

Mustafa M. Hariri

*P O Box 685, Dhahran, 31261
Earth Sciences Department, King Fahd
University of Petroleum & Minerals
(KFUPM), Dhahran,
Saudi Arabia
mmhariri@kfupm.edu.sa*

Nature, affects, and possible causes of rock fractures within Dammam, Khobar and Dhahran cities, eastern Saudi Arabia

Mustafa M. Hariri

*Earth Sciences Department, KFUPM, P O Box 685,
Dhahran, 31261, Saudi Arabia*

ABSTRACT

Study of rock fractures is an important factor that should be considered in any urban planning and /or development. Fractures can be a cause of landslides, collapses and ground subsidence, in addition to many other geohazards. Rock fractures are very pronounced and dominant features in the Dammam, Khobar, and Dhahran cities. They affected the local area and acted as conduits for meteoric water that produces cavities in many places. Presence of those fractures is attributed to the fragile geological nature of the area. The area is underlined by carbonate rocks and located within the limit of Dammam dome. Fractures in the area are of different types; major and large size fractures mainly related to the emplacement of Dammam dome. Other minor and small size fractures are localized, due to local stresses, and affected by the rock properties. This study characterizes fractures in the Dammam, Khobar and Dhahran cities area. It also displays the fracture distributions, concentration and trends. The outcomes of this study are important for the planning and development of those three cities and the surrounding areas.

INTRODUCTION

The major three cities Dhahran, Khobar and part of Dammam are located within the border of Dammam dome. The dome is located in the eastern province of the Kingdom of Saudi Arabia and is bounded approximately by Longitudes 50 and 50 14N and Latitudes 26 12 and 26 26E (Figure 1). It hosts the first oil discovery Dammam-7 well and characterizes by gentle sloping topography in all directions with four stand out hills; Jabal Umm Er Rus, nearby KFUPM Jabal (at the top of the dome), Jabal Midar Ash Shamali and Jabal Midar Al-Janubi (east of the dome). Elevations of these hills are 150m, 100m, 125m and 92m respectively (Weijermars, 1999).

The Dammam dome is anticlinal structure with a core excavated by erosion with a major axis trending N 30-40 west and covering an area of about 60 sq. mile (Figure 1). The rocks exposed within the Ad Dammam are gently dipping Tertiary rocks covered with Quaternary deposits

locally developed into sand dune and sheet deposits or extensive sabkha (Figure 2).

GEOLOGICAL SETTINGS:

The exposed rocks of the Dammam dome range in age from Paleocene to middle Miocene. The rocks sequence from the base upwards consists of the following formations; Umm er Radhuma Formation, Rus Formation, Dammam Formation, Hadrukh Formation, and Dam Formation. At the core of Dammam dome both the lower and upper Rus units of Taleel (1973) are present (Figure 2). The lower Rus is made up of alternation of marls and thin dolomitic limestone beds with abundant slumps and geodes. The upper part of the unit is vuggy weathered calcarenite with abundant mud balls. Jointing is more pronounced in the upper part of the lower Rus Formation due to the nature of the rock. The upper Rus Formation is mainly made up of fine-grained chalky limestone with few marls and clay layers at the top. The depositional environment of Rus Formation consists at the base of sabkha, which subjected episodically to shallow marine incursions and changes towards the top of the Formation into regressive facies, lagoonal associated with continental facies (Weijermars, 1999). The Rus Formation is overlaid conformably by Dammam Formation (Figure 2). Dammam Formation is subdivided into five members; Midra shale, Saila shale, Aveolina limestone, khobar and Alat members of dolomitic marl and dolomitic limestones. The four lower members of the Dammam Formation are present in a small ridge at the core of the Dammam dome (Weijermars, 1999). The Dammam Formation represents a transgressive facies sequence (Weijermars, 1999). The sabkha and sub tidal to continental lagoon facies were progressively transformed into an open shallow marine environment.

The Miocene Hadrukh Formation fringes the outer rim of the Dammam dome and comprises sandy marl at the base with intercalations of thin limestone beds, and sandstone. Towards the top the facies changes into calcareous sandstone and shales interbedded with minor amounts of marl and gypsum. The Hadrukh Formation represents continental to shallow marine facies (Power et al., 1966; Weijermars, 1999).

The Dam Formation unconformably overlies either Rus or Dammam rocks, depending upon location. At Jebel Midra Al – Janubi the Dam Formation comprises sandy conglomerate at the base overlain by stromatolitic limestone. The middle part of the sequence is dominated by clastic limestone, and intercalations of microcrystalline with calcite geodes. In the top of the sequence consists of massive calcrudite, with ancient subaerial collapsed dissolution caves. This facies changes up into massive reef limestone.

The Dam Formation indicates a major marine transgression, and it shows shallow marine environment (Weijermars, 1999). Shallow subtidal to intertidal environment is also indicated at the type locality of Al-lidan escarpment (Irtem, 1996).

Quaternary coastal deposits, Sabkha plains and eolian sands are covering the low area at the porphyries of Dammam dome (Figure 2) and large alluvial fans of conglomerate and sand deposited within major wadies (Weijermars, 1999).

GENERAL CHARACTERISTICS OF ROCK FRACTURES

Fracture is defined as surface along which rocks or minerals have broken and lost cohesion (Twiss and Moores, 1992). They are characterized by having two parallel approximately planar surfaces (Pollard and Aydin, 1988). The term fracture encompasses both joints and faults (Pollard and Aydin, 1988). The difference between the two is in that joints are extension fractures and show no shear displacement whereas, faults display shear displacement (Pollard and Aydin, 1988).

Fractures were divided in literature into many types. However the following section is summarizing the fractures classification according to their relationship to the principle stresses σ_1 , σ_2 and σ_3 .

Mode I (extensional fractures), the relative movement is perpendicular to both the maximum compressive principal stress (σ_1) and the fracture surface and parallel to (σ_3), the least principal stress (Atkinson, 1987; Twiss and Moores 1992). Engelder (1987) indicated that mode I fractures carry no shear tractions and propagate where the component of maximum effective tensile stress is normal to the plane of the crack. Moreover, Atkinson (1987) named mode I fracture as the tensile or opening mode. Pollard and Aydin (1988) argued that extensional (opening) fractures could result by both tensile and compressive stresses, especially if fluid pressure is involved.

Mode II (shear fractures), the fracture surface is oblique to σ_1 (making an angle of 30° to $< 45^\circ$ with it), but parallels the relative movement in the fracture plane. Relative movement in mode III (shear fracture) is parallel to both the fracture surface and fracture edges (Atkinson, 1987; Engelder, 1993).

A mixed mode of I, II, and III was suggested by Engelder (1987) and Twiss and Moores (1992). In mixed mode (oblique extension fracture), the sliding motion is both parallel and perpendicular to the fracture surface.

Segall (1984) suggested that extensional fracture begins to propagate when the crack extension force reaches a critical value, which is a property of the rock and environmental conditions. After fracture

propagation, the fracture extension force varies depending on the following factors: the increase in fracture length, change in remote strain, elastic interaction with nearby fractures, change in the internal fluid pressure, and stress relaxation due to growth of fractures in the surrounding rock (Segall, 1984). The stress field at the fracture tip controls the fracture propagation path and the fracture will propagate in a direction normal to the least principal stress (Engelder, 1993). As the fracture volume decreases, the pore pressure decreases and the fracture propagation will arrest.

NATURE AND GROWTH HISTORY OF DAMMAM DOME:

Dammam dome is a result of a subsurface salt diapirism that is related to Hormuz salt body. Hormuz salt started its initial growth in Jurassic and Cretaceous time in response to general tectonic extension that took place within the Arabian plate (Weijermars, 1999). The tectonic extension was further accelerated in Miocene time. Based on the elevation of Dam Formation of 150m over 20 Ma Weijermars (1999) estimated the uplift rate of Dammam dome in Neogene time to be in the rate of 7.5m/ Ma. He also estimated an uplift rate of 7m / Ma in Oligocene from the maximum hiatus of 150m in stratigraphic section over 22 Ma. Furthermore, Weijermars, (1999) suggested a minor structural growth of Dammam dome during middle Eocene according to the Dammam formation thickness. The suggested modern uplift of the dome is at a rate of 5.6 to 7m /Ma (i.e. 0.56 to 0.75 mm per century

ROCK FRACTURES WITHIN DAMMAM DOME

Based on their size, trend and extension fractures within Dammam dome were divided into three types; regional (major) fractures, local (minor) fractures and very small size -localized fractures. Mode of fracture, filling materials opening and spacing were noted for each type (Hariri and Abdullatif, 2004).

Field study indicated that two fractures Modes present within Dammam Mode I and Mode III. No indication or presence of Mode II fractures within the Dammam dome. Mode I fracture is extension or tension fractures and characterized by lack of displacement in both the horizontal and vertical directions. Fracture opening in this type is perpendicular to the fracture planes (Figure 3). Mode III fractures are normal faults where movement is parallel to the fracture surface and in the vertical direction (Figure 3).

Field study indicated that regional fractures are the most prominent or dominant type of fractures present within Dammam dome. These fractures characterized by their large size, long extension (>500m) and

systematic trends compared to the other two types. These characteristics made them the best candidate to be studied to determine their relationship of fractures to the tectonic (doming) and structural settings. In addition, those fractures are more important than the other local types concerning the engineering, environmental and hydrocarbon implications. Pattern and trends of those fractures were determined in several locations within the Dammam dome. The resulted pattern confirmed the relationship of those fractures to the doming in the area (Figure 4). Concentric and radial trends are characterizing the fracture pattern that is coincided with a pattern produced by an elliptical shape dome (Figure 4; Hariri, 1995). Trends of those fractures were determined within KFUPM (at the apex of the dome) and at the periphery of the dome (Figures 4). Major trend of regional fractures varies from one location to another within the dome. Variation in trend is attributed to the fractures location with respect to the dome (Figures 4). Variation of trend might also be related to the rock physical properties and bed thickness. Very pronounced and greater spacing can be observed with the more consolidated and intact rock unit of Rus Formation compared to the more friable variety (Figure 5).

PATTERN OF MAJOR FRACTURES:

Fracture's trends within an oval shape dome structure show radial and concentric pattern as suggested by many workers (Figure 6 and Wisser, 1960; Price and Cosgrove, 1992; Hariri, 1995). Concentric and radial fracture patterns are predicated to be developed as ellipses and curves in elongated dome. As the Dammam dome has an elongated oval shape the expected fracture's patterns will also be of concentric and radial nature. Those fractures are most likely related to the formation of the dome and their major trend will be changing from one location to another with respect to their location within the dome (Hariri, 1995; Hariri and Abdullatif, 2004). Moreover, those fractures are most likely produced as a result of the dome emplacement and growth. (Hariri and Abdullatif, 2004). The radial and concentric fracture patterns within dome structures are attributed to the tensile concentric and radial stresses that acted within the dome during its growth. Radial stress regime produced concentric fractures and the concentric regime produced the radial fractures (Hariri and Abdullatif, 2004, Wisser 1960).

LOCAL (MINOR) FRACTURES:

Local (minor) and very localized fractures are the other two types of fractures that present within Dammam dome. Minor fractures are characterized by their limited extensions and smaller size compared to the

regional fractures. Length of those fractures varies between 1 meter and a maximum of 10 meters with an average width of 3 cm (Figures 5 and 7). Those fractures expose in some places Mode III type fractures. No major or dominant trend can be determined for the local fractures, as they show variable trends. Local fractures have irregular surfaces and very limited depth. In some parts, the local fractures are filled with calcite and clayey material that are derived from the surrounding rock units.

Local fractures present in between and cross cutting the regional fractures. This relationship may indicate that they are younger in age compared to the regional (major fractures). Local fractures may also be related to the rock block movement in-between the regional major ones (Figures 5 and 7).

The very localized and small size fractures are characterized by their limited extension, less than 1 m and small dimensions (Figure 7). Compared to the other two types these fractures are very localized to the outcrops and have shallow average depth and small average width 4cm and 2cm respectively. Those fractures are mostly related to the rock properties. No dominant trend can be determined for those fractures as they are not reflecting any particular geological event. Density of those fractures varies from one place to another according to the rock unit engineering and geological properties.

FRACTURES AFFECT ON URBANIZATION:

Fractures distribution and nature should be considered in all urban planning. Major fractures within limestone rock units considered to be the main conduits for the meteoric and ground water circulation. Ground water circulation and penetration through limestone will cause dissolution and produces karsts and cavity structures within the rock formation (Kastning, et al. 1999). These features are the main cause for ground subsidence. In many locations within Dammam dome ground subsidence has been observed. This might be related to fractures, cavities and ground water circulation.

In recent years, major cities within Dammam dome experienced dramatic population and industrial activity increases (Figure 8). These were associated with urbanization development; city sizes expansion and infrastructure establishments. To avoid any ground subsidence and associated geohazard fractures distribution and trends within the dome need to be considered in all aspects of urbanization.

CONCLUSION AND RECOMMENDATION:

The Dammam dome is a major structural features encompasses three major cities (Khobar, Dhahran and part of Dammam) of the eastern province of Saudi Arabia. The dome characterizes by presence of intensive fractures system. Fractures within the dome into three types; regional (major) (Figure 5), minor (local) and very localized (small size) fractures (Figure 7). The regional fractures type is the most important ones and need to be considered in any urbanization development in the area. Those fractures extend for great distances (1 km in some places) and characterized by defined trends that reflect the doming nature of the Dammam dome. They most probably formed as a result of the doming processes. Cavities and subsurface opening might associate with those fractures.

The cities expansion, population increases and industrial activities within the dome limit emphasize the need of detail fractures study (Figure 8). Sites investigation and search for possible subsurface cavities need to be conducted for any major project in the area.

It is highly recommended that the result and finding of this study to be considered in any urban planning and development in the area. Moreover, rock fractures and fractures system should also be considered in any area that have similar geologic settings to the Dammam dome or where limestone and dolomite rock units are the basic rocks present.

ACKNOWLEDGEMENTS:

This study is part of a funded project of SABIC (Saudi Arabian Basic Industry Company) project # SABIC 2002-06. Thanks and appreciations are to SABIC and to the KFUPM (King Fahd University of Petroleum and Minerals) for the support and the provided facility. Many thanks are also go to the co-researcher in this project Dr. Osman Abdullatif for his help and great efforts. Thanks and appreciations to Mr. Fadhel Al-Khalifah, Mr. Mushabab Qasim and Mr. Mohamed Ahmed during project work. Fawaz Al-Khalidi and Mr. Ahmad Al-Shihab are thanked for their support and help in the field works.

REFERENCES:

Atkinson, B. K., 1987. Introduction to fracture mechanics and its geophysical applications, *in* Atkinson, B. K. ed.: Fracture mechanics of rock Academic press, New York, p. 1-26.

Engelder, T., 1987. Joints and shear fractures in rocks, *in* Atkinson, B. K. ed., Fracture mechanics of rock: Academic press, New York, p. 26-69.

Engelder, T., 1993. Stress regimes in the lithosphere: Princeton University Press, New Jersey, 457 p.

Hariri, M. M., 1995, Lineament studies and fracture control on the Tertiary gold-silver deposits, northern Black Hills, South Dakota, USA., [Ph.D. thesis]: South Dakota School of Mines and Technology, 159p.

Hariri, M.M.and Abdullatif, O. M. 1994. Characterization of fractures within Dammam dome, Saudi Arabia. *GeoArabia*, V 9 Number 1, p.76

Irtem,O.1986. Miocene Tidal Flat Stromatolites and the Dam Formation Saudi Arabia, *Arabian Journal of Sciences and Engineering*, v.12, no.2, p.145-153

Kastning, E. H., Kastning, K. M. and Virginia Deprtemnt of Enirnemntal Quality, 1999. Misconception About Caves and Karst: Common Problems and Educational Solutions, National Cave and Karst Mangment Symposium, pp 99-107

Pollard, D. D., and Aydin, A., 1988. Progress in understanding jointing over the past century: *Geological Society of America Bulletin*, v. 100, p. 1181-1204.

Powers, R.W., Ramrirez, L.F., Redmond, C.D., and Elberg, E.L. 1966. Sedimentary Geology of Saudi Arabia, USGS Professional Paper, 560-D, Wasington, 147 p.

Price, N. J. and Cosgrove, J. W., 1990. Analysis of geological structures: Cambridge University Press, New York, 502 p.

Segall, P., 1984. Formation and growth of extensional fracture sets: *Geological Society of America Bulletin*, v. 95, p.454-462

Taleel, J. W. 1973. Surface geology of the Dammam dome, Eastern Province, Saudi Arabia. AAPG Bulletin. v. 57. no. 3. p. 558-576.

Twiss, R. J. and Moores, E. M., 1992. Structural Geology: Freeman and Company, New York, 532 p .

Weijermars, R. 1999. Surface geology, lithostratigraphy, and Tertiary growth of the Dammam dome, Saudi Arabia. A new guide. GeoArabia. V. 4. no.2. p. 199-266.

Wisser, E., 1960. Relation of ore deposition to doming in the Northern America Cordillera, Geological Society of America Memoir, n. 77. p. 110.

Figures for paper REF # 542-7

*Nature, affects, and possible causes of rock fractures within Dammam,
Khobar and Dhahran cities, eastern Saudi Arabia
Mustafa M. Hariri*

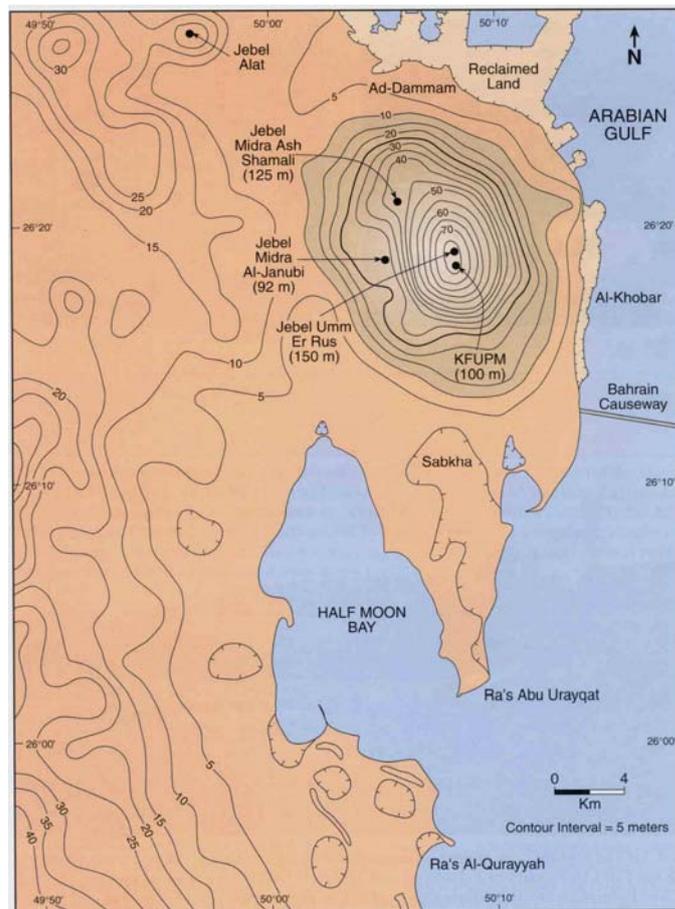


Figure 1: Topographic map of the Dammam Peninsula showing location of Dammam, Dhahran, Khobar and main outcrops in the study area (After Weijermars 1999)

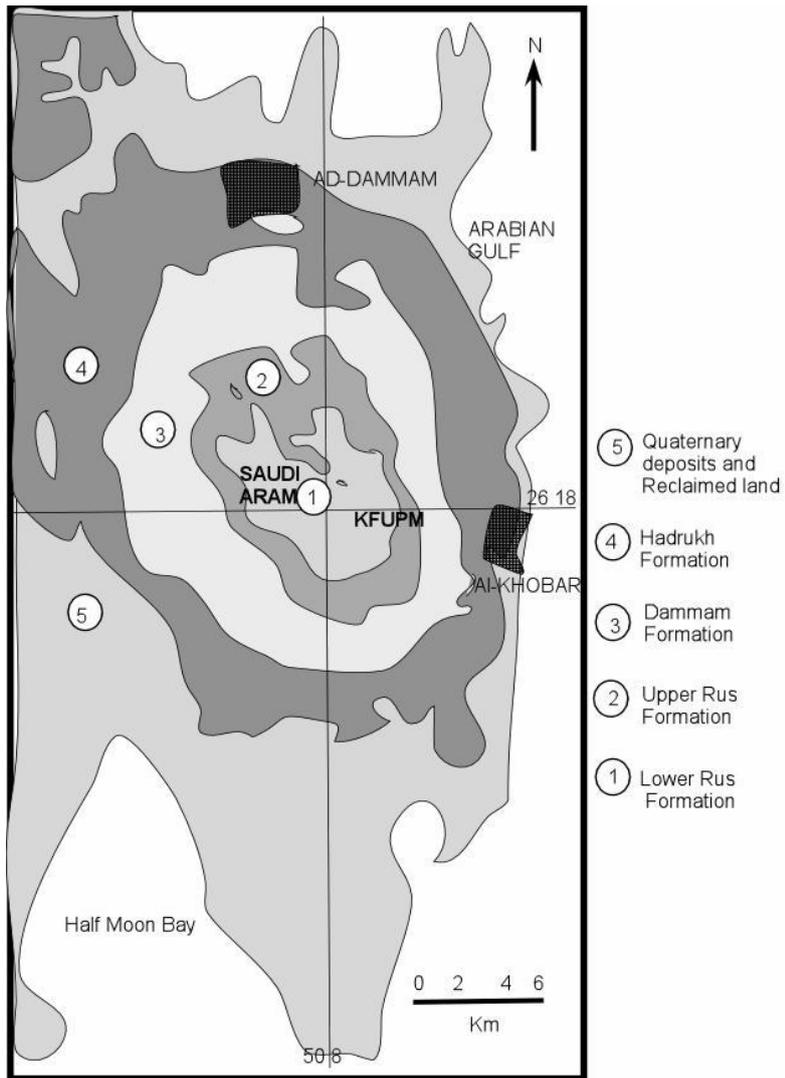


Figure 2: Simplified geological map for the Dammam dome area (modified after Wijermars, 1999)

Figures for paper REF # 542-7

*Nature, affects, and possible causes of rock fractures within Dammam,
Khobar and Dhahran cities, eastern Saudi Arabia
Mustafa M. Hariri*

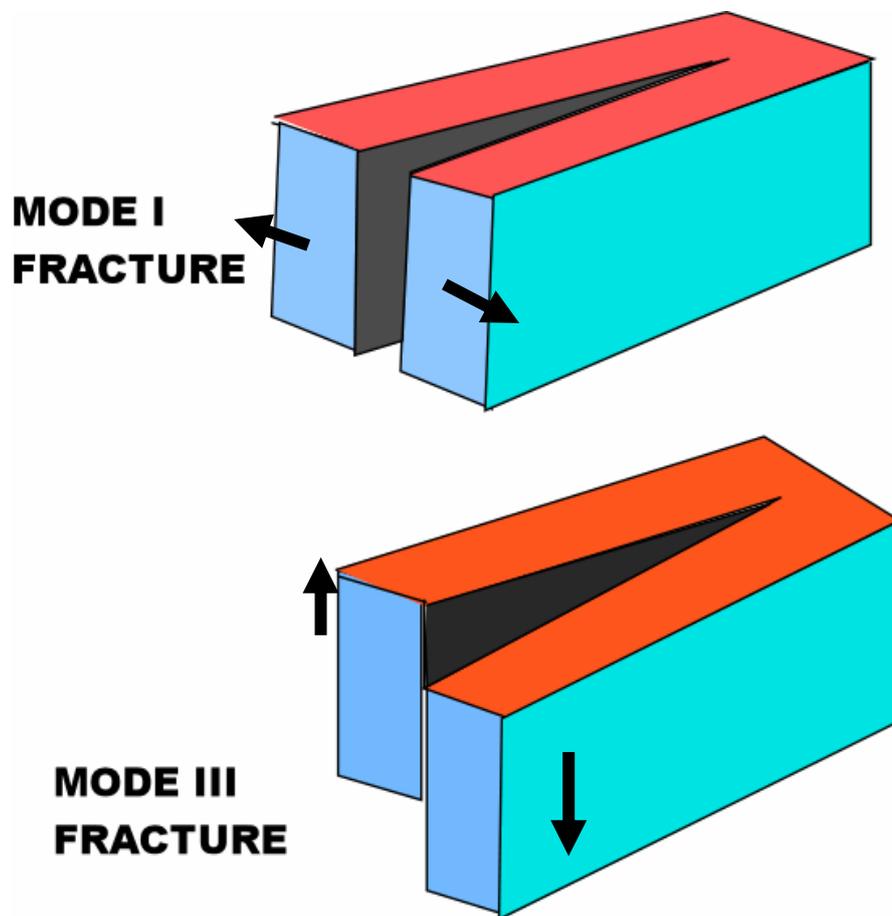


Figure 3: Mode I and Mode III fractures. These two Modes are observed within Dammam dome.

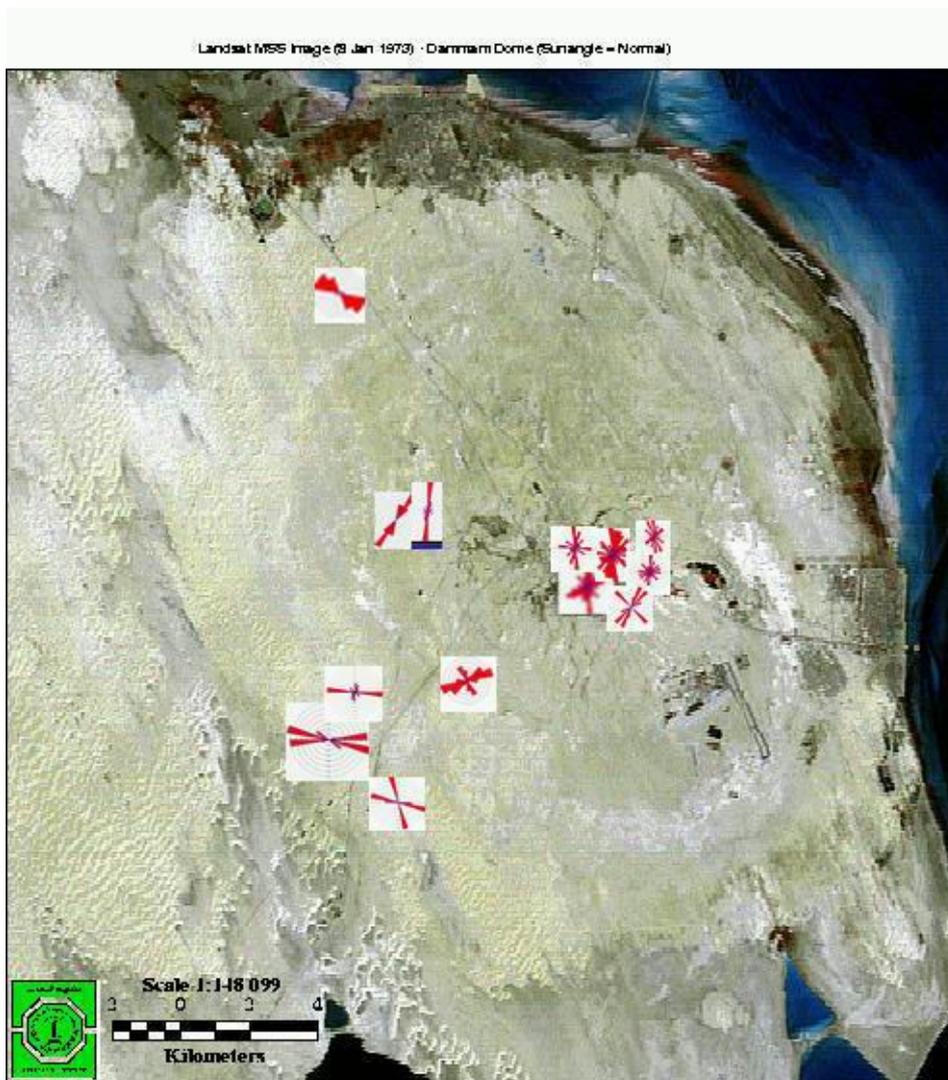


Figure 4: Satellite image of Dammam dome shows trends of regional fractures at various parts within the dome

Figures for paper REF # 542-7

*Nature, affects, and possible causes of rock fractures within Dammam,
Khobar and Dhahran cities, eastern Saudi Arabia
Mustafa M. Hariri*



Figure 5: Two photos show the systematic nature and great extension of regional (Mode I) fractures (red arrows). Local Mode III fractures (black arrows) are cross cutting the regional ones

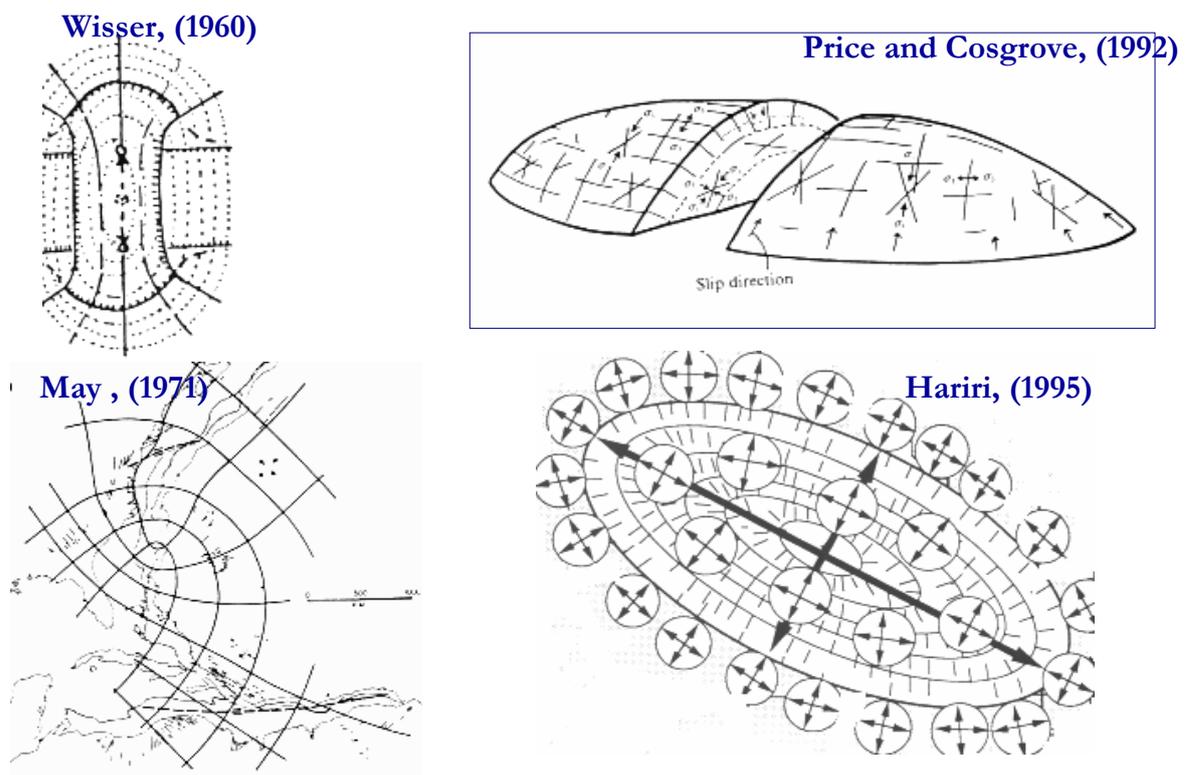


Figure 6: Four suggested models for the pattern of fracture trends within dome structures. All these models indicate radial and concentric patterns.

Figures for paper REF # 542-7

*Nature, affects, and possible causes of rock fractures within Dammam,
Khobar and Dhahran cities, eastern Saudi Arabia
Mustafa M. Hariri*

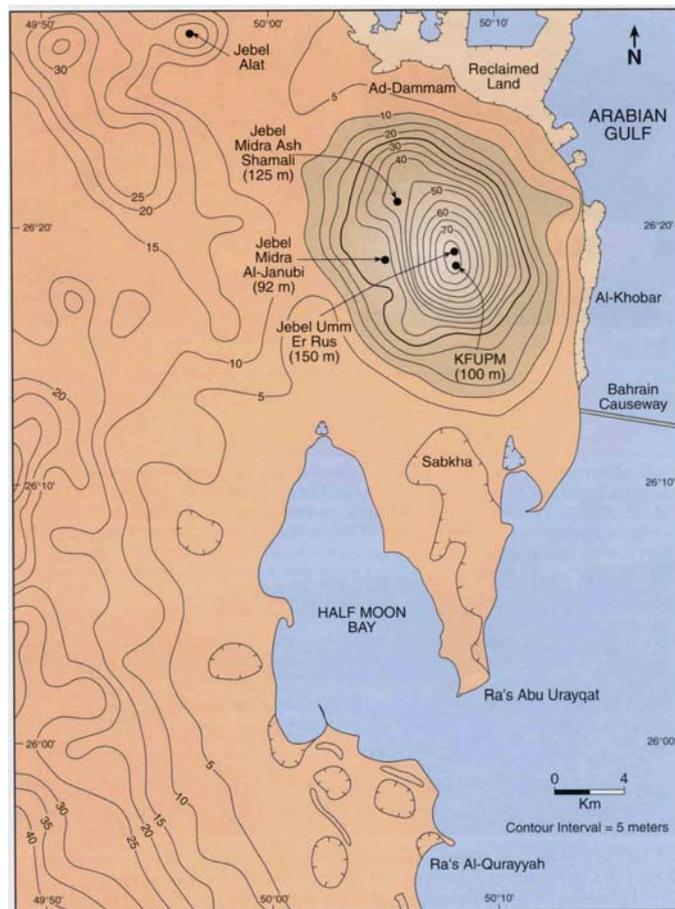


Figure 1: Topographic map of the Dammam Peninsula showing location of Dammam, Dhahran, Khobar and main outcrops in the study area (After Weijermars 1999)

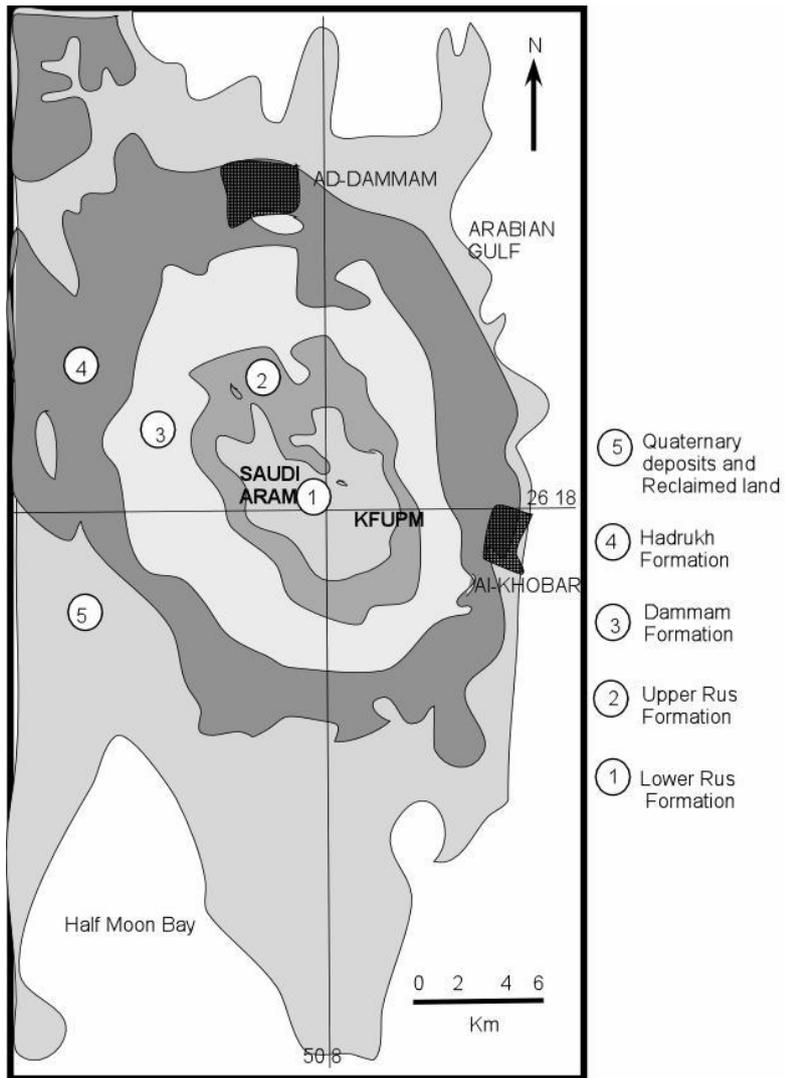


Figure 2: Simplified geological map for the Dammam dome area (modified after Wijermars, 1999)

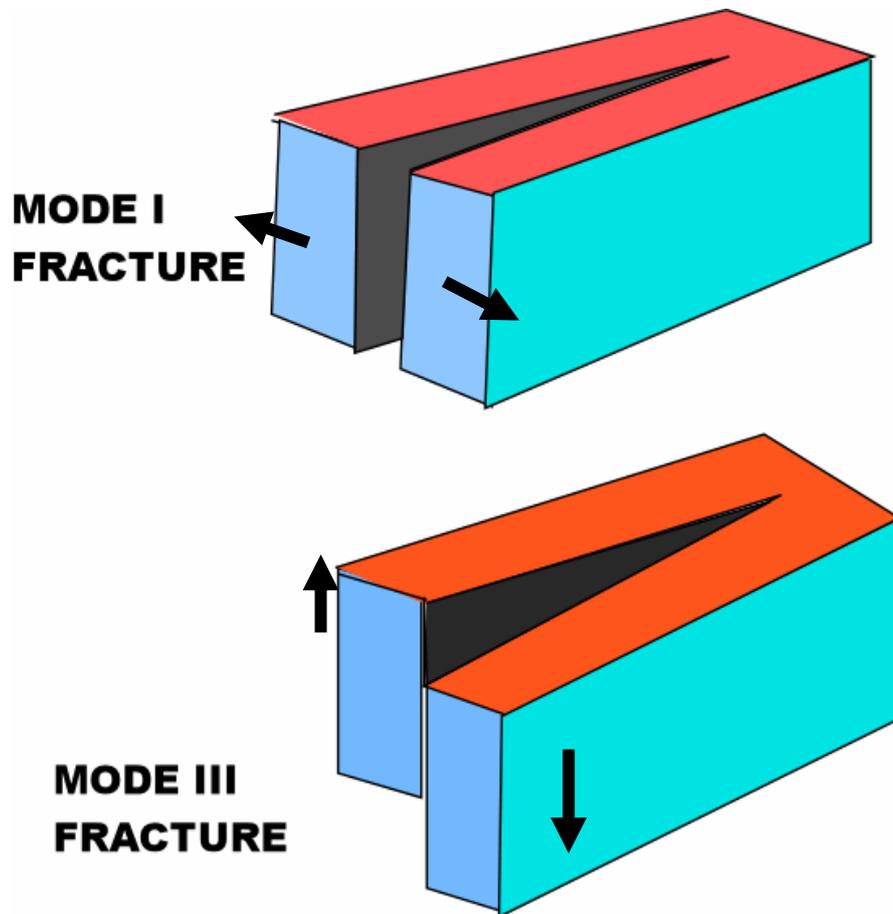


Figure 3: Mode I and Mode III fractures. These two Modes are observed within Dammam dome.

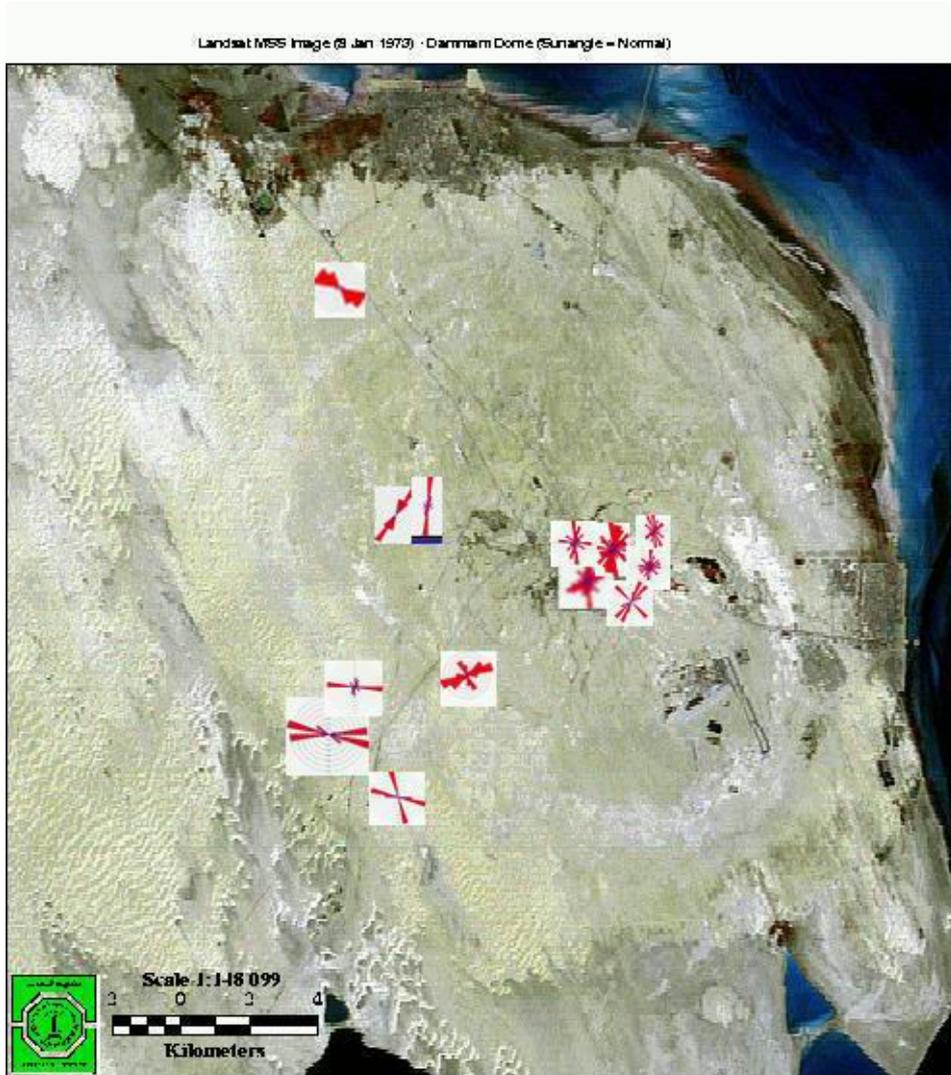


Figure 4: Satellite image of Dammam dome shows trends of regional fractures at various parts within the dome



Figure 5: Two photos show the systematic nature and great extension of regional (Mode I) fractures (red arrows). Local Mode III fractures (black arrows) are cross cutting the regional ones

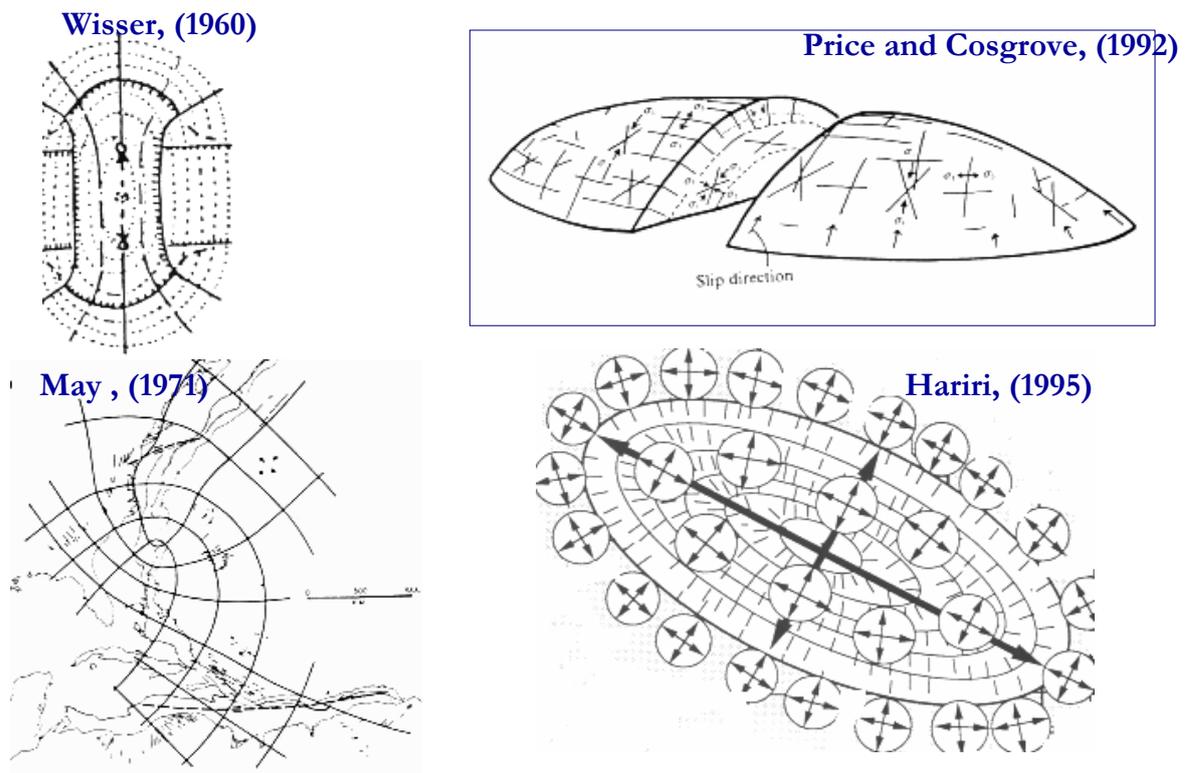


Figure 6: Four suggested models for the pattern of fracture trends within dome structures. All these models indicate radial and concentric patterns.



Figure 7: Two photos show the minor local and very localized type fractures within the Dammam dome

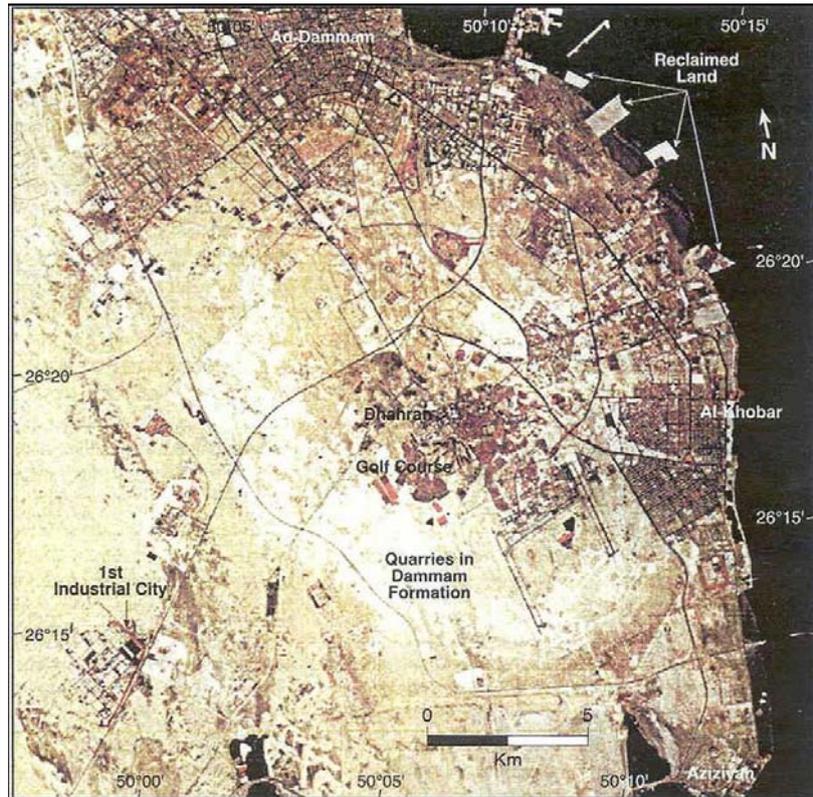


Figure 8: Satalite image for Dammam dome in 1998 shows the spreading of the constructions, infrastructures and cities limit

Figures for paper REF # 542-7

*Nature, affects, and possible causes of rock fractures within Dammam,
Khobar and Dhahran cities, eastern Saudi Arabia
Mustafa M. Hariri*



Figure 7: Two photos show the minor local and very localized type fractures within the Dammam dome

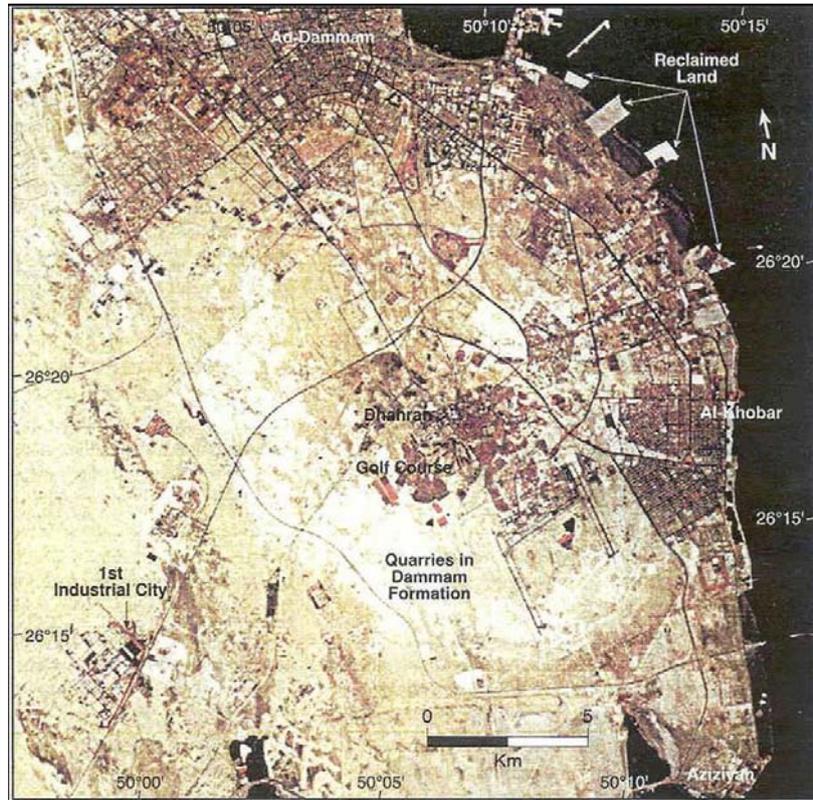


Figure 8: Satalite image for Dammam dome in 1998 shows the spreading of the constructions, infrastructures and cities limit

