The Prevention and Repair of Salt Damage to Roads and Runways

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ROADS DEPARTMENT

Under the policy direction of the Ministry of Works, Transport & Communications, Roads Department is responsible for providing an adequate, safe, cost-effective and efficient road infrastructure within the borders of Botswana as well as for facilitating cross-border road communications with neighbouring countries. Implied in these far-ranging responsibilities is the obligation to:

1. ensure that existing roads are adequately maintained in order to provide appropriate level of service for road users;

2. improve existing roads to required standards to enable them to carry prevailing levels of traffic with the required degree of safety;

3. provide new roads to the required geometric, pavement design and safety standards.

The Department has been vested with the strategic responsibility for overall management of the Public Highway Network (PHN) of some 18, 300 km of roads. This confers authority for setting of national specifications and standards and sheared responsibility with the District Councils and Department of Wildlife and National Parks for the co-ordinated planning of the PHN.

Roads Department is also responsible for administering the relevant sections of the Public Roads Act, assisting local road authorities on technical matters and providing assistance in the national effort to promote citizen contractors in the road construction industry by giving technical advice wherever possible. This task is facilitated by the publication of a series of Technical Guidelines dealing with standards, general procedures and best practice on a variety of aspects of the planning, design, construction and maintenance of roads in Botswana that take full account of local conditions.

Guideline No. 1 The Design, Construction and Maintenance of Otta Seals (1999)

Workshop Proceedings, September 2000, Addendum with reference to
Guideline No. 1 The Design, Construction and Maintenance of Otta Seals (1999)

Guideline No. 2 Pavement Testing, Analysis and Interpretation of Test Data (2000)

Guideline No. 3 Methods and Procedures for Prospecting for Road Construction Materials (2000)

Guideline No. 4 Axle Load Surveys (2000)

Guideline No. 5 Planning and Environmental Impact Assessment of Road Infrastructure (2001)

Guideline No. 6 The Prevention and Repair of Salt Damage to Roads and Runways (2001)

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

REFERENCES

LIST OF APPENDICES

FOREWORD

The prevention of soluble salt damage to bituminous roads and runways plays a vital role in reducing the cost of both construction and maintenance of roads in Botswana.

Without adequate prevention measures and monitoring of soluble salt during construction, the road may deteriorate and will often result in extensive rehabilitation. There is, therefore, a need to draw the attention of designers and engineers to the dangers of soluble salts in the early stages of road construction.

Because of Botswana's environment, construction materials and construction water contain soluble salts which when used in construction has resulted in severe damage to roads and runway surfaces. These problems have been encountered in several projects including Sua Pan airstrip, Nata-Gweta road, Orapa-Mopipi-Rakops road, Selibe-Phikwe runway, the trans-Kgalagadi road and many others.

It is exorbitantly expensive to avoid the use of saline materials and water by importing non-saline alternatives. By providing guidelines for the use of available saline materials and water where technically feasible, significant cost savings can be achieved.

The guidelines discuss the occurrences of salt damage in Botswana and elsewhere worldwide, detailed design and construction procedures are provided for the prevention of salt damage. Methods of testing and measurement of salts are also given together with repair methods where damage has already occurred.

The user, whether a technician or an experienced engineer will find the guideline useful in identifying whether there is likelihood of damage occurring and in determining the design and construction measures required to prevent damage.

The guideline will also be useful to those working in other semi-aid environments of the SADC region where much of the available materials and contain soluble salts.

Gaborone
July 2001

A. Nkaro
Director of Roads

Roads Department
Ministry of Works, Transport and Communications

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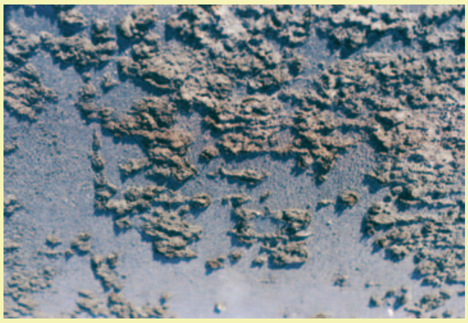
1. INTRODUCTION

1.1 Background

Due to the semi-arid environment of Botswana much of the available construction materials and water contain soluble salts. In some areas the subgrade upon which the roads are constructed are also saline. As a result road and runway surfacings have been severely damaged by salts. Roads Department has been engaged in a 12-year research programme in collaboration with the UK Transport Research Laboratory and others. The results of this research and other works undertaken both in Southern Africa and elsewhere in other countries are embodied in these guidelines.



Blistered bituminous prime due to salt crystallisation (Nata-Maun road).

Soluble salt damage to bituminous road surfacings occurs when dissolved salts contained in either the pavement layer materials, construction water or subgrade migrate to the road surface.

This migration, through capillary action, is mainly caused by evaporation at the surface. At or near the surface, the salts in solution become supersaturated and crystallise. This creates pressures with associated volume change, which can lift and physically degrade the bituminous surfacing and break the adhesion with the underlying pavement layer.

The damage may appear in the form of 'blistering', 'doming', 'heaving' and 'fluffing', of the bituminous layer.

1.2 Purpose and Scope of Guideline

This guideline provides design and construction methods for the prevention of salt damage to road and runway surfacings. Details are also provided for the repair of damaged surfacings.

The guideline is intended to assist Engineers and Senior Technicians within Roads Department and Consultants and Contractors engaged by the Roads Department or other Government bodies to:

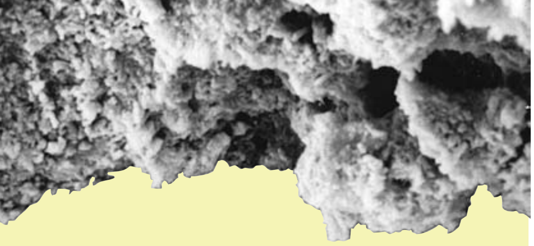
- Assess the likelihood of salt damage occurring in a particular road project given the environment and salinity levels;
- Identify, measure and interpret levels of salinity in water, construction materials and subgrade including field and laboratory methods for determination of salt contents;
- Design and specify appropriate preventative measures, where necessary, for a particular project;
- Undertake quality control and monitoring of salt levels and prevention during and after construction;
- Design and implement repairs for damaged bituminous surfacings.

1.3 Structure of the Guideline

The guideline is divided into seven chapters comprising:

Chapters 1, 2 and 3 (Occurrence and Testing for Salts)

These chapters introduce the problem of salt damage, where it occurs and how to identify damaged surfacings. Techniques and methodology for determina-



tion of salt content are described together with an introduction to interpretation, comparison and presentation of test results.

Chapters 4 and 5 (Risk Evaluation and Design of Preventative Measures).

A sequential procedure for assessment of the likelihood of damage occurring is provided in chapter 4. The risk depends on climate, materials and salt contents for a particular project. Once it is established that there is a high probability that salt damage will occur, the preventative measures to be considered are also detailed in chapter 5.

Chapter 6 (Repair of Damaged Surfacing).

This chapter provides currently used methods for repair of damaged surfacings, both for temporary and permanent surfacings.

Chapter 7 (Summary).

This chapter includes the summary. The list of References and Appendices are given at the end of this chapter.

Details of international practise and salt limits are at Appendix A and is intended only as background literature. Appendix B details methodology for salt content analysis using the Electrical conductivity whilst Appendix C provides an example of risk evaluation and worked example for selection of preventative measures for a given project following the procedures described in chapters 4 and 5 of this guideline. Appendix D contains a glossary of terms to assist the reader. Appendix E contains a list of abbreviations.

The general layout of the guideline is shown in the flowchart below.

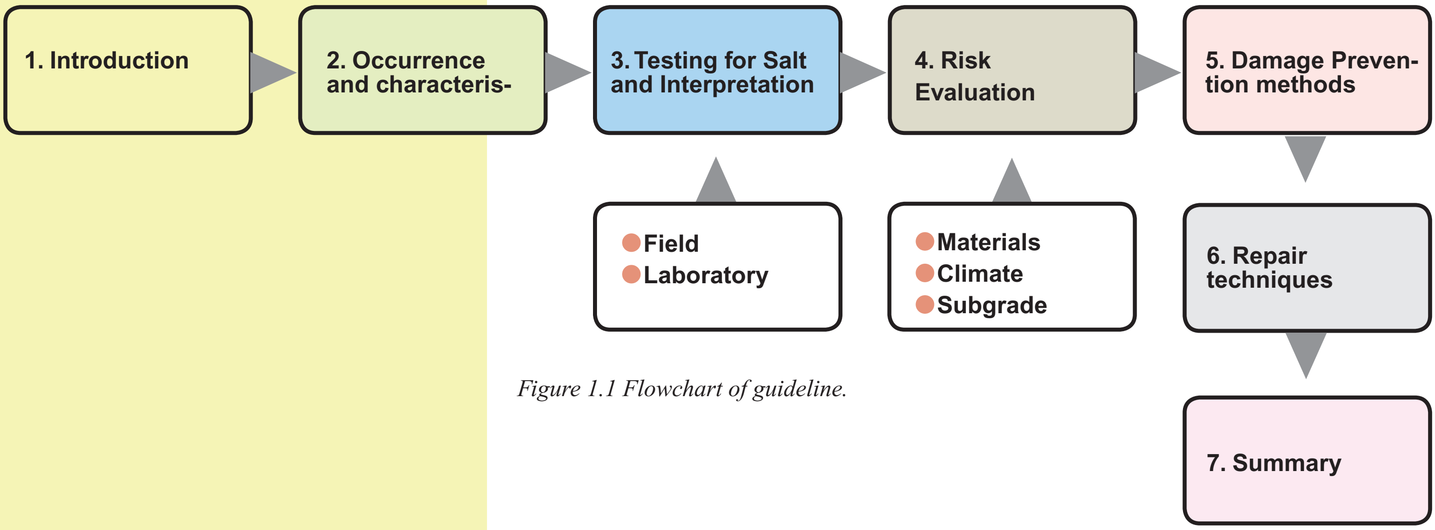
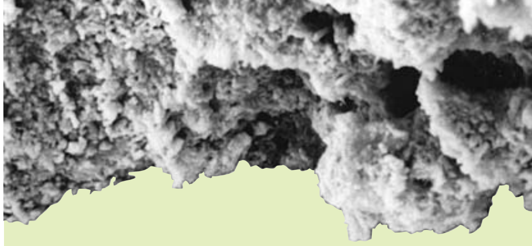


Figure 1.1 Flowchart of guideline.



2. OCCURRENCE AND CHARACTERISTICS

2.1 General

Soluble salt damage to bituminous surfacings occurs in many countries with semi-arid, arid or warm dry climates such as exists in many parts of Botswana.

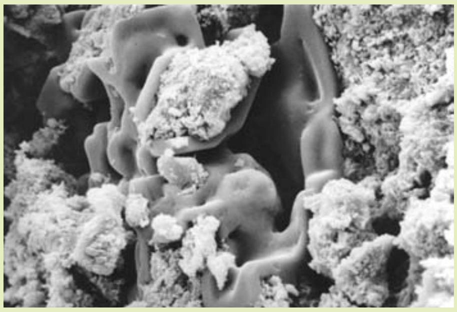
In these countries the annual evaporation exceeds the annual rainfall and there is a net upward migration of soil moisture. If soluble salts are present in this moisture, they will be precipitated (crystallise) at or near the surface.

In such environments there is also a large variation between day and night temperatures and humidity. This results in some salts dissolving and recrystallising more than once in a day, thereby creating disruptive pressures which can damage road surfacings.

Figure 2.1 shows areas of the world with arid and semi-arid climates. Also shown are some locations where salt damage has been reported in published literature.

The purpose of this section of the guideline is to provide a general understanding of the damage process. Preventative measures suggested in general literature should not be used in Botswana as they lack detailed information and applicability.

Zoroga Salt Pans. Roads cross highly saline pans in some parts of Botswana.



The semi-arid climate to Botswana creates conditions conducive to salt damage.

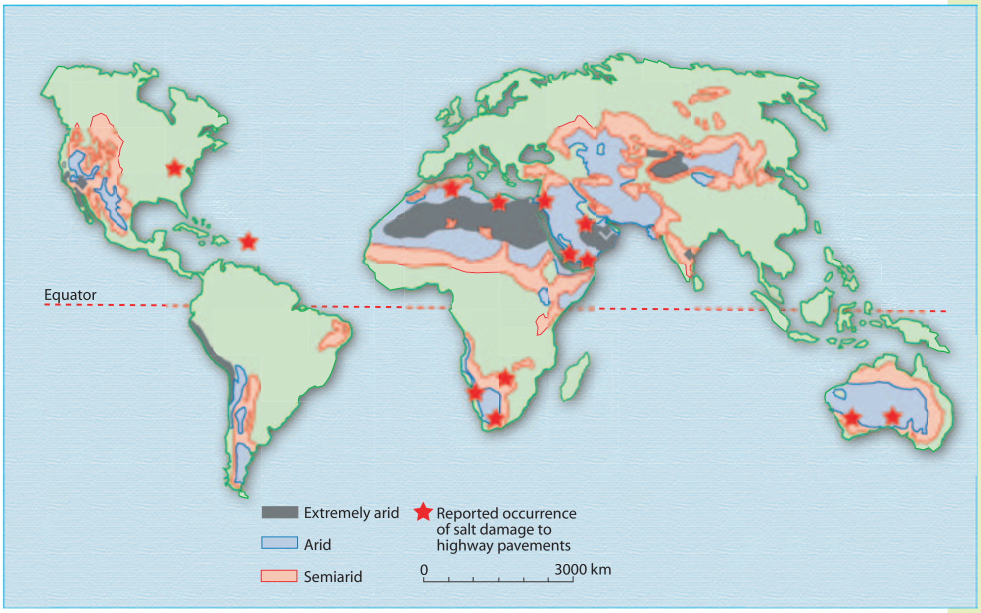
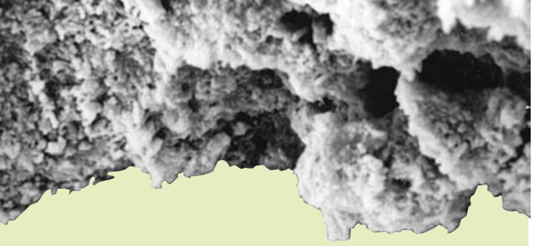


Figure 2.1 World Distribution of dry climates and occurrence of Salt Damage.



2.2 Salt Damage Occurrence in Botswana

Figure 2.2 shows areas of Botswana (lighter shaded) most susceptible to the occurrence of salt damage to bituminous surfacings. In these areas the dry climate combined with the presence of saline materials (often calcrete) and saline groundwater or surface water (such as Sua Pan) create conditions necessary for salt damage to occur. Reported locations of salt damage in Botswana include:

Maron grass, a tough, coarse grass not liked by cattle, found on some road verges can indicate presentce of saline ground. Western part of the Kalahari desert.

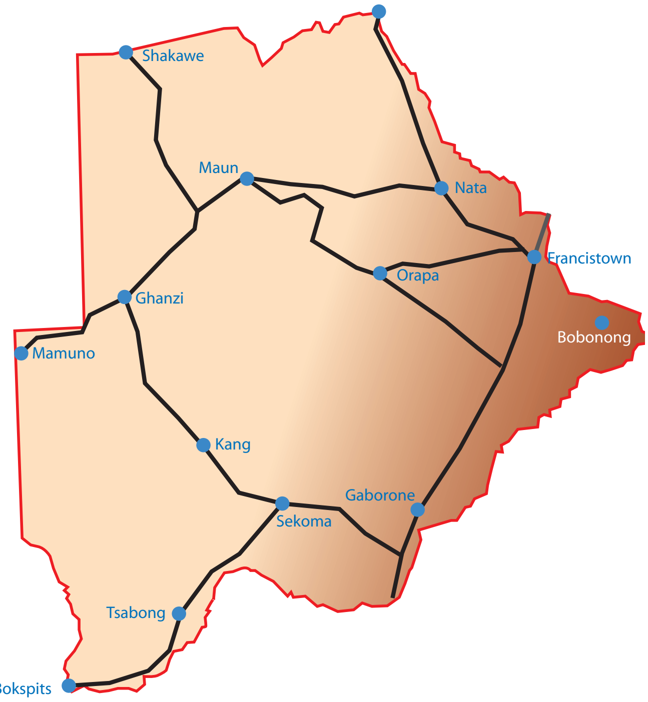


Figure 2.2 Dark areas are less susceptible to occurrence of salt damage

Salt damage during the construction of
- Mopipi-Rakops
- Sekoma-Makopong
- Kang -Hukuntsi
were prevented by judicious materials selection using conductivity tests.

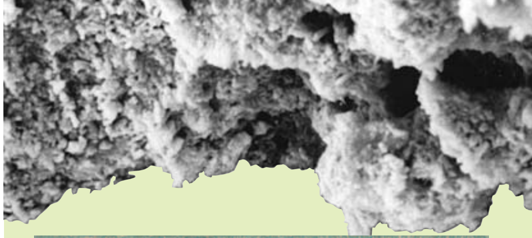
Sua Pan Airstrip
Nata - Maun Road (km 0-45)
Phikwe Runway
Sekoma - Kang road (Trans-Kalahari road)
Sekoma - Makopong
Kang - Hukuntsi
Tsabong - Makopong road
Orapa - Mopipi road
Rakops-Motopi
Maun Runway

The first four above cases are described below together with the preventative measures adopted.

Sua Pan Airstrip

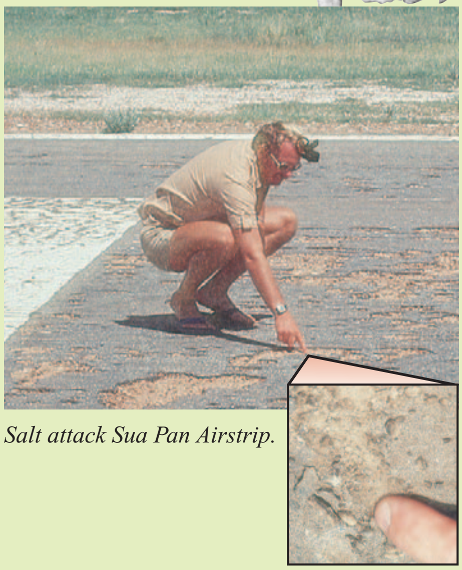
The Sua Pan airstrip was constructed in 1988. The pavement comprised calcrete subbase and base with a Cape Seal bituminous surfacing. Within six months after construction, the surfacing developed star shaped blisters and domes ranging in size from a few millimetres to 15 mm in diametre and 1 to 5 mm in height. The damage occurred initially in the untrafficked edges of the runway and progresed towards the centre of the runway. Some of the domes had opened up to reveal clusters of white salt crystals.

Domed cape seal surfacing due to salt attack Sua Pan Airstrip.



Preliminary field investigations and X-ray studies at University of Birmingham showed that the salts originated from the saline subgrade and comprised of sodium chloride and Trona salt (sodium hydrogen carbonate or "soda ash").

A number of remedial measures were considered including bitumen rubber reseal to increase impermeability. It was finally decided to remove and reconstruct the damaged parts of the runway with concrete pavement slabs. An alternative solution would have been to reconstruct with an impermeable plastic layer placed at the top of subgrade to prevent upward salt migration.



Salt attack Sua Pan Airstrip.

Nata - Maun Road

Sections of the Nata to Maun road between Nata and 20 km past Zoroga cross the northern extensions of the Makgadikgadi Pans. As a result, these sections contain saline subgrade soils with salinities ranging from 0.1% Total Dissolved Salts (TDS) to 7% TDS. During design trials, damage occurred in the form of blister and powdering of both bituminous cutback (MC 30) and emulsion (KR 60) primes. The damage generally occurred within 48 hours to several days after priming depending on the salinity of the top 50 mm of the base course.

Damage to single and double surface seals also ocurred in areas of saline subgrade or where the salinity of the calcrete basecourse exceeded 0.4% TDS.

To prevent damage to the main road, impermeable plastic sheets were placed at the top of subbase along the saline subgrade sections of the road. In areas of non saline subgrade, damage was prevented by careful timing of the duration between priming and placement of the permanent surfacing. The shoulders were also double sealed to minimise evaporation and upward salt migration. These preventative measures have performed well to date, 11 years after construction.

Powdered cutback prime and top of base course due to salt attack. Nata - Maun road.

Phikwe Runway

Extensive blistering of the Phikwe runway was reported several months after construction. The damage occurred in the form of star shaped small blisters of the double surface treatment surfacing. Recent investigations (Maswikiti and Obika, 2000) indicate that the damage is attributable to pyritic oxidation which forms soluble sulphides. The pyrites probably originated from the mine waste used for the pavement construction. As the source of the salt is finite, the damage has not progressed substantially since it's initial identification

Sekoma - Kang Road

Salt damage in the form of blistering, doming and powdering occurred to the single seal before construction of the second seal of the carriageway along sections of the first 12 km of the Sekoma - Kang road. Within twelve months after construction further damage to the single seal shoulders occurred over several sections extending to Km 250. The damage on the shoulders were notably worse where there were imperfections on the surfacing and salts could migrate due to evaporation.

Salt blistering on the Sekoma - Kang road.

The salts had originated from the saline water used for compaction of lower pavement layers. The salt had migrated to upper pavement layers. Table 2.1 shows the distribution of salt within the pavement approximately 13 months after construction. There had been a general increase in salt content under the surfacing (0-50 mm) indicating a need for timely reseal to prevent evaporation and consequent salt damage.

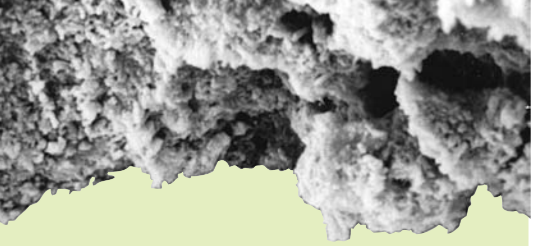


Table 2.1 Salt content of pavement layers (Sekoma - Kang road).

Average salt content % TDS (from E.C measurements)				
Depth, mm	**Edge of shoulder**	**Centre of shoulder**	**Shoulder/ carriageway interface**	**Centre of carriageway**
0-50	0.23	0.38	0.45	0.31
50-100	0.18	0.39	0.43	0.30
100-150	0.13	0.33	0.33	0.28
150-200	0.11	0.26	0.28	0.12
200-250	0.10	0.19	0.24	0.17

Remedial measures included removal of the damaged single seal and reseal of the carriageway. Severely damaged sections of the shoulder were removed and reconstructed. In areas of less severe damage material in the area surrounding the dome was dug out approximately to 20 mm diameter and 50-100 mm depth) and replaced with an emulsion based premix. As shown in table 2.1, salt is still present in the pavement and it will be necessary to maintain impermeability by timely reseal in order to avoid further salt damage.

2.3 Salt Damage World-wide

The most extensive work to date on the mechanism of salt damage has been undertaken by Obika et al (1989).

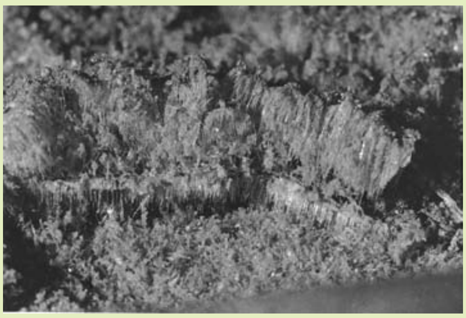
There is a paucity of published work on salt damage to bituminous pavements which probably does not reflect the scale of occurrence. The published papers deal with local environments and materials, and this has resulted in a variety of recommendations for damage prevention and repair. These recommendations have not always been used successfully in other environments, and have resulted in delays to construction or damage to the bituminous surfacing.

2.3.1 India

Uppal & Kapur (1957) and Mehra et al (1955) reported on the detrimental role of soluble salts on stabilised and unstabilised soils in India. In these cases the damage was due to soluble sulphate salt attack on asphaltic surfacings.

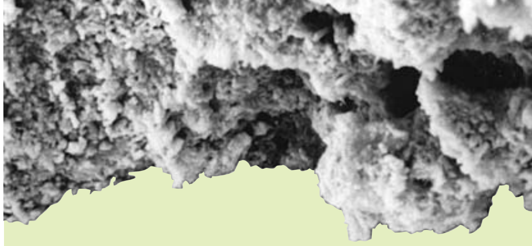
2.3.2 Australia

There is clear Documentation of physical salt damage to bituminous surfaced pavements in Australia (Cole & Lewis 1960). The deterioration often took the form of ‘fluffing’ and ‘powdering’ of sandy loam soils immediately beneath the bitumen surface. Failed and sound areas linked the deterioration to high sodium chloride ($NaCl$) content. This salt was believed to have migrated from a saline water table varying from 4.5 to 24 metres below surface level. Most of the salt damage in Australia is limited to high sodium chloride ($NaCl$) in the subgrade and construction materials.



Filamentous (whisker) crystals lifting a road surfacing. In this case the whiskers are visible to the naked eye. In other cases a magnifying glass or microscope is required.

Simple laboratory tests were performed on samples of soil taken from sound and failed sections of the pavement. The samples were compacted and allowed to stand under laboratory conditions. After 9 months the samples that con-



tained up to 0.5% NaCl did not show any deterioration but the observed deterioration on the specimens containing over 0.5% NaCl was due to the growth of white 'hair like' crystals. An upper limit of 0.2% NaCl content in sandy clay soils was adopted providing a factor of safety of 2.5.

Januszke & Booth (1984) have documented severe blistering of sprayed seals in Western Australia where highly saline water (6.3 to 13.6% NaCl) and natural gravel (0.27 to 0.45% NaCl) are used in the pavement construction. Deterioration of the surfacing generally occurred in the form of blisters up to 40 to 100mm in diameter rising up to 10mm in height.

2.3.3 Southern Africa

A detailed examination of soluble salt damage to bituminous sealed roads in several regions of South Africa was undertaken by Weinert & Clauss (1967) following the widespread occurrence of blistered surfacings. Early occurrence of salt damage, sodium and magnesium sulphates present in mine waste material used for pavement construction were identified to be responsible for the salt damage problem. The pavement material was a quartzite waste from industrial mine processes.

By analogy with permissible levels of sulphate in building stones an upper limit of 0.05% sulphate content was recommended for highway materials, whilst accepting the chloride limits of 0.2% NaCl suggested by Cole & Lewis (1960).

Extensive work relating to the Southern African experience was undertaken by Netterberg (1970, 1979, 1984), Netterberg et al (1974), Netterberg & Maton (1975), Netterberg & Loudon (1980) and Blight et al (1974).

Netterberg (1970) discussed the various types of soluble salts present in highway construction materials and concluded that sodium chloride (NaCl), sodium sulphate (Na_2SO_4), sodium carbonate (Na_2CO_3), magnesium sulphate ($MgSO_4$) and calcium sulphate ($CaSO_4$) were likely to be the deleterious salts most commonly encountered. A simple conductivity test was proposed as a preliminary test for materials used in highway construction in arid and semi-arid zones. Netterberg discussed some possible sources of error in the salt limits suggested by Cole & Lewis (1960) and by Weinert & Clauss (1967). In particular he noted that the maximum limits of 0.2% NaCl by Cole & Lewis and 0.05% for sulphates by Weinert & Clauss were determined by analysing the top few centimetres of the base after upward migration of salt had occurred.

It is important to take into account not only the initial salt content of the material but also the salt content near the surface (0-50mm) after evaporation and migration may have taken place. The latter is more indicative of potential for damage to occur.

The limits suggested were, therefore, not necessarily the initial salt content of the bulk material.

Problems have also been reported in Zimbabwe (Netterberg 1984) where blistering and cracking of bituminous surfacing was linked to the formation of salt within the sub-base and subgrade layers. These acidic sulphates were derived from the oxidation of sulphides in industrial waste material which was used for pavement construction. Although present in the material, gypsum was not contributory to the degradation of the surfacing, possibly due to its low solubility.

The electrical conductivity limits previously suggested by Netterberg (1970) were found to be inadequate for prediction of the potential for damage.

Whilst other authors looked at the effect of salt in bases and at the base surfacing interface, Blight et al (1974) investigated the properties of rolled asphalt made with quartzite mine waste sands with various soluble salt contents. The asphalt layer constructed with sand of up to 2.0% soluble salt had no deleterious effect on the asphalt after 6 years. The authors demonstrated that soluble salts can have significant effect on the flow and stability properties of asphalt mixes.

Cases of salt damage have been reported in Namibia, particularly near Swakopmund. However these are not documented in detail.

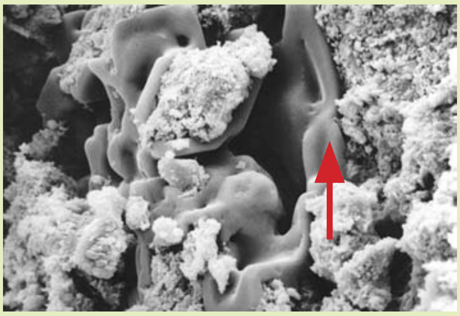
Road near Swakopmund, Nambia.

2.3.4 Middle East

Fookes & French (1977) with considerable experience of soluble salt damage in the Middle East, produced a paper which considered in detail pavement damage from natural saline materials. They differentiated clearly between soluble salt damage due to a high saline water table and that due to saline materials. The authors defined four relevant zones of moisture associated with the groundwater table, groundwater fluctuations, capillary rise and transient moisture which can be used to locate pavements away from hazardous ground. A range of soluble salt limits for various types of pavement construction, local moisture regimes and materials was presented. Attention was also drawn to the possible role of various salt combinations.

Tomlinson (1978) also reported the blistering of sealed aircraft pavement surfaces in the Middle East without explanation of how it occurred.

2.3.5 North Africa



Non crystalline salt causes little damage.

Microscopic sized salt whiskers breaking through road surfacing. This type of crystal causes maximum damage due to high pressures.

Following observations of salt damaged roads and runway pavements in the Algerian Sahara, Horta (1985) produced an interesting physico-chemical analysis of the salt damage mechanisms. He ascribed the damage of 50mm thick wearing coarse to the crystallisation of halite (NaCl) whiskers or filamentous crystals and identified some physico-chemical parameters relevant to the damage mechanism. Attempts to repair a salt damaged surface by recompaction of the blisters completely failed. A new airport was finally built at a different location. Horta's observation drew attention to some critical crystal growth factors, which had not been considered previously in highway work.

2.3.6 North America

Soluble salt damage to bituminous surfaces has also been reported in other areas. For example, Dunn (1984) reported on the development of small domes, 50mm to 100mm in diameter on bituminous road pavements in Virginia, North America, due to growth of pickeringite (magnesium alum) crystals.

These above cases have provided a background to understanding the salt damage process.

2.4 International Experience on Salt Damage, Limits and Preventative Measures

The existing salt limits do not account for upward migration of salts and should, in general, not be used.

Various recommendations of maximum salt content in highway materials have emerged from the above studies. These recommendations are detailed in Appendix A. These salt limits are generally based on local experience of salt types and pavement design in other parts of the world. They also lack any detailed understanding of salt migration and other influencing factors.

These salt limits should not be applied in Botswana. They are given in this guideline only for general understanding of the levels of salt content that can cause damage.

In addition to the recommended maximum salt contents, various other preventative and remedial measures have been suggested.

2.4.1 Thickness of Surfacing/Permeability Ratio

With a few exceptions (Horta 1985, Januszke & Booth 1984) pavement damage from soluble salts is confined to thin bituminous surfaces such as double surface treatment. Relative impermeability can be achieved by using a minimum of 30mm dense asphalt concrete. The essential function of a thick surfacing is to stop evaporation and hence migration and crystallisation of salt at the surface. If salt is kept in solution or in a totally dry state, damage will not occur. Damage will occur once the salts are allowed to re-crystallise.

Although a thick impermeable surface can be effective in preventing short-term damage particularly at the bitumen-base interface, in practice, complete impermeability is difficult to achieve. As bitumen dries micro-cracks develop which allows evaporation (see photograph). Furthermore, salt may continue to accumulate beneath relatively impermeable surfaces as a result of temperature changes. Degradation of the base and sub-base material may result in loss of density with rutting and pot holing in the longer term

2.4.2 Bituminous Surfacing Layers

Unsealed roads generally perform well in saline ground. For unsealed roads salt helps to bind the surface and suppress dust. Salt efflorescence is commonly observed on unsealed surfaces in arid areas and there is no evidence of physical degradation of the surface. When a thin seal is applied it may blister and crack within 36 hours.

The sequence and type of damage appears to depend on the thickness of the bituminous layer, salt content in the pavement material, the climate and other factors discussed in section 2.5.

Emulsions primes are less susceptible to salt damage than cutback or tar primes.

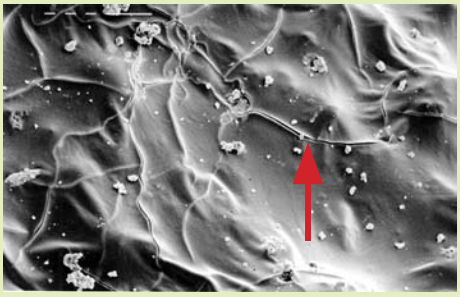
Emulsion primes tend to sit on the surface rather than penetrate into the pavement layer. This provides lower permeability and hence reduce the damage potential. Road sections with emulsion prime will generally not suffer damage despite high soluble salt contents, provided the prime are left no longer than 48 hours before application of a double seal.

2.4.3 Brooming

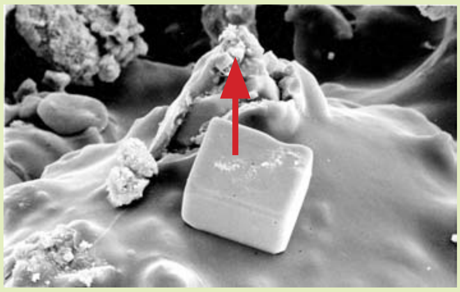
In cases where there is no source of salt replenishment from a saline water table, careful surface brooming of the base can be carried out to remove the salts before the bituminous surfacing is applied (Horta 1985). This process had not been studied but the effectiveness of such a process would depend on the reduction of salt content achieved. However, depending on the circumstances, further salt migration to the surface may occur.

2.4.4 Immediate cover

Immediate sealing can prevent the accumulation of the salt at the surface after compaction with a relatively impermeable surfacing. This reduces evaporation and ensures that salt does not migrate rapidly and crystallise at the surface.



Microscopic cracks in binder allows evaporation, hence salt crystallisation.



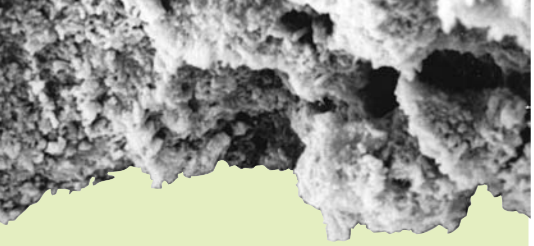
Salt crystal braking through a bituminous surface (viewed through electron microscope).

Calcrete gravel road, western part of Botswana.

Gravel road on saline ground with additon of salt water sprinkle. Road near Swakopmond, Namibia.

Brooming was used successfully on parts of Sehitwa-Tsau, Tsau-Gumare and Tsabong-Makopong roads.

It is important to maintain impemability of the surfacing when salts are present in underlying pavement layers



This approach was used commonly on Rural Roads projects where salts were identified to be problematic.

2.4.5 Prevention of Moisture Rise - Cut Off

Salt migration by upward capillary rise of soil moisture can be prevented by placing an impermeable or semi-impermeable membrane in the base course (French et al 1982). A granular layer in the base course may also reduce capillary rise (Horta 1985). French et al (1982) experimented with 'filtram', a commercial geofabric, and concluded that neither salt nor groundwater will pass through the geofabric if placed outside the zone of near saturation in the soil.

The provision of a coarse grain uniform layer between the sub-base and subgrade has been shown to be ineffective.

2.4.6 Relevance of Published Literature to Botswana

The published work does not explain the fundamental mechanism of the damage. Existing methods of prevention and repair are based mainly on experience of local materials and conditions and should not be used blindly for Botswana conditions.

2.5 Factors Influencing Salt Damage

2.5.1 Climate

Temperature, relative humidity, wind-speed and rainfall all influence salt damage. They affect evaporation significantly and hence the potential for upward salt migration. Temperature and relative humidity also determine whether salt crystallisation thresholds are crossed. This is discussed by Obika et al (1989). Precipitation influences the net water balance at a given location and also whether there is a seasonal or perennial moisture deficiency which would provide the conditions for a net upward saline moisture migration. Where rainfall is insufficient to leach out minerals from weathering rocks, in-situ accumulation of mineral salts generally occurs.

2.5.2 Geology and Hydrogeology

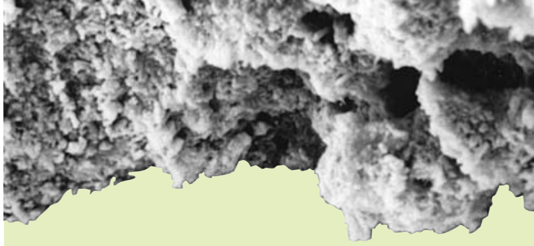
Weather station measurement of local climate is useful.

The depth and quality of groundwater contributes significantly towards creating bituminous surfacing damage from salts. Saline groundwater may result from the solution of minerals present in sediments or from the ingress of seawater to the host material. The predominant type of salt depends on a variety of geochemical processes, the source of the salt and the local climatic environment. The most commonly encountered salt in many arid and semi-arid zones is sodium chloride, known as halite.

In arid and semi-arid zones the capillary moisture rise can be more than ten metres. The height of capillary moisture rise depends on a variety of factors including porosity and temperature gradients.

2.5.3 Materials Characteristics

The various salt types which can contribute to the damage of pavements in dry lands include but are not limited to sodium chloride (NaCl), sodium sulphate (Na_2SO_4), sodium carbonate (Na_2CO_3), and magnesium sulphate ($MgSO_4$).



The various salt types that contribute to the damage of pavements are presented in Table 2.2.

Table 2.2 Some salts which can contribute to salt damage of pavements .

Name	Formula	Common Name
Sodium Chloride	$NaCl$	Halite, common salt
Magnesium sulphate	$MgSO_4$	
Magnesium Sulphate Hydrates	$MgSO_4.xH_2O$	e.g Epsomite
Sodium sulphate	Na_2SO_4	Thenardite
Sodium sulphate hydrate	$NaSO_4.10H_2O$	Mirabilite
Sodium Hydrogen carbonate	$NaHCO_3$	Glaubers salt (Soda Ash)

Fine-grained porous materials can encourage deleterious filamentous crystal growth and also the pore characteristics of the individual particles can influence the movement of saline moisture in the pavement layers. Obika et al (1991) have discussed the nature and magnitude of salt crystal pressures. For materials of equal mechanical strength, those which contain large pores, separated from each other by micropores, are the most liable to salt weathering. This is analogus to frost susceptibility criteria. Thus fine grained pavement materials are more likely to encourage higher capillary rise of saline moisture. The resulting salt crystal pressures are also higher. See Obika et al (1992) for more detailed description.

To mitigate salt damage it is better to avoid fine graded basecourse finish where practical. Slushing, for example, should be avoided where other considerations permit.

Figure 2.3 illustrates the salt damage process in relation to pavement salinity and water table.

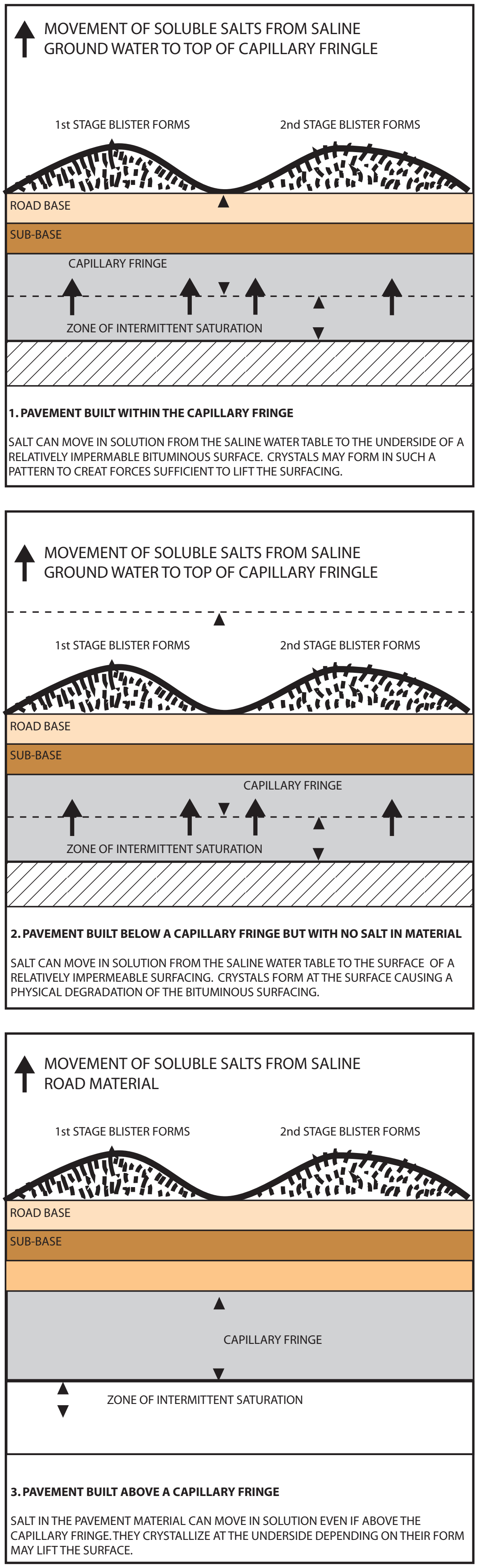


Figure 2.3 Salt damage process in the relation to pavement salinity and water table.

2.5.4 Pavement Surfacing Design

The type of bituminous surfacing and its application rate influences the rate of evaporation from the pavement surface and therefore the rate of upward salt migration. Pavement damage from soluble salts appears to be confined to thin bituminous surfaces, generally less than 50 mm thick. However, a few exceptions have been recorded in Algeria and Western Australia (Stuart Highway).

In southern Africa, Netterberg, Blight, Theron and Marais discovered that damage from sulphates in mine waste pavement material could be prevented by applying a bituminous surface seal, which had permeability to thickness ratio not exceeding 30 (permeability in mm/sec, surfacing thickness in mm). Thick surfacings minimise evaporation and hence reduce migration and crystallisation of salts at the surface.

Obika and Freer-Hewish and Woodbridge et al have shown that bitumen emulsion primes perform slightly better than bitumen cutback primes in reducing salt damage. The emulsion 'sits' on the surface rather than penetrating into the base, thereby forming a less permeable surface than cutback primes. However, emulsion generally gives a poorer bond to the underlying pavement layer.

Bitumen rubber or polymer modified binders used for sealing have been shown to retain impermeability for longer periods than conventional binders. Where there is a high risk of salt damage Rubber bitumen should be considered.

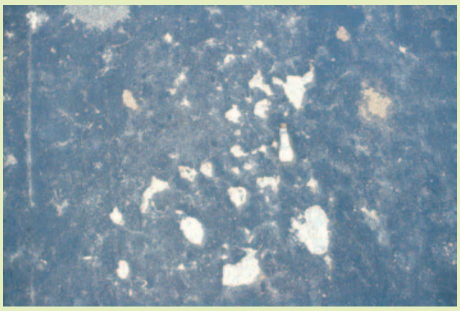
2.5.5 Construction Practice

The intervals between the construction of the pavement layers, a water bound or cemented material, a bituminous prime coat and a final surfacing, such as a surface dressing, can be critical if evaporation is high and when salts are present in the pavement material and/or a shallow groundwater. Substantial salt accumulation may occur at the exposed surface in periods longer than 24 hours.

Brackish water is often used for compaction and/or curing of pavement layers. This can lead to a significant precipitation of salt on the surface of the compacted layer. Also, there is evidence, from laboratory studies and field observations, to suggest a high risk of surfacing damage when salts in a pavement layer are subjected to repeated wetting and drying (solution and re-crystallisation).

Construction practises which involve repeated wetting of the pavement during construction should be avoided. In Botswana, damage is often observed within days after a rainy period due to the re-crystallisation of salts.

Salt damage to shoulders. Damage will normally start at the shoulders and progress to the centre of the carriageway. This is due to high evaporation and less traffic at the shoulders.



Close-up of salt blirsters above.

2.6 Appearance and Identification

Depending on the environment, salt levels and type of surfacing salt damage may occur within days after priming or up to 2 to 3 years after surfacing.

Surfacing Type	Typical duration before first signs of damage
Bituminous cut back primes	1 day to 7 days
Bituminous emulsion prime	2 days to 14 days
Single surface dressing	7 days to 6 months
Slurry seal	5 days to 3 months
Cape seal	14 days to 6 months
Double surface dressing	3 months to 3 years
Otta Seal -Single with sand cover seal	3 months to 3 years
Otta Seal -Double	12 months to 4 years

2.6.1 Damage to Primes

Salt damage is often observed within days after priming or up to 2-3 days after surfacing. Tsabong - Makopong road.

Bituminous prime coats are the most susceptible to salt damage because of their thickness and high permeability to evaporation. Damage to prime coats typically occurs in the form of small blisters which, when opened, reveal white salt powders. This can often be mistaken for vapour blisters, which result from vapour pressure differentials following rainfall on a freshly primed road surface.

In other cases damage to primed surfaces occurs in the form of powdering of the surface such that it becomes completely loose and has a brown 'dead' appearance instead of black. Damage typically starts at the edge of the road where evaporation occurs most or where there has been disturbance to the surface texture such as along the overlap of spray applications or along construction vehicle wheel tracks. The top of the underlying base layer may also appear loose. In many cases hair-like (whiskers) crystals can be observed with land lens and in severe cases of damage, with the naked eye. Initial signs of damage to prime coats can be observed within 24 hours after surfacing.

2.6.2 Damage to Permanent Surfacings

Salt damage to more permanent surfacings such as double surface treatments and slurry seals may take several days to a few years to manifest at the surface. This will generally appear as star shaped domes that open at the top to reveal clusters of white salt powder. The domes can range from a few centimetres to 20 cm in diameter with a typical height of 2 to 6 cm.

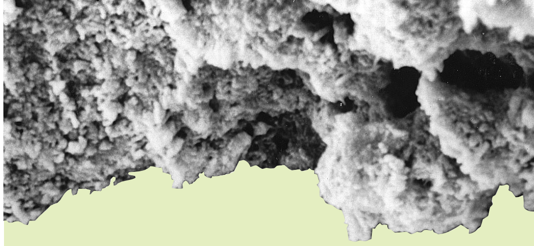
2.7 Summary of Physico-chemical Influences on Salt Damage

The main factors governing the mechanism of salt damage are salt solubility, migration, crystallisation, crystal growth habit and crystal pressures.

Highly soluble salts can re-crystallise several times a day as temperature changes causing physical damage to road surfacings.

Solubility

Only those salts that are soluble in water can migrate to the surface of a pavement. The solubility of some natural salts is shown in Figure 2.4 in relation



to temperature. The solubility of sodium chloride, the most 'common' salt, is only slightly temperature-dependant, whereas other salts show rapid changes in solubility with change in temperature. In practice this means that these salts can re-crystallise several times a day with disruptive crystal growth pressures at the road surface.

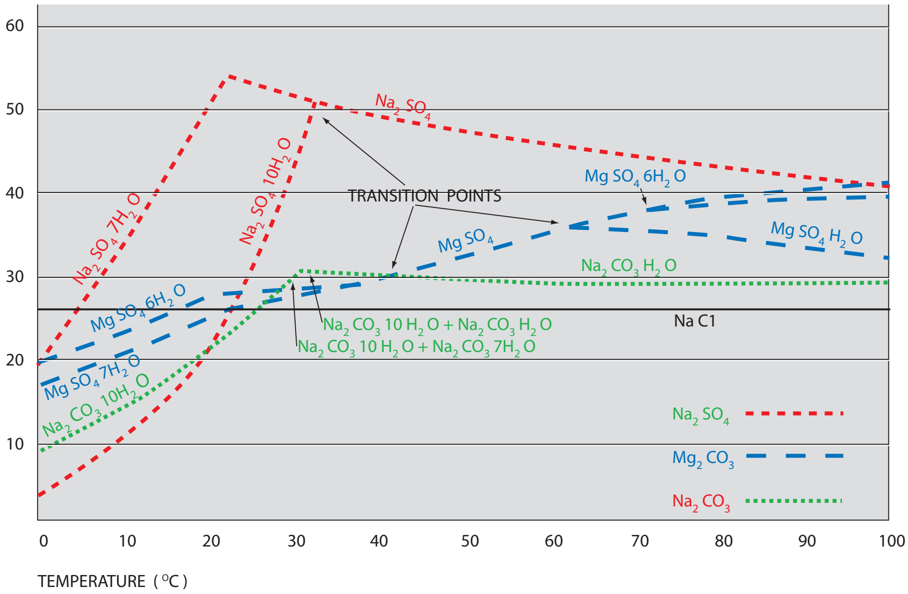


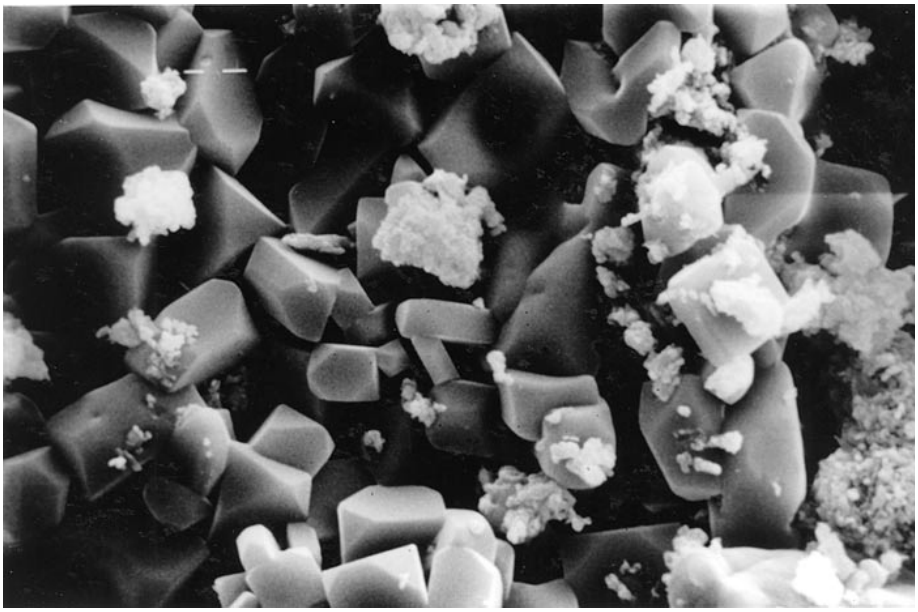
Figure 2.4 Solubility of some natural salts in relation to temperature

Sodium chloride (NaCl) crystals are stable at relative humidity below 76%. Above this humidity (typically at night) the crystals will attract moisture from the air (hygroscopic) and go into solution. As the humidity drops during midday they re-crystallise creating disruptive pressures sufficient to disintegrate road surfacings.

The magnitude of salt crystal pressures generated by crystal growth is sufficient to heave over one metre thick concrete slabs and buildings. Prevention of salt damage to roads must, therefore, rely solely on methods of stopping migration and crystallisation of salts. See Pincher and Hawkins, 1986. for more detail on the magnitude of salt crystal pressures.

An alternative is to ensure that supersaturation does not occur. High supersaturation results in the formation of the most deleterious type of salt crystals with high growth pressures. These crystals are known as filamentous crystals or salt 'whiskers'.

Obika (1989, 1992) provides a detailed description of the physico-chemical mechanisms of salt damage including the magnitude of crystal pressures which are outside the scope of this guideline.



Cubic NaCl crystals cause little damage.

Whisker NaCl crystals cause maximum damage.