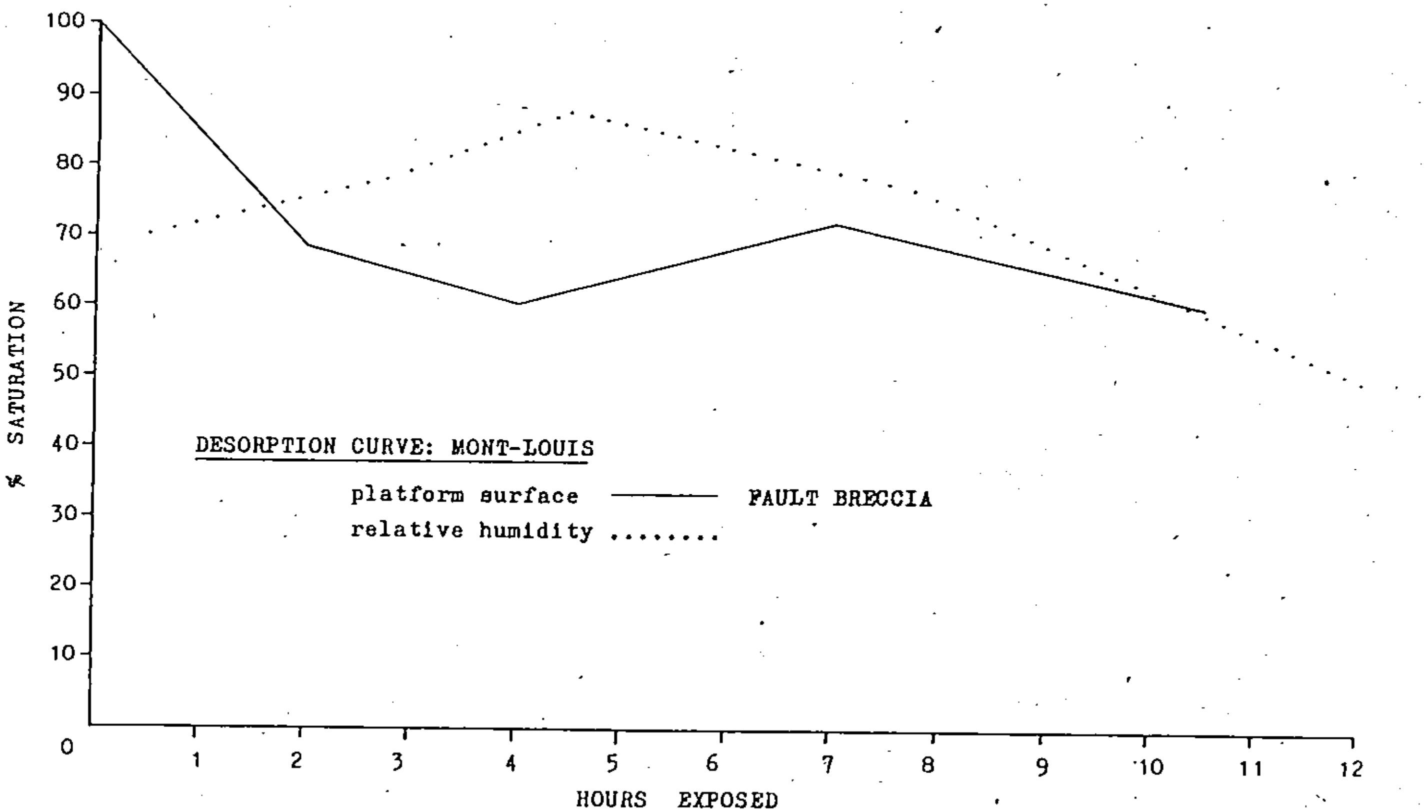
DESORPTION CURVE: MONT-LOUIS
platform surface ——— FAULT BRECCIA
relative humidity ....
% SATURATION
100
90
80
70
60
50
40
30
20
10
0
1
2
3
4
5
6
7
8
9
10
11
12
HOURS EXPOSED

FIG. 24

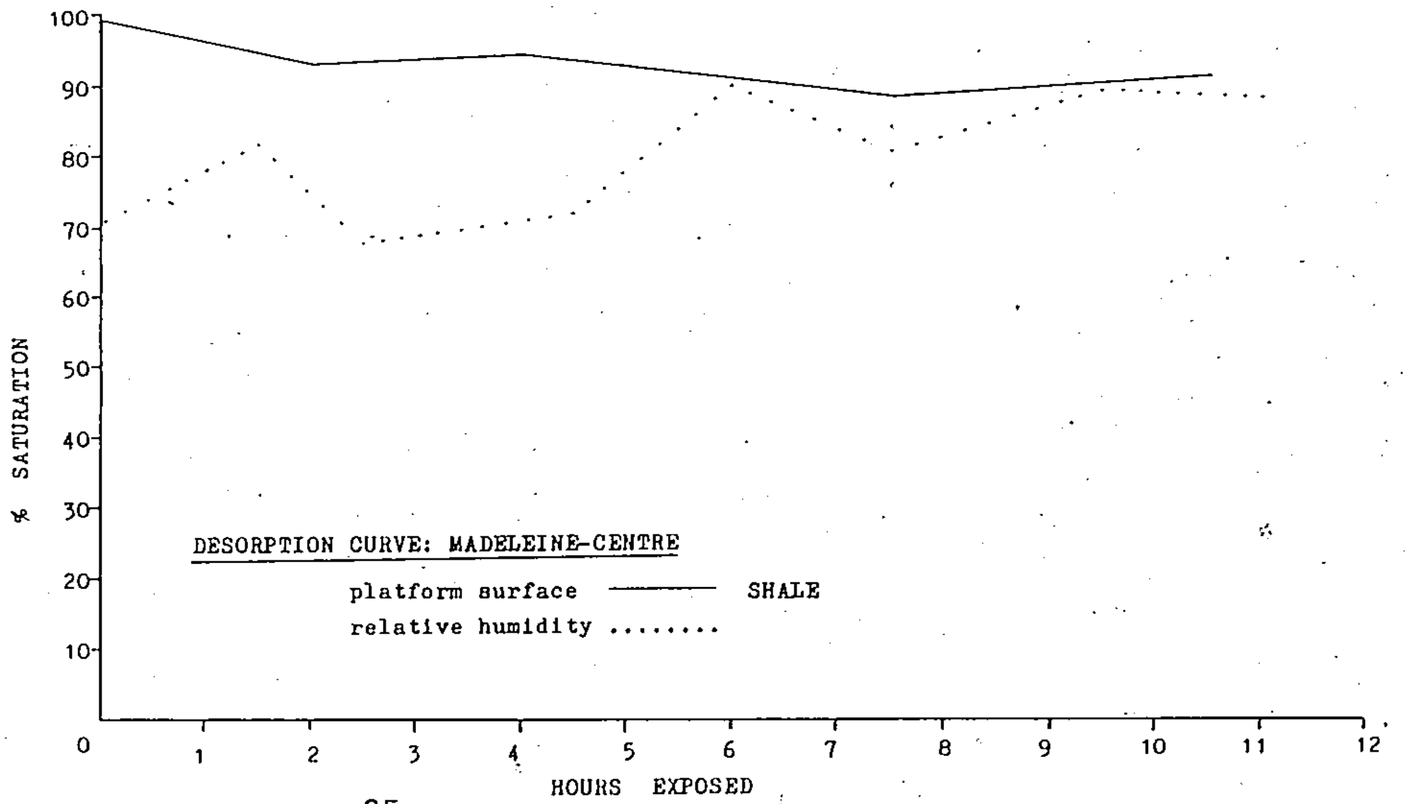
DESORPTION CURVE: MADELEINE-CENTRE
platform surface ——— SHALE
relative humidity ....
% SATURATION
100
90
80
70
60
50
40
30
20
10
0
1
2
3
4
5
6
7
8
9
10
11
12
HOURS EXPOSED

FIG. 25

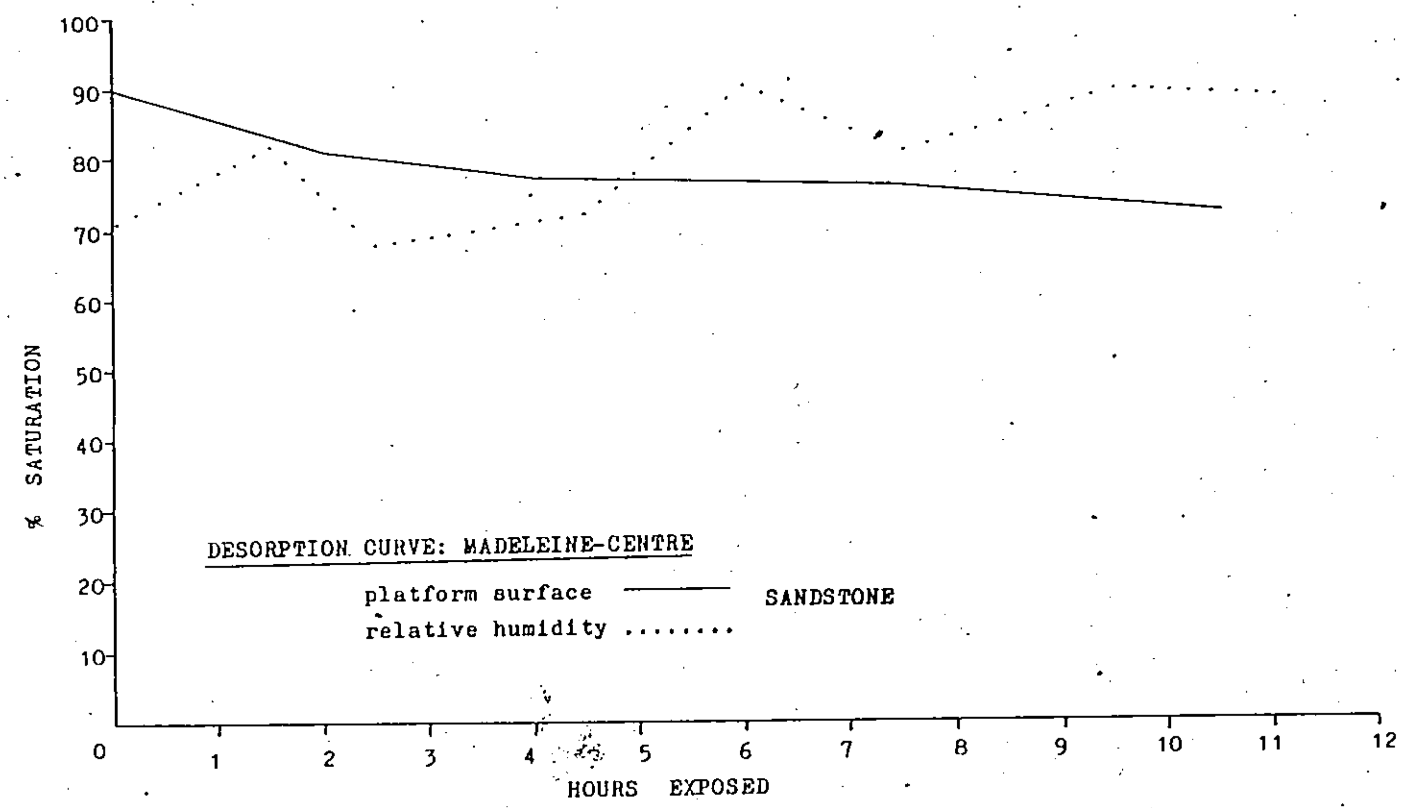
DESORPTION CURVE: MADELEINE-CENTRE
platform surface ——
relative humidity ....
SANDSTONE
% SATURATION
100
90
80
70
60
50
40
30
20
10
0
1
2
3
4
5
6
7
8
9
10
11
12
HOURS EXPOSED

FIG. 26

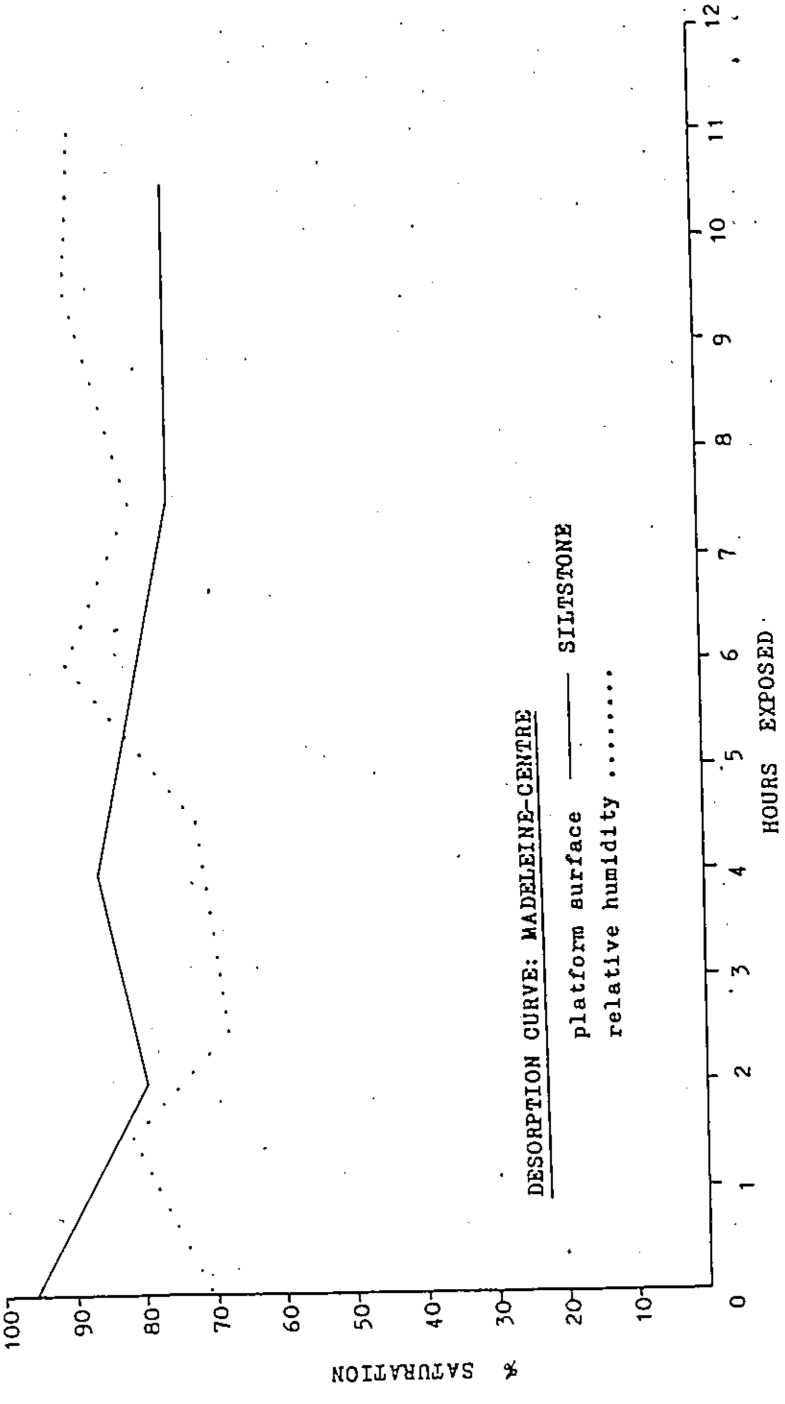
DESORPTION CURVE: MADELEINE-CENTRE
platform surface —— SILTSTONE
relative humidity ....
% SATURATION
100
90
80
70
60
50
40
30
20
10
0
1
2
3
4
5
6
7
8
9
10
11
12
HOURS EXPOSED

FIG. 27

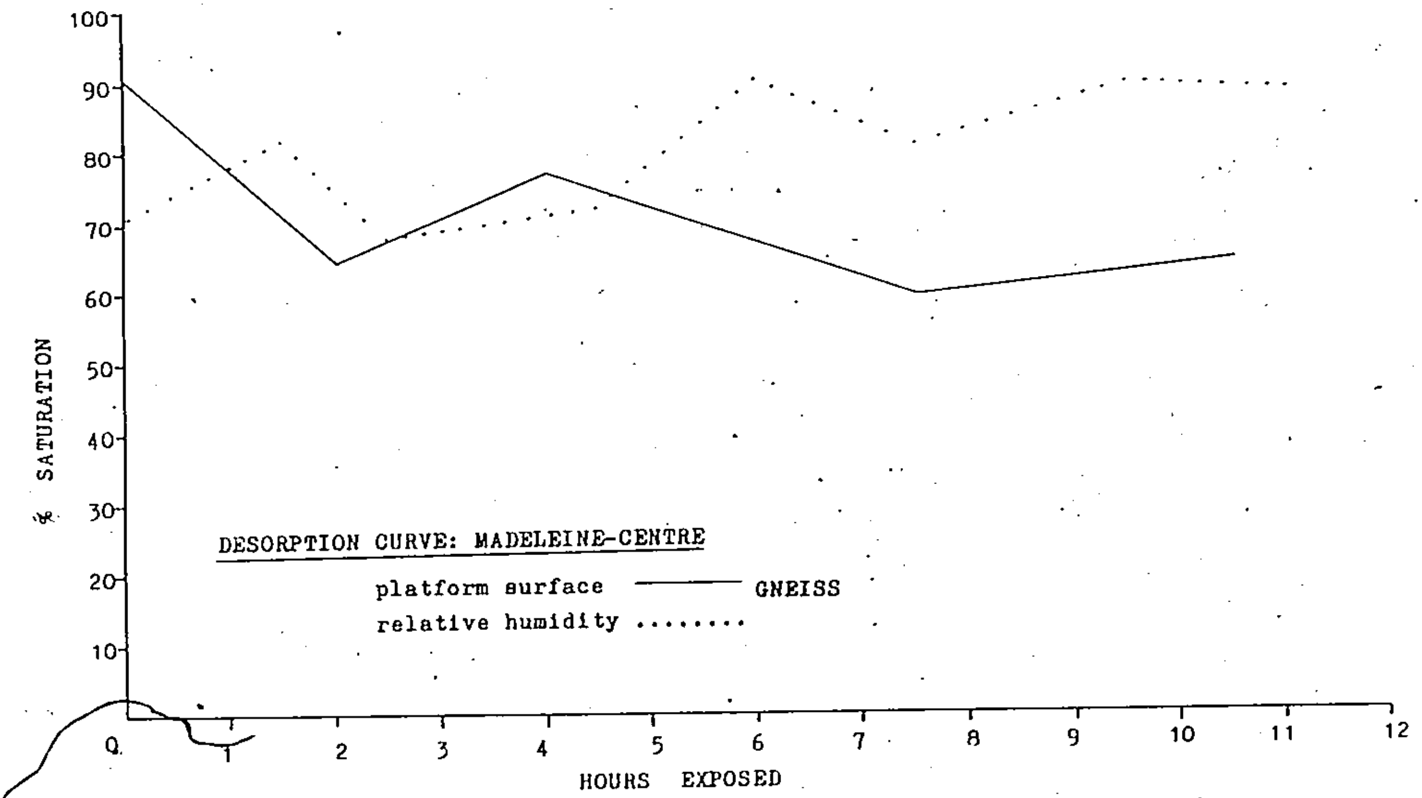
100
90
80
70
60
50
40
30
20
10
% SATURATION
0
1
2
3
4
5
6
7
8
9
10
11
12
HOURS EXPOSED
DESORPTION CURVE: MADELEINE-CENTRE
platform surface —— GNEISS
relative humidity ....

FIG. 28

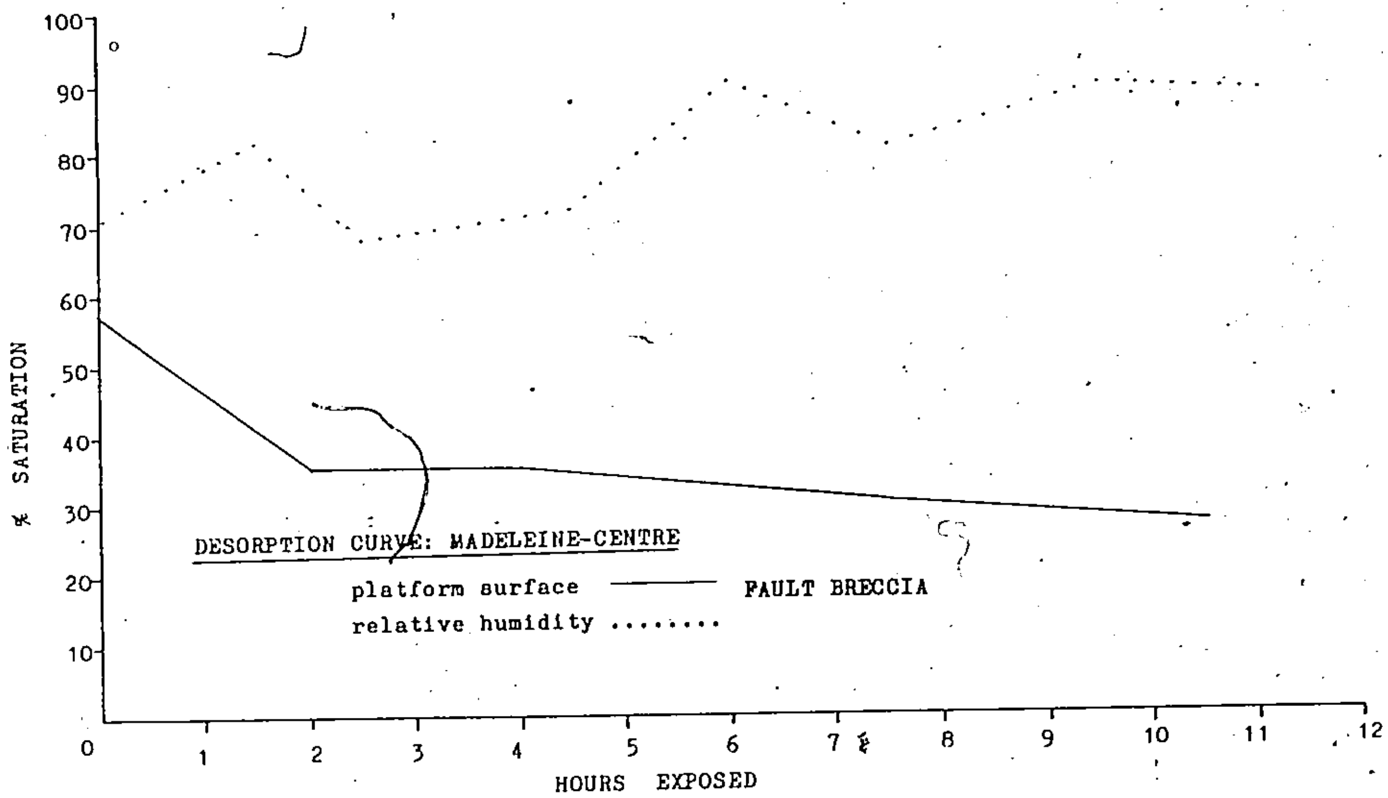
DESORPTION CURVE: MADELEINE-CENTRE
platform surface ——— FAULT BRECCIA
relative humidity ....
% SATURATION
100
90
80
70
60
50
40
30
20
10
0
1
2
3
4
5
6
7
7½
8
9
10
11
12
HOURS EXPOSED

FIG. 29

found to be losing weight in their dry state, influencing the measurement results. These irregularities are the result of natural processes continuing to operate in the laboratory, as well as natural field conditions which were not discovered until laboratory work had begun. These involve such things as flaking of the shales because of salt crystallization and/or wetting and drying. One shale sample in particular was discovered to have completely shattered along cleavage planes after only a few procedures were performed (#12). Other samples were surrounded by small pieces of rock after they were taken from the oven and left on a table overnight. Some of this disaggregation may have been the result of handling, but the rocks must have been considerably weakened beforehand. One greywacke sample was observed to flake on its bottom side after oven drying; closer inspection revealed that it was algae covered (not noticed in the field) and that the algae dried up and flaked off after being placed in the oven. Such a sample would naturally have a greater weight when measured in the field than when measured in the laboratory. Also, tiny mollusks were observed to be attached to the rocks as they were sampled from the shore platform, and it is possible that those not removed in the field were detached later in the laboratory. Although the field samples were surface dried with a towel before field measurements were taken, algal coverings and inaccessible surface irregularities may have prevented all the water and foreign material from being removed. Such conditions might conceivably make it very difficult to obtain accurate field measurements quickly, since many platform samples had to be collected in as brief a time period as is reasonably possible after the shore platform became exposed.

Comparison of the field data with the laboratory data is difficult. The only real comparison between similar rock types which could be made was between gneiss from Gaspe with the gneiss-A&B used in the laboratory experiments. The comparison however, had to be made between platforms located near the high tidal elevation, using the laboratory results, with platforms located near the mid tidal elevation, using the field results. The experimental data may be considered to represent Australasian high tidal platforms, which may then be compared with Gaspésian mid tidal platforms. The laboratory results indicate that high tidal platforms in gneiss-A and gneiss-B rocks in microtidal regimes achieved 27% and 25% saturation respectively (Table 6). However, the mid tidal platform in gneiss rock from Gaspé had achieved 91% saturation on the platform surface at Madeleine-Centre and 83% saturation in platform pools at Mont-Louis after being uncovered by the tide (Table 21). It appears, therefore, that the laboratory results, confirmed by the field results, indicate that coastal rock within the intertidal zone is not saturated at the mid tidal elevation or above.

It is possible to make comparisons between the laboratory and field results for the different rock types found at the same intertidal elevation. Generally the

Gaspésian pool samples at the mid tidal elevation had extremely high saturation values, most being saturated or nearly so. Only the sandstone and the gneiss had low values, and these were in the low 80's. Platform surface samples at Mont-Louis and Madeleine-Centre nearly all were 90% saturated or greater, the only exception being the fault breccia on the Madeleine-Centre platform which had only achieved 57% saturation after exposure. Somewhat lower saturation values were obtained with the laboratory samples which were submerged for the longest time (2 hours) at the mid tidal elevation. The limestone had a rather low value of 57.4%; the schist-A had achieved 81.5% saturation, which is more in line with the lower Gaspésian values; and schist-B had obtained 94.1% saturation which is quite similar to the majority of the Gaspésian values; gneiss-A was 88% saturated and gneiss-B 81% saturated, both being somewhat lower than in the field. There may be two reasons for the higher saturation values in the field: first, unlike the laboratory rocks, the field rocks were weathered and probably in equilibrium with the processes acting upon them, so that the maximum saturation possible under those conditions was achieved. The laboratory rocks, with their lower saturation values, may not have been in equilibrium with the test conditions although they were subjected to 5 'tidal' cycles before measurements were taken. Probably of more significance is the fact that the platforms were water covered for approximately 7 hours of a semidiurnal tidal cycle, compared with only 1-2 hours in the laboratory.

Perhaps such a submergence period is necessary in order to achieve critical saturation of the intertidal rocks.

Samples of coastal rock from the cliff face above the high tidal elevation were collected so that a comparison could be made with the results of the adsorption experiment in the laboratory. When the data are compared, the vast differences in the degree of saturation are readily noticed (cf. Table 6 with Table 21). All the laboratory rocks had fairly low saturation levels. The metamorphic rocks were exposed at a relative humidity of 94% for 12 hours. The gneiss rocks had values in the low and mid 20's, whereas the schists had saturation values in the mid 20's to low 30's. In the field, metamorphic slate in Gaspé achieved 69% saturation, at a time when the relative humidity was 100%. Although it is not known how long this state of saturated air existed, it probably did not exist for the 12 hours prior to sample collection. In the laboratory, coarse grained, porous, and permeable limestone attained only 0.9% saturation, with a relative humidity of 94% for 12 hours. The Gaspésian sedimentary rocks achieved 7% saturation at 88% relative humidity (sandstone) and 18% saturation at 100% relative humidity (greywacke). However, the finer grained, less porous, and less permeable shale was saturated at a relative humidity of 100%, and attained 79% saturation at 88% relative humidity. These results reflect differences in rock type re adsorption. Saturation of some argillaceous rocks, especially shale, is possible under high humidity. Since adsorbed water is virtually unfreezable, however, breakdown is by temperature dependent wetting and drying, and possibly chemical action.

The relationship between desorption in the field, and relative humidity is graphically represented according to location and site, for each rock type (Figs. 12-29). The rates of desorption seem to follow certain patterns. The anorthasite (Fig. 19) and fault breccia (Fig. 29) show rapid initial desorption followed by a continued, though much more gradual desorption. The slate (Fig. 16), shale (Fig. 21), and sandstone (Fig. 23) exhibited rapid initial desorption, but this was followed by a levelling off of the desorption rate. Consistently moderate rates of desorption characterized the shale (Fig. 12), greywacke (Fig. 14), and marble (Fig. 17). Rocks which desorbed, for the most part, at a gradually steady rate throughout the centre exposure period were chert (Fig.13), shale (Fig. 25), and sandstone (Fig. 26). The gneiss (Fig.18) displayed rapid initial desorption, then levelled off, and then once again desorbed rapidly. All these curves followed the general pattern of desorbing water during exposure. However, some anomalies existed in which this general pattern was not followed. The quartz syenite (Fig. 20) did not desorb any water at all, but remained saturated throughout the entire exposure period. This nonporous and impermeable rock was the only pool sample to do so. The impermeability of this kind of rock does not allow water to be lost easily; this may account for the water retention. It also absorbs water very slowly, however, and could only attain saturation in deep rock pools which do not completely drain during the low tidal period. The greywacke (Fig. 22) showed a similar result, except that it desorbed water a few hours after being exposed, and was a platform surface sample. At its low point on the curve, the relative humidity is high (90%) and it appears that the clay matrix of this rock may have begun to adsorb water under such conditions, explaining the return to a saturated state. This same phenomenon may be operative with the sandstone as well (Fig. 15). Upon exposure, the rock was approximately 80% saturated, but the air was also saturated with moisture. Again, adsorption by the clay minerals in the rock seem to account for the increase in the degree of saturation, up to the point where the two curves almost intersect. Thereafter, the sandstone desorbed water as the relative humidity decreased. The siltstone (Fig. 27) and gneiss (Fig. 28) were from the same location and site, and experienced the same general desorption pattern. These rocks initially rapidly desorbed, as the moderate relative humidity increased. Thereafter, they adsorbed water as the relative humidity decreased, desorbed as the relative humidity fluctuated, and then tended to absorb water slightly (gneiss) or stabilize (siltstone). The response of these rocks may have lagged the changing relative humidities, but this is difficult to determine from a discrete, rather than continuous measurement of rock weight and relative humidity. Continuous measurements of the variables might reveal a somewhat different desorption pattern. The fault breccia

(Fig. 24) revealed a similar pattern of desorption, adsorption, then desorption, but was measured under different conditions than the gneiss or siltstone. Instead of oscillating relative humidities, the fault breccia was subjected to increasing relative humidity to a high of 90%, then a continued moderate decrease. However, perhaps a lag in the rock's response to its environment may account for this desorption pattern.

No comparison can be made between laboratory and Gaspésian field desorption results, as desorption was not studied in the laboratory. However, a comparison between the Gaspésian results and the author's previous study can be made (1980), since desorption in the laboratory was studied then. Those results reveal a consistent pattern for all the rocks studied: an extremely rapid initial desorption which is continued, but at a slower rate, followed by a moderate desorption and ending with an extremely rapid desorption. However, these laboratory samples were not subjected to varying temperatures or relative humidities, but to a constant temperature and moderate humidity during the desorption period. The fans within the environmental chamber which circulated the air to maintain the constant temperature unquestionably contributed to the rapid desorption of the rocks. Such turbulent conditions did not always exist in the field, hence the lower in situ desorption rates which were experienced by the Gaspésian rocks.

CHAPTER 5

CONCLUSION

5.1 Model evaluation

The *a priori* model (Fig. 2) includes both the sorption and desorption aspects of the saturation of coastal rock, although only the sorption aspect was considered in the laboratory experiments. Those results suggest that the saturation of coastal rock varies between rock types, and according to the intertidal elevation of the rock. Generally, there is a greater difference between sedimentary rock and metamorphics, than within the metamorphics alone. The limestone had attained only moderate saturation values immediately following immersion; the metamorphic rocks, however, had usually attained very high saturation values, and in certain situations, they probably approached a saturated state. The gneiss-B and schist-B rocks, following immersion, approximated the saturated state moreso than the gneiss-A and schist-A rocks, under the same conditions. Generally, a pattern emerges which is consistent between all the rock types, when the intertidal saturation values of each rock type are considered. The saturation of coastal rock does indeed vary within the intertidal zone, with the least amount of saturation occurring at the high tidal elevation and the greatest saturation occurring at the low tidal elevation (approaching a saturated state following immersion, particularly for the gneiss-B and schist-B rocks). However, the permanent saturation level of coastal rock was not found to exist intertidally. The laboratory results also revealed that coastal rock in the supratidal zone is generally far from being saturated, as all saturation values were low (under $\simeq$ 30%), with the limestone being almost dry (0.9% saturation).

The field results generally confirm the findings of the laboratory experiments. However, the saturation values for the field site were generally higher. This indicates that although the salient parameters of the environmental setting simulated in the laboratory were largely accurate, there is still some variation which the a priori model has not been able to account for. It seems then, that although the model closely represents the environmental setting, there is still room for improvement.

It has recently been demonstrated that horizontal shore platforms can develop in areas where chemical weathering down to the saturation level can be excluded (Trenhaile, 1978). This occurs in cool environments such as eastern Canada. Even in warmer climates such as Australasia, horizontal platforms occur where there is no marked level of permanent saturation of intertidal rock, separating unweathered rock below from weathered rock above. In such situations, there is a gradual transition in the degree of saturation from the high tidal level, which is very unsaturated, to the low tidal level, which is nearly saturated. Mercan (1980) found that the saturation of rock within the intertidal zone fluctuates with ~~the~~ submergence period, rock type, and seasons. The chemical processes at work within the entire intertidal zone weather all rock to some degree, so that there is no unweathered rock within this zone. This study goes further to suggest that the role of chemical weathering, even in warm, wet climates, is ineffective in developing horizontal shore platforms, other than weakening cliff structures, so preparing them for wave erosion, which may otherwise be too weak in some areas to accomplish sufficient cliff recession.

This study has revealed that the saturation level of coastal rock is located below the low tidal elevation, and opposes Bartrum's assertion (1916) that the saturation level is between the mid and high tidal elevations. As weathering is believed to operate down to the saturation level, revisions to these theories of platform development are required at the very least.

The data from this study support other evidence (Trenhaile, 1980, in preparation-b) that horizontal shore platforms just below the high tidal elevation cannot be the result of weathering. This is because: a) the permanent saturation level of coastal rock does not exist intertidally; and b) the amount of water saturation in coastal rock varies with the tides, and with rock type. The saturation level below low tide (Fairbridge, 1952) must exist, but most horizontal shore platforms are located above this level (Trenhaile, 1980). Frost action cannot planate intertidal shore platforms because: a) the saturation of coastal rocks at the moment they first become exposed is not sufficiently high for frost action to operate at the high tidal elevation, b) there is no abrupt change from saturated to unsaturated rock within the intertidal zone, and c) high initial saturations occur in some rock types at all elevations within the intertidal zone, although this tendency increases towards the low tidal level. Many rock types may be subject to frost action in the intertidal zone, but it is probably most active, most often, and on the greatest variety of rock types, near low tide. Platforms could only be planated by frost at this low elevation, but the elevations of platforms in the cool mid and high latitudes actually range from the mid to the high tidal levels. It would appear therefore, that they have been planated by processes other than frost.

Unlike frost, the rate of desorption of intertidal rocks upon exposure is of crucial importance to an evaluation of the weathering theory of platform formation. There is no fixed saturation level in the intertidal zone. Rocks which absorb water quickly and are saturated upon exposure to subaerial weathering, are also those which loose water quickly. There can be no marked break between weathered and unweathered rock in the intertidal zone, and sub-horizontal platforms in the warm temperate and tropical areas of the world must therefore have been planated by other processes.

Physical and chemical weathering processes probably play an important role in the retreat of coastal cliffs in cool and warm environments, but there is no evidence to suggest that they are able to operate only down to a specific datum, thereby planating the residual surface. This, and other evidence which indicates that wave action is vertically concentrated within tidal ranges (e.g., Trenhaile, 1978; Trenhaile and Layzell, 1980, 1981), provide further support for the wave erosional school (Bartrum, 1924, 1935, 1938; Jutson, 1931, 1939; Johnson, 1933, 1938; Edwards, 1941, 1951; Trenhaile, 1978, 1980, in press-a&b, in preparation-b; Trenhaile and Layzell, 1980, 1981).

5.2 Limitations of the study

The major limitation of the study was that the distribution of water in the rock was not known. One part of the rock may have been saturated (e.g., the outer shell) whereas, overall, the rock was unsaturated. Second, for rock samples to be representative of intertidal rock, they must be in the same condition as the rock in situ; therefore they should be weathered to the same extent which intertidal rock is weathered. Finally, a curve which represents the rise and fall of the tides should be used so that an accurate submergence period for a particular intertidal elevation is obtained.

5.3 Recommendations for future research

The most important recommendation is that experimental coastal investigations should be designed which will use realistic saturation levels, rather than assuming that the rock is saturated. Also, rock samples for the laboratory experimentation should come from rock located within the intertidal zone of coastal areas. The desorption phenomenon of wetted rocks should be studied alongside absorption, in order to achieve a more complete understanding of the saturation of coastal rock through a tidal cycle, particularly with regard to the role of chemical weathering. This might necessitate concentration upon a single rock type, but in greater depth and possibly also with a larger sample size than was used in this study. Perhaps it would be more prudent to only study the saturation of intertidal rock just above the low tidal elevation initially, because if any intertidal elevation will be found to be saturated, it surely will at least occur at this intertidal elevation. Another consideration which might be taken into account is the type of tide in the study area. Diurnal tides occur once a day, but for longer periods of time, whereas semi-diurnal tides occur twice a day but for briefer time periods. Mixed tides occur twice a day, but the tidal head of each cycle varies. This variability of the tides will have important consequences with respect to a comparison between laboratory and field results. These recommendations are aimed at achieving a more accurate laboratory simulation of the environmental conditions.

APPENDIX 1

Bulk Specific Gravity Results

Sample	BSG	Sample	BSG	Sample	BSG
Limestone		Gneiss-A		Schist-A	
189	2.01	227	2.28	251	2.41
190	2.01	228	2.27	254	2.39
191	2.02	229	2.30	255	2.40
192	1.98	230	2.28	258	2.40
193	2.02	231	2.30	261	2.40
194	1.99	232	2.29	266	2.40
195	2.00	233	2.27	269	2.40
196	2.01	234	2.28	271	2.39
197	2.00	235	2.29	272	2.41
198	2.01	236	2.28	279	2.37
199	2.00	237	2.29	281	2.39
200	2.00	238	2.29	283	2.39
201	1.97	239	2.28	284	2.41
202	2.02	240	2.28	290	2.40
203	2.00	241	2.27	291	2.40
204	2.04	242	2.28	297	2.37
205	2.04	243	2.28	299	2.39
206	2.02	244	2.29	301	2.41
207	2.02	245	2.29	303	2.41
208	2.02	246	2.27	306	2.40
209	1.98	247	2.29	307	2.41
210	1.96	248	2.27	308	2.39
211	2.01	249	2.29	312	2.41
212	2.02	250	2.30	313	2.41
213	1.99	$\bar{X}$=	2.28	314	2.41
214	2.01			316	2.39
215	2.00			321	2.41
216	1.99			322	2.40
217	2.01			323	2.39
218	2.01			329	2.40
219	2.05			331	2.41
220	2.02			333	2.41
221	2.04			334	2.41
222	2.03			336	2.39
223	2.00			337	2.42
224	1.99			339	2.40
225	1.99			346	2.34
226	2.01			347	2.39
$\bar{X}$=	2.01			348	2.39
				351	2.39
				$\bar{X}$=	2.40

APPENDIX 1 (cont'd)

Sample	BSG	Sample	BSG
Gneiss-B		Schist-B	
252	2.31	257	2.33
253	2.31	259	2.32
256	2.30	264	2.31
260	2.30	267	2.34
262	2.31	276	2.34
263	2.30	277	2.35
265	2.31	278	2.33
268	2.28	285	2.36
270	2.31	289	2.39
273	2.31	294	2.34
274	2.30	295	2.34
275	2.31	302	2.34
280	2.31	304	2.33
282	2.31	305	2.34
286	2.33	309	2.34
287	2.31	310	2.34
288	2.18	311	2.35
292	2.33	315	2.34
293	2.32	318	2.34
296	2.31	325	2.34
298	2.31	327	2.34
300	2.31	328	2.34
317	2.30	330	2.34
319	2.30	335	2.33
320	2.30	340	2.35
324	2.31	341	2.34
326	2.31	342	2.33
332	2.31	344	2.34
338	2.31	345	2.34
343	2.31	349	2.34
350	2.31	352	2.31
353	2.31	354	2.34
$\overline{X}=$	2.30	$\overline{X}=$	2.34

2

APPENDIX 2

Adsorption Experiment Apparatus Set-up

8. Precautions

8.1 The following precautions should be observed in the use of any of the three Methods A, B, or C for obtaining constant relative humidity.

8.1.1 Container - Although an airtight container is called for by both Methods A and B, it may be desirable to have a vent under certain conditions of test or with some kinds of containers. . . . The container should be small in order that the temperature throughout the container will differ little from that of the solution. The volume of the air space per unit area of surface of solution should be low. Ten cubic inches or less per square inch is advisable unless a larger volume is necessary because of the size of the device to be conditioned. Creepage distance over the surface between the solution and the material being conditioned should be long enough to prevent the solution creeping to the material being conditioned. Creeping is more likely to occur with some of the salts than with either glycerin or sulfuric-acid solutions.

Source: ASTM (1981), Part 41: E104-51

APPENDIX 3

```
1.      //DENNIS JOB (XXXXXXXXXX,1,1), DENNIS [illegible]
2.      // EXEC SPSS
3.      //SYSIN  DD   *
4.      RUN NAME           ONEWAY
5.      VARIABLE LIST      X1,X2
6.      N OF CASES         166
7.      INPUT FORMAT       FIXED (F6.1,1X,F1.0)
7.1     COMPUTE            X1=1/X1**1/2
8.      ONEWAY             X1 BY X2 (1,5)/
8.1                        RANGES = SCHEFFE (.05)
8.2                        RANGES = SCHEFFE (.01)
9.      STATISTICS         ALL
10.     READ INPUT DATA
10.001    60.0 1
          ......
          ......
10.038    62.0 1
10.039    94.4 2
          ......
          ......
10.062    82.4 2
10.063   102.6 3
          ......
          ......
10.102    86.4 3
10.103   104.3 4
          ......
          ......
10.134    97.5 4
10.135   100.2 5
          ......
          ......
10.166    91.4 5
11.      FINISH
12.      //
```

APPENDIX 4

DEFINITIONS

Absorbed Water: water retained mechanically within a soil mass and having properties similar to those of ordinary water at the same temperature and pressure.

Adsorbed water: water held by adsorption, as contrasted with absorption and chemical combination. Its physical properties are substantially different from those of absorbed water or chemically combined water at the same temperature and pressure. Adsorbed water in soil [rock] is held so strongly that it is resistant to the pull of gravity and to capillary action.

Capillary fringe (capillary rise): immediately above the water table ($\Psi = 0$), there is a zone that is saturated with water, or nearly so, because a certain suction must be reached before any substantial reduction in water content can be produced. Then, above this zone, there is a marked drop in the water content with a relatively small rise in the capillary pressure. This zone contains most of the water present in the zone of aeration.... This nearly saturated zone above the phreatic surface, when it occurs, is the capillary fringe. Within the capillary fringe, there is usually a gradual decrease in moisture content with height above the water table. Just above the water table, the pores are practically saturated. Moving higher only the smaller connected pores contain water. Still higher, only the smallest connected pores are still filled with water. Hence, the upper limit of the capillary fringe has an irregular shape. In the capillary fringe, the pressure is less than atmospheric ($\Psi < 0$), and vertical as well as horizontal flow of water may take place.

Material	Capillary Rise (cm)
Coarse sand	2 - 5
sand	12 - 35
Fine sand	35 - 70
silt	70 - 150
clay	200 - 400

Groundwater: all waters found beneath the ground surface.

Permeability: an average (or macroscopic) medium property that measures the ability of the porous medium to transmit fluid through it **(rate of flow).**

Phreatic surface = water table

Porosity: the ratio of the volume of the total void space to the bulk (total) volume of a porous medium.

- effective porosity: the ratio of the interconnected pore volume to the total volume of the medium (with at least several continuous paths from one side of the medium to the other).
- primary porosity: porosity due to the medium matrix
- secondary porosity: porosity due to solution or fracturing.

Saturated, Saturation: Corey (1977) made a distinction between the use of the words saturated and saturation. In a two phase system (liquid and gas) within a rock, the volume fraction of the total pore volume that is occupied by the liquid is termed saturation, which should not be confused with the term saturated, which means that only a liquid phase exists. The liquid phase of the two phase system is referred to as degree of saturation, thereby implying that the rock is not water saturated, but contains some trapped gas.

Saturation zone: all the interconnected interstices (pores) of the rock formation above some impervious stratum are completely filled with water. It is bounded above by a water table, or phreatic surface. This is a surface on which the pressure is atmospheric.

Vadose zone: extends from the lower edge of the soil water zone to the upper limit of the capillary zone. Non-moving (pellicular) water in the vadose zone is held in place by hygroscopic and capillary forces. Temporarily, water moves downward through this zone as gravitational water.

Void space (pore space, pores, interstices): that portion of the rock not occupied by solid matter <u>or</u> that space within the porous medium that is not part of the solid matrix.

- void ratio: the ratio between the volume of voids and the volume of solids.

Water table: the surface at which the fluid pressure (p) in the pores of the porous medium is exactly equal to atmospheric pressure, i.e., $\Psi = 0$.

Zone of aeration: overlies the zone of saturation. The pores contain both gases (mainly air and water vapour) and water. It extends from the water table to the ground surface. It usually consists of three subzones: the soil water zone, the intermediate zone (vadose water zone), and the capillary fringe.

Source: American Geological Institute, 1972;
Bear, 1972; Corey, 1977; Freeze and Cherry, 1979.

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