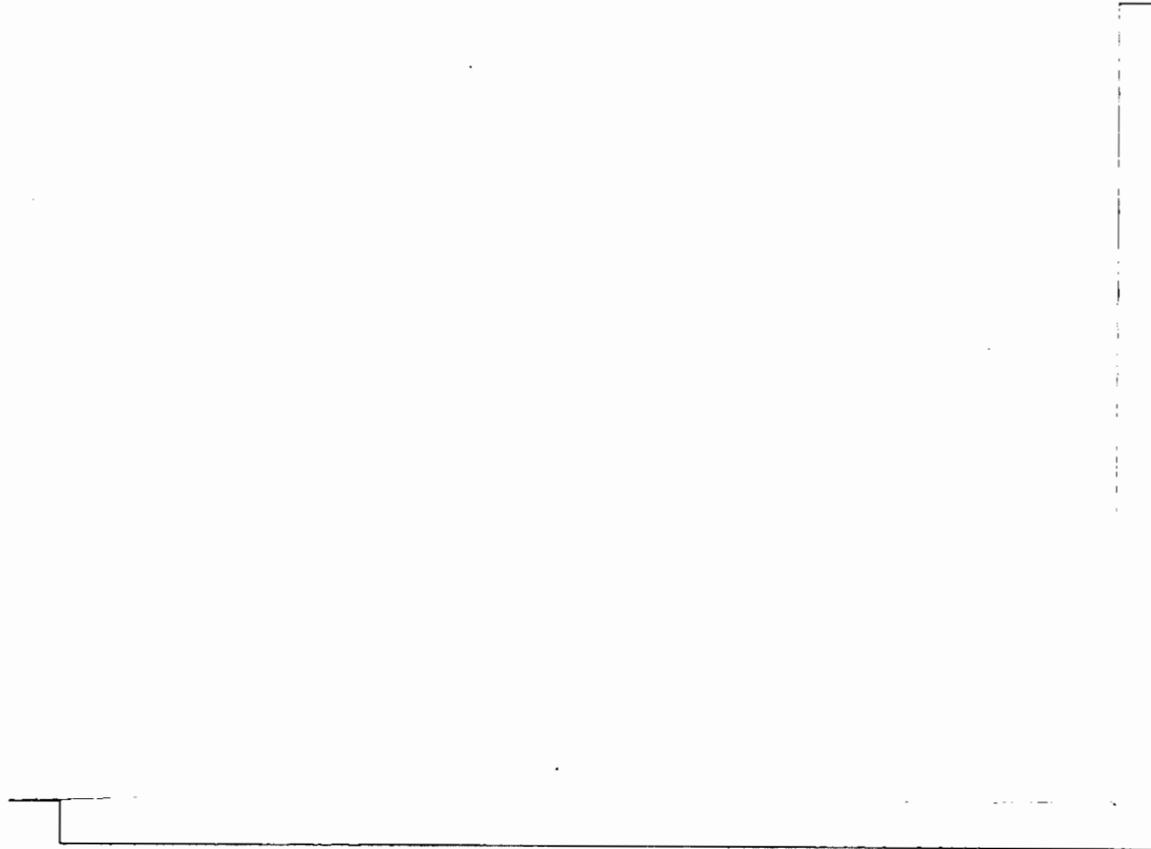


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Atmospheric Factors Affecting Materials Degradation in New Zealand

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ATMOSPHERIC FACTORS AFFECTING MATERIALS DEGRADATION IN NEW ZEALAND

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INTRODUCTION

The New Zealand Meteorological Service (1983a) distinguishes 17 different macro-climate types in New Zealand. Each has a particular combination of temperature, rainfall and humidity characteristics, but a factor common to nearly all is a significant level of atmospheric moisture. There are a few material degradation processes that do not need the presence of water - heat damage to plastics, and ozone effects on rubber are two examples. But generally the other atmospheric factors superimpose their own degradation processes on top of that caused by atmospheric moisture. Martin and Price (1982) have pointed out how water is involved in the destruction of almost all building materials, ranging from the obvious effects on corrosion of metals, through strength loss of timber composites, to its less obvious involvement in accelerated breakdown of plastics and paints by solar radiation.

It is impossible in a short paper such as this to examine all the adverse reactions which may be encountered; the purpose, instead, is to highlight some of the important atmospheric factors, and indicate some of the research that is addressing them. It should be emphasised that the climate around a building can be markedly different from that implied by meteorological station measurements (from which some data are shown in Table 1). The meteorological station measurements are made in a standard way, and so allow comment about geographic zones of difference, but surface orientation, colour, shelter and other factors can affect the general climate around buildings. Distinctions must be drawn between this macro-climate and the climate immediately adjacent to the surface. The "micro-climate" can be quite different (Trethowen and Eyles, 1990) and can have a marked effect on reactions at surfaces.

ATMOSPHERIC MOISTURE

Table 1 shows rainfall and humidity data for some New Zealand cities. Most of New Zealand has relatively frequent rainfall, for most months of the year. This brings positive effects in cleansing surfaces of contaminants (especially sea salt) which may promote degradation, and negative effects by increasing the duration of "wet" periods in wet and dry cycles which are important in the degradation of many materials. However, rain tends to be a short-lived phenomenon, and in terms of degradative effects is much less important than relative humidity.

"Relative humidity" is the percentage level to which the atmosphere is saturated with water vapour; with 100% representing saturation - the point beyond which additional vapour usually condenses out of the atmosphere. The relative humidity is affected by the temperature. At a constant atmospheric water content, a decrease in temperature causes an increase in relative humidity. Trethowen (1976) has published data on the frequency of occurrence of relative humidity and temperature combinations at a few New Zealand sites. Relative humidities in most parts of New Zealand often exceed 80% (Table 1).

Expansion and contraction of timber as it takes up and loses water can pose severe degradation problems for surface coatings. (BRANZ 1990).

ACID DEPOSITION

Yates *et al* (1988) describe the materials degradation problems experienced in the Northern Hemisphere which are caused by direct deposition of acidic gases (especially sulphur and nitrogen oxides) or dissolution of these gases in atmospheric moisture to give "acid rain". Sulphur dioxide - a gas produced in almost all fossil fuel combustion processes - is a minimal problem in New Zealand, with the effects usually restricted to "footprints" of enhanced attack close to roads, around domestic flues and extending up to 100 metres downwind of some industrial flues. Even the local meteorology of the Christchurch urban area, which is subject to smogs, produces monthly average values of only around 50 - 70 microgrammes per cubic metre ($\mu\text{g}/\text{m}^3$) in the worst winter months (Department of Health 1982). Holden and Clarkson (1986) have reviewed the likelihood of areas of New Zealand receiving acidic rainfall due to sulphur dioxide emission into the air from industrial sources (including trans-Tasman movement from Australian sources). They provide references to other studies of pH of rainfall in New Zealand, which found mean values in the range 5.2 to 6.0 (The pH of water in equilibrium with normal atmosphere pressures of carbon dioxide would be around 5.5). Holden and Clarkson therefore concluded that "acid rain" is not likely to be a significant problem in New Zealand.

There is, of course, the geothermal region of the North Island that has troublesome levels of sulphur-containing gases (predominantly hydrogen sulphide) in its atmosphere. There can be very great variations in concentrations of these gases within a few tens of metres, depending on closeness of fumaroles and soil permeability. In a month's monitoring at the Rotorua Telephone Exchange site, Burns *et al* (1972) found a median hydrogen sulphide content in the air of 8-15 $\mu\text{g}/\text{m}^3$ with about 2% of values exceeding 300 $\mu\text{g}/\text{m}^3$. At the median values found, the reaction with

pigments, usually to produce blackening, is fast. This has caused problems at various times for paint formulators (Macdonald 1978) and local authorities (Shannon et al 1984).

SOLAR RADIATION

There are two important effects of solar radiation on degradative processes: heating, and breakdown of polymers by UV.

Heating/Cooling

Solar heating leading to degradation is a complex issue, but one that must be considered when examining effects on building surfaces. Trethowen and Eyles (1990) have discussed the "solair" temperature, which takes account of solar gain and loss and other factors to derive likely temperature profiles which will be achieved on surfaces. Cooling by radiative loss to the atmosphere can lead to dew formation on a surface, but for most of the daylight hours surfaces exposed to sunlight will be at or above the air temperature. Table 2 shows mean solair temperature elevation for "black" surfaces (which will have the greatest daytime gain) for summer and winter in Wellington. Colour has a very large effect on the degree of solar heating; cooling at night will however be relatively independent of colour.

For some materials breakdown processes, such as plasticiser loss from PVC, heat alone is degradative - and a simple rule of thumb is that the breakdown rate will double for every 10 °C rise in temperature. For other multifactor processes, heat will usually also make the process go faster; so that corrosion reactions in solution - say a pond on a roof - will go faster in hotter weather, for example.

But heating will also result in water evaporation from surfaces, and reduction of relative humidity in the immediately-adjacent air which will lessen the rate of any water-mediated reactions at the surface. Table 3 shows the effect of some changes in surface temperature on the relative humidity of the zone immediately adjacent to the surface, when the bulk air relative humidity is 80%. It should be noted that water loss from the surface, especially if it is absorbed in the substrate, will not be instantaneous. Thus a temperature rise induced by sun coming out after a shower of rain may first cause an acceleration of the water-mediated reaction before the rate subsides. Obviously, if the wet-dry cycling is such that just as the drying ends, the substrate is rewetted, there can be very rapid degradation, and this principle is used in some accelerated weathering tests.

UV Effects

Many anecdotal remarks have been made about abnormally greater effects of UV breakdown on susceptible paints and polymers in New Zealand than overseas. Care should be taken that a true comparison is being made in evaluating such anecdotal evidence. There are scientific reasons which explain some difference; there can be more absorption of UV by polluted atmospheres, and the ellipticity of the Earth's orbit means the sun is closer to Earth in the Southern Hemisphere summer. There can therefore be a greater solar energy flux reaching New Zealand in summer than reaches

Northern Hemisphere countries of equivalent latitude (Figure 1) and cloudiness in their summer.

Table 4 lists some spectral sensitivities of polymers. It will be seen that the UV radiation at wavelengths 295 to 330 nm is important for polymer degradation (as it is for sunburn). Nichol and Basher (1986) have presented data suggesting that mean monthly total UV radiation in the erythemal (sunburn) band is less at Invercargill than at two sites of equivalent latitude in North America, and attribute this to differences in cloudiness. They found the annual total erythemal UV values at Melbourne (Australia) to be 50% higher than in Invercargill and say this Melbourne value "may be taken as approximately representative of the northern latitudes of New Zealand".

There has been speculation about the effect of changes in the ozone layer on erythemal UV levels reaching New Zealand. Changes in ozone concentrations have no effect on the spectrum above about 320 nm wavelength. Though there have been some data published (e.g. Bittar and McKenzie, in press), which show some signs of change at the very short wavelength end, there need to be more data collected before reliable conclusions on the extent of enhanced hazards to materials in New Zealand atmospheres can be reached.

Sharman (1987) has catalogued some problems of unexpected breakdown of paints and polymers that have been seen in New Zealand. Some of these phenomena may be understandable in terms of a synergistic action of solar radiation and water on a surface, which has been reported in some studies.

For example, Clark and Roberts (1982) tested cover plate materials for solar collectors using natural exposure at three sites outdoors and in an artificial test regime with no water spray. The two outdoor sites with higher moisture levels (rain, dew, and humidity) gave higher transmittance loss for poly(methyl methacrylate) and fibre-reinforced plastics for equal total radiation than were found at the "dry" site (in Arizona) or in the artificial test.

AS 1745.1 (Standards Association of Australia 1989) has proposed a series of climatic area designations for assessment of degradation of plastics during outdoor weathering. In apparent acceptance of a synergistic effect, these designations are based on annual mean daily global radiation and rainfall, with a special zone at high altitudes (above 1000 to 1500 metres, depending on state). Nowhere in New Zealand meets the criteria for zones A or B, which respectively require daily radiation means above 21.6 and 18 megajoules per square metre (New Zealand Meteorological Service 1983b); at face value, then, parts of Australia should pose greater durability problems to paint and polymers than does New Zealand.

Davis and Sims (1983) discuss at considerable length the large range of factors that can affect the weathering of polymers. Thus, two specimens of generically equivalent material may have quite different degradation rates in outdoor weathering as a result of traces of chemicals, or pigments, in the polymer, or even of the surface state produced during manufacture. It is currently impossible, therefore, to unequivocally identify the effects of UV, specifically and in co-action with other environmental parameters, on plastics exposed in New Zealand atmospheres.

But a better understanding of the ways to avoid breakdown of paints and polymers from this mechanism is important for New Zealand industry.

ATMOSPHERIC CHLORIDE

Chloride-containing salts are important in promotion of corrosion, facilitating attack on virtually all technologically useful metals. But almost as important a property is their ability to act as hygroscopic generators of surface water layers. The "critical" relative humidity - that is, the humidity at which water is absorbed from the atmosphere by a deposit of salt over a surface - is relatively independent of temperature for sodium chloride, at around 78% RH.

If a surface is lightweight and insulated - a fair assumption for a sheet metal cladding on a building - its surface temperature will be similar to the "solair" temperature referred to above. Trethowen and Eyles (1990) have published Table 5, based on a climatic data file for Wellington, showing the fraction of time a clean surface would have dew on it due to solair cooling, and the fraction of time a sea-salt contaminated surface would have absorbed moisture due to the critical relative humidity (for which they used a value of 75%) being exceeded at the surface when the solair temperature is taken into account. These values will be independent of colour, because they relate to long-wave IR cooling by radiation to the sky. It will be noted that the contaminated surface can be wet for over 50% of the time.

New Zealand lies in a latitude band of strong westerly winds, and there is clear evidence from maps of sodium distribution in grass (Department of Scientific and Industrial Research 1962) that the winds carry sea-salt fairly long distances inland from west and south coasts, as long as mountain chains do not get in the way. Studies by the Building Research Association of New Zealand (BRANZ) (Ballance and Duncan 1985) have examined the decrease in chloride deposition onto sheltered surface with increasing distance inland in Manawatu and Southland. Analysis by neutron activation of deposited salt suggests that it is sea-salt, even as far inland as Palmerston North. There are also very large variations in the monthly amounts of salt deposited (Ballance and Duncan, 1985, Cordner et al 1987).

This sea-salt is a principal determinant of atmospheric corrosion rates in New Zealand. In the BRANZ studies, the amount of salt deposited was related to corrosion rates measured on vertically-exposed steel coupons, and by an aluminium-wire-on-threaded study system (Duncan and Ballance 1987). An expression could be derived from the data from either detector type that linked almost all the variation in corrosion rate to the logarithm of the amount of salt deposited.

Duncan and Whitney (1982) proposed a map of atmospheric corrosion hazard zones for steel in New Zealand based on theoretical principles, data on rainfall and humidity data, and the DSIR data on sodium in grass. This proposal used definitions from AS2312: Guide to the Protection of iron and steel against exterior atmospheric corrosion (Standards Association of Australia, 1980). The map was used again in a commentary for New Zealand conditions on the Australian Standard (Standards Association of New Zealand, 1987). The most important result to note here is that, because

of the sea-salt carriage inland and the wetness of the New Zealand atmosphere, each hazard zone for which a protection system is prescribed in the Australian Standard extends rather further inland in New Zealand than it does for most of Australia (except Queensland).

The work by Ballance and Duncan (1985) suggested that for Manawatu and Southland, the map derived by Duncan and Whitney was basically correct, though the moderate zone extends further south in the South Island than originally drawn. A comprehensive measurement of atmospheric corrosion rates of mild steel, galvanised steel and aluminium is in progress, using metal panels exposed at 45 degrees facing North at 168 sites throughout New Zealand.

The first year's results (Cordner, in press, Harper (1990)) have provided further evidence that the shapes of the proposed zonings for steel corrosion were correct. The maps of the theoretical proposal and the actual rates for steel corrosion are shown in Figures 2 and 3.

However, a problem in classification has arisen. A task group from International Standards Organisation has proposed a five-category classification system (Dean 1987), which relates likely corrosion rates to time of wetness, sulphur dioxide concentration and chloride deposition rates. While the tables in AS 2312 are difficult to interpret to determine typical corrosion rates for the environmental zones proposed, it seems that "mild" areas in the AS 2312 scheme fall into "category 2" of the scheme proposed by the ISO task group, while some sites in the "very severe" zones in the AS 2312 scheme fall only into "category 3" in the ISO scheme. More work will be needed to allow expression of the New Zealand sites in these ISO terms.

The patterns of corrosion rate found for galvanised steel and aluminium were different from those for mild steel, and not so obviously related to chloride deposition rates, confirming the comment made by Duncan and Whitney in 1982 about extrapolation from one metal to another. There was measurable corrosion of aluminium only at sites close to the coast, and at Kinleith. The rate of zinc corrosion decreased sharply with distance from the sea, but was very high and variable (a comment also true for mild steel) in the geothermal area around Rotorua, (where there was very low (if any) corrosion of aluminium). Also, zinc corrosion rates at Kinleith were double those at neighbouring sites.

MICRO-CLIMATES

Reference has been made at several places above to the effects of micro-climates. It is perhaps worth pulling this together in one place.

Consider a building facade with recessed windows. The whole building surface, both facade and the soffit of the recess, is liable to have any pollutant gases or wind-borne solids deposited on it. All surfaces exist in the same bulk environment with respect to relative humidity.

Only the fully-exposed facade can have deposits washed off again by rain.

There is likely to be solar warming of the parts of the facade, but little of the soffit of the recess, and this warming might be beneficial in keeping the surface dry, or (if the temperature goes too high) detrimental by inducing heat damage. The facade is also at greater risk of degradation processes involving UV radiation.

The soffit, and sheltered areas of the facade will rarely be directly wetted by rain, and so will get wet only under dew-forming or fog conditions, or if the design does not shed water at the junction of the facade and soffit, or due to water uptake by deposited chemicals.

We can thus have the following different durability requirements within a few tens of centimetres of one another:

Exposed Facade: Resistant to heat and UV and general degradation due to wetting.

Sheltered Facade and Soffit: Highly resistant to deposited pollutants, some UV resistance to cope with diffuse radiation, resistance to heat fairly unimportant.

Sill: Highly resistant to heat, UV and degradation due to wetting.

Clearly, there are some interesting problems here for the designer who must select materials and/or surface finishes which meet the client's need and take account of these micro-climate differences.

SUMMARY

The principal hazards to materials in the NZ environment come from moisture, solar radiation and windborne sea-salt, with the localised hazard area in the geothermal zone. While the extents of these hazards are only imperfectly understood, research is providing clearer guidance documents. Descriptions of zones of corrosion hazard to metals, information on the likely effects of solar radiation levels in New Zealand on polymers, and assessment methods for likely surface micro-climate temperatures and relative humidities, are now available, to assist designers and materials specifiers. There still remains more work to be done in areas of interactive effects of UV and moisture on polymers, and the influence of micro-climates.

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TABLE 1: Meteorological parameters for some New Zealand towns and cities (NZ Meteorological Service 19836)

	Sunshine hours	Mean Radiation MJ/m ² /day	Rainfall		9 am R.H.				Temperature		
			Total annual mm	Feb mm	Aug mm	Mean annual	Mean Feb	Mean Aug	Mean annual	Mean Feb	Mean Aug
Kaitaia	2113	15.0	1418	109	160	82	79	87	15.6	20.0	12.0
Auckland Airport	2140	15.6	1150	83	114	83	79	88	15.1	19.7	11.3
Hamilton	2006	-	1201	81	110	81	77	85	13.3	18.1	9.4
Whakarewarewa	1948	15.3*	1439	103	131	81	78	85	12.6	17.7	8.3
New Plymouth	2114	-	1539	107	142	78	77	79	13.5	17.5	10.1
Gisborne	2204	14.5	1058	69	116	74	70	81	14.0	18.8	9.9
Wellington	2019	14.1	1240	81	122	81	80	84	12.5	16.6	8.9
Nelson	2397	15.3	986	67	98	78	72	85	12.1	17.2	7.6
Hokitika	1846	12.7	2783	169	251	84	84	84	11.6	15.7	8.2
Christchurch	1974	-	666	42	53	78	73	86	11.6	16.3	7.0
Dunedin Airport	1676	12.4	659	41	50	77	78	81	10.2	14.7	6.5
Invercargill	1621	12.6	1037	75	66	83	81	87	9.7	13.6	6.2

* At Rotorua Airport

TABLE 2: Mean All-Sources Temperature Elevation for "Black" Surfaces, by Season, derived from actual climate records for Wellington.

	Whole Year	Summer °C	Winter °C
Horiz	3.2	6.0	0.6
N	3.7	3.9	2.9
NE	3.7	4.7	2.2
E	3.0	4.5	1.1
SE	1.8	3.2	0.3
S	1.2	2.0	0.2
SW	2.5	4.0	1.0
W	2.5	4.0	1.0
NW	3.2	4.1	2.1

TABLE 3: Effect of Heating or Cooling on Micro-climate Relative humidity when Bulk Air Relative Humidity is 80%

Air Temperature in bulk	Local Cooling (degrees)	Local Heating (degrees)		
		2	5	10
		R.H. at new temperature		
5	91	71	58	43
10	91	71	59	44
15	90	71	60	45
20	89	71	60	46

TABLE 4: Plastics - Wavelength of Maximum Photochemical Sensitivity
(Sharman and Van Gosliga 1989)

Plastic	Wavelength, nm
acrylic (polymethyl methacrylate)	290 - 315
ABS (acrylonitrile butadiene styrene)	300 - 310, 370 - 385
CAB (cellulose acetate butyrate)	296
nylon	290 - 315
polyamides (acromatic)	360 - 370
polycarbonate	290 - 310
polyester	325
polyethylene	300 - 310, 340
polypropylene	290 - 300, 330, 370
polystyrene	310 - 325
polyurethane (aromatic)	350 - 415
PVC	320
SAN (styrene acrylonitrile)	290, 310 - 330

TABLE 5: Cumulative Frequency of Relative Humidity at Surfaces

Temperature Band	(Dew Forming)	(Salt Self Wetting)
	RH > 85% hour/y (%)	RH > 75% hour/ly (%)
0 C	28 (0.3)	417 (4.8)
5 C	358 (2.9)	2009 (22.9)
10 C	554 (6.3)	1807 (20.6)
15 C	556 (6.3)	796 (9.1)
20 C	165 (1.9)	772 (8.8)
25 C	4 (.05)	4 (.05)

(a) Horizontal Roof (all colours)

0 C	97 (1.1)	506 (5.8)
5 C	374 (4.3)	2269 (25.9)
10 C	369 (4.2)	1791 (20.4)
15 C	107 (1.2)	354 (4.0)
20 C	2 (.02)	4 (.05)

(a) North Wall (all colours)

0 C	106 (1.2)	506 (5.8)
5 C	413 (4.7)	2516 (28.7)
10 C	391 (4.5)	1968 (22.5)
15 C	116 (1.3)	381 (4.3)
20 C	2 (.02)	3 (.03)

(a) South Wall (all colours)

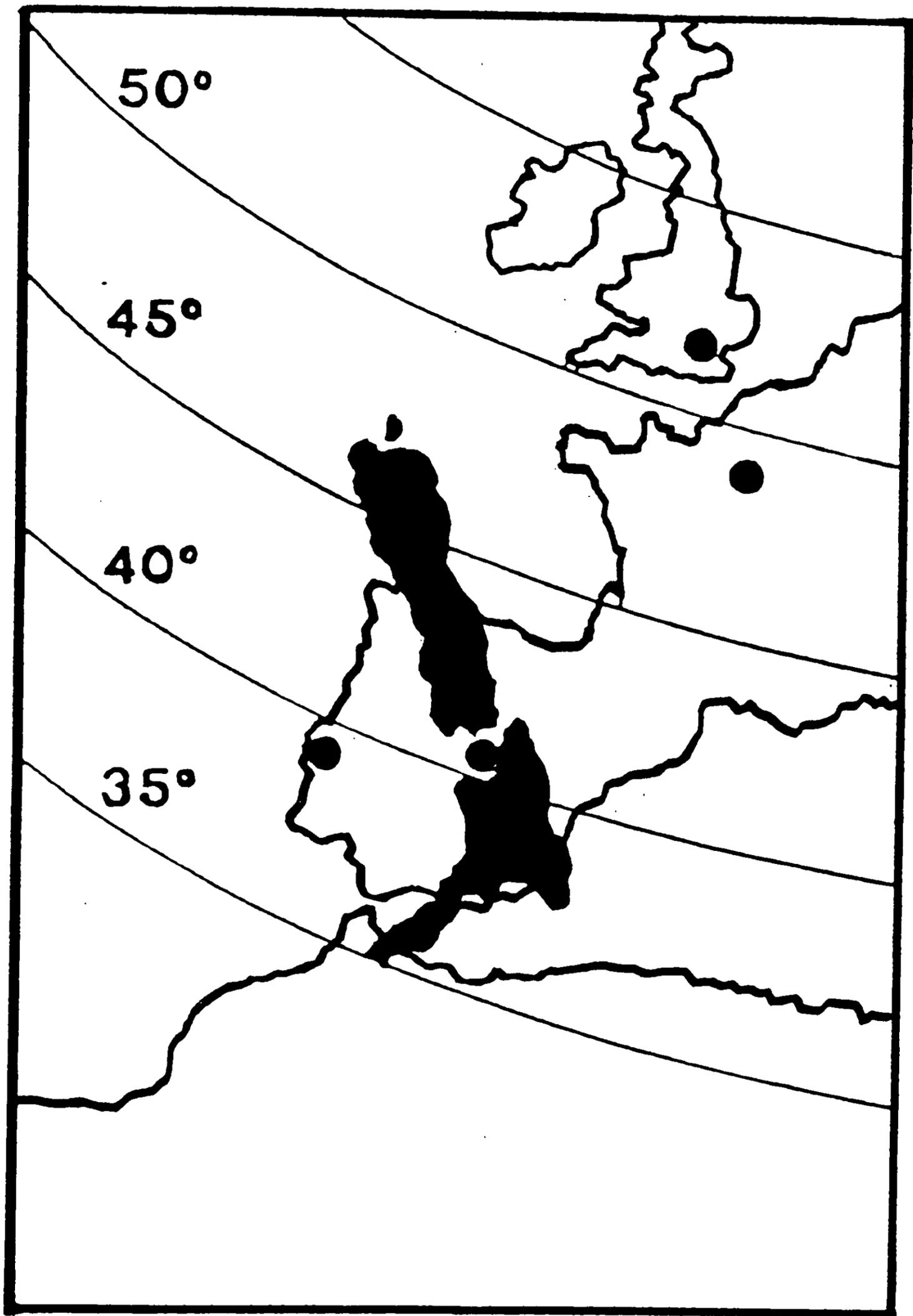


Figure 1: New Zealand mapped on to its antipodes in Europe.

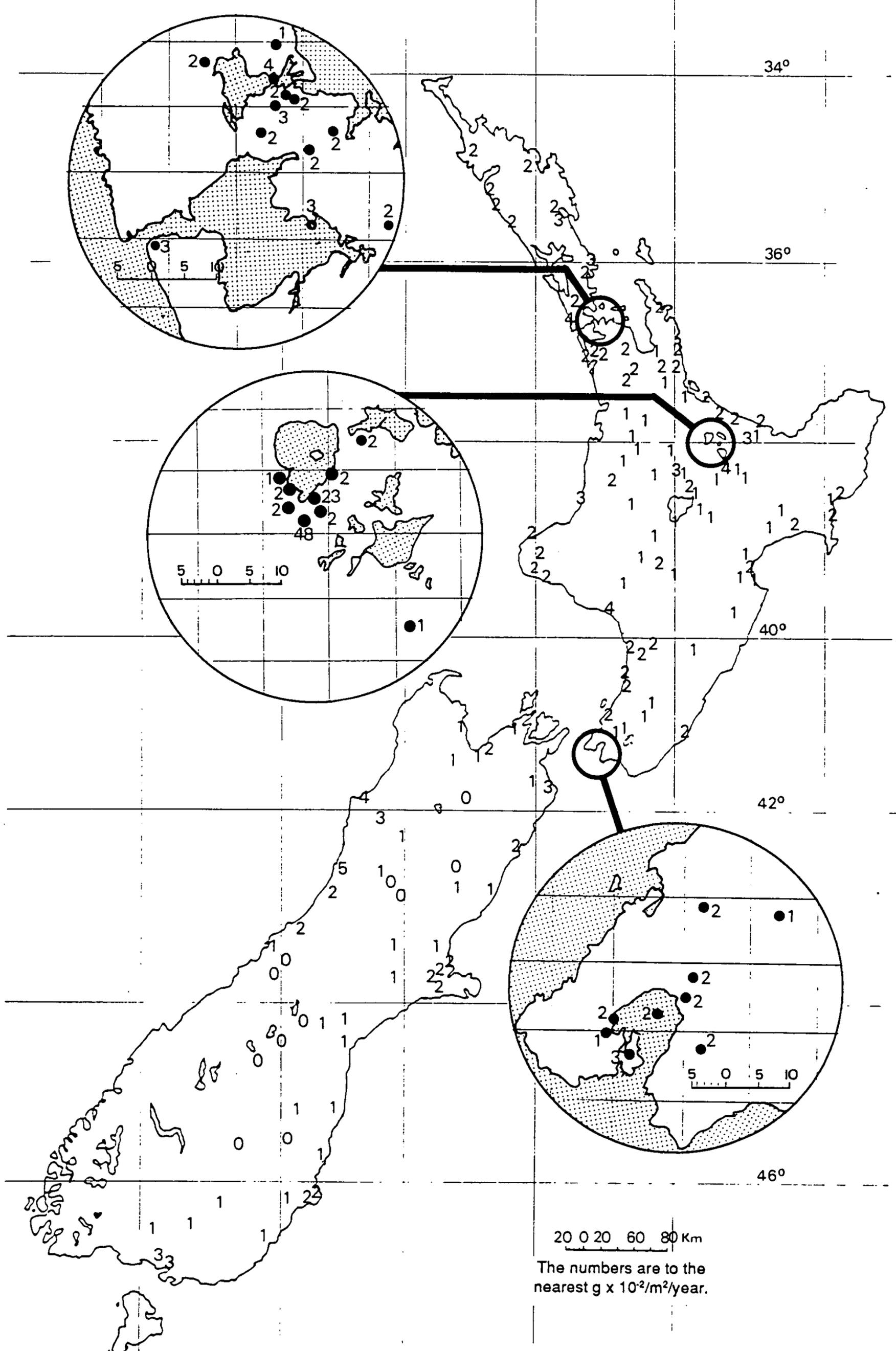


Figure 3: Actual relative atmospheric corrosion rates for steel at sites in New Zealand. (Cordner, 1990)

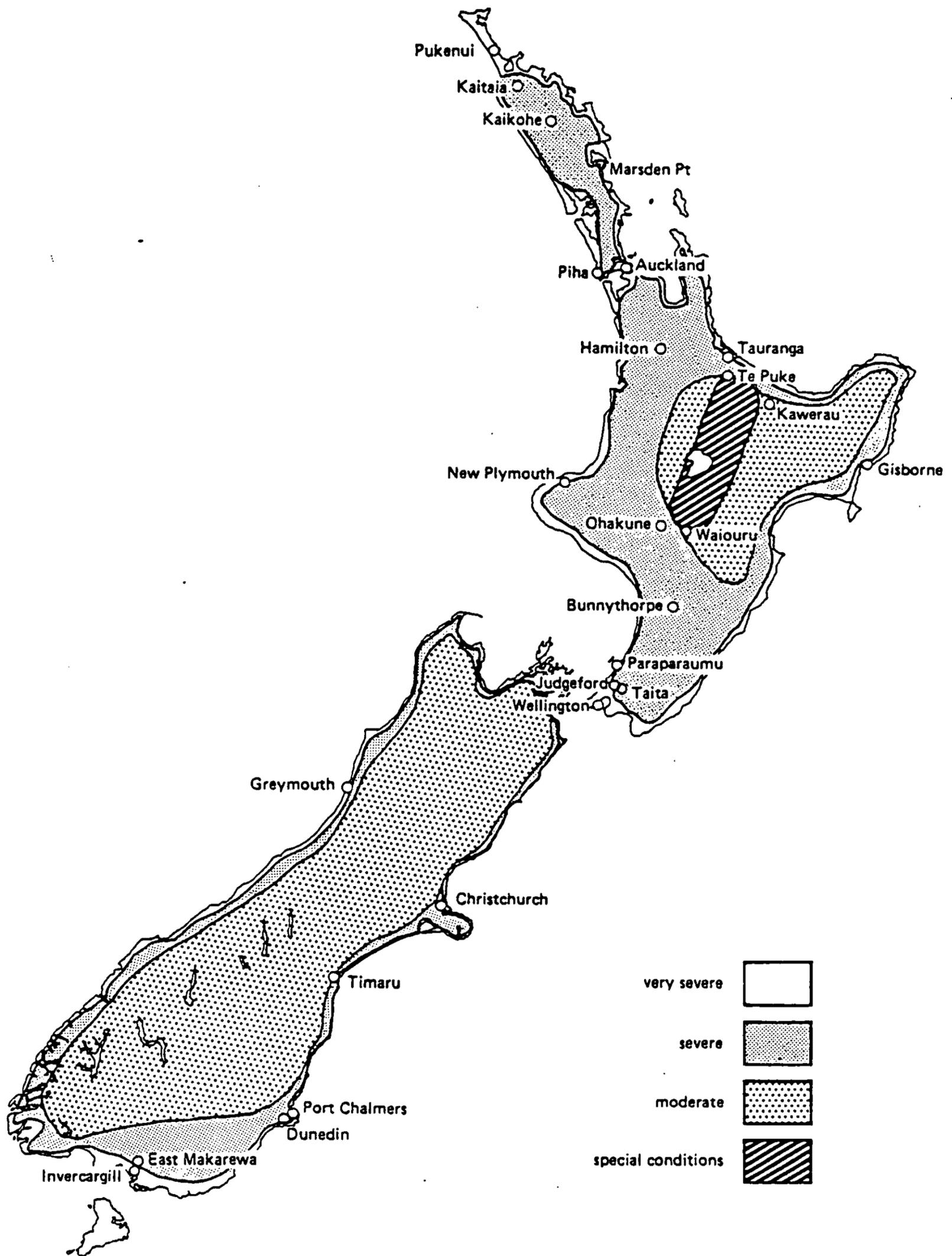


Figure 2: Proposed zones of atmospheric corrosivity for steel (*Duncan and Whitney, 1982*)



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