11. SYMMETRY OPERATIONS ON THE BIOPOLYMER UNITS OF THE PARTIALLY DEGRADED EXINE OF PHOENIX DACTYLIFERA L.

M. KEDVES and ZS. THURZÓ

Cell Biological and Evolutionary Micropaleontological Laboratory of the University of Szeged, H-6701, P.O. Box 993, Szeged, Hungary

Abstract

Symmetry operations were carried out on two regular pentagonal and a hexagonal biomacromolecular units of the partially degraded ectexine of *Phoenix dactylifera* L. At one of the regular pentagons the tenfold rotation resulted in unusual and completely new results. In two circles two times ten regular pentagons appeared around the rotation center. This phenomenon may be modelled with a three dimensional quasicrystalloid skeleton. The inner globular units of the outer regular pentagonal circle has six connections with the other globular biopolymer units. At the hexagon the incomplete rotation methods were also used and some methodical alterations were introduced.

Key words: Biopolymer symmetry operations, *Phoenix dactylifera*, ectexine.

Introduction

In a previous paper (KEDVES, PÁRDUTZ et al., 2003) the ultrastructure of the partially degraded pollen grains of *Phoenix dactylifera* L. was published. Experiment with 2-aminoethanol for 48 hours and with $KMnO_4$ for 24 hours revealed regular pentagonal biopolymer units. In this paper it is pointed out that these regular pentagons are smaller than those observed in the partially degraded ectexine of *Phoenix sylvestris* L. (KEDVES et al., 2001). We investigated again the TEM negatives taken with high resolution power and we planned to carry out symmetry operations on the two regular pentagons. During our new investigations we observed a regular hexagon also. This kind of biomacromolecular unit observed and discussed previously may be:

1. TICOS polyhedra established by BURSILL and PENG JU LIN (1985) which was demonstrated previously in the partially degraded ectexine of *Pinus griffithii* (KEDVES, 1991b).
2. Regular hexagon without any connections (cf. KEDVES, 1990a, 1991a).
3. Hexagon connected to a regular pentagon as a fragment of a biopolymer structure which may be modelled with fullerenes (KEDVES, BÉRES et al., 2003).

The aim of this paper is to investigate these biopolymer units with the two dimensional rotation method and to obtain new data on this field of research.

Materials and Methods

The Negative No.: 10529 was used for these symmetry operations which were previously published in P.C.B.D. vol.15, p. 87. For the regular pentagon we started with fivefold and tenfold rotation methods. For the hexagon sixfold, twelvefold and two kinds of incomplete rotation were used. At the incomplete rotations, in contrast with our previous publications, the number of the biopolymer units are indicated in index.

The most important methods for the investigations of the quasi-crystalloid skeleton are as follows: 1. Two dimensional, the modified Markham (MARKHAM et al., 1963) rotation method 1.1. Rotation of a regular pentagon in nm dimension, ROWLEY (1967) 1.2. Rotation at the intermediate diameter of the nm and Å dimension, FLYNN and ROWLEY (1971) 1.3. Rotation in Å dimension (KEDVES, 1988a,b, 1989a,b, 1990a,b, KEDVES et al., 1991, KEDVES and FARKAS, 1991, KEDVES et al., 1992, KEDVES and PÁRDUTZ, 1993, KEDVES, TÓTH and GOTTL, 1994, KEDVES and TÓTH, 1994, KEDVES, TÓTH and VÉR, 1995, KEDVES et al., 1998, KEDVES and BORBOLA, 1998, KEDVES, PÁRDUTZ and MADARÁSZ, 2000, KEDVES et al., 2001, KEDVES, SASHALMI and SZÉCSÉNYI, 2002, KEDVES, BÉRES et al., 2003, KEDVES and JACSÓ 2003, KEDVES, PÁRDUTZ et al., 2003, KEDVES, PRISKIN et al., 2003). 2. Three dimensional modelling (KEDVES, 1991c, 1992, KEDVES, TÓTH and FARKAS, 1993). 3. Computer modelling (KEDVES, M. and KEDVES, L., 1995, 1996, 1997, 1999).

Results

Plate 11.1., fig. 5 illustrates the biopolymer units of the partially degraded ectexine. Well shown are a number of biopolymer structures, we chose two regular pentagons (A and B) and a hexagon (H) for symmetry operarations.

Biopolymer A (Plate 11.1., figs. 1,2, plate 11.2.)

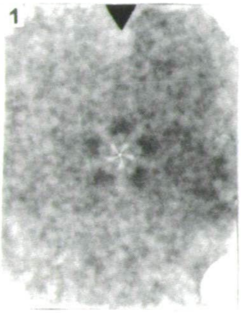
The fivefold rotation reinforced the globular biopolymer units of the regular pentagon and in the same time varified the regularity of the biopolymer structure. A not so characteristic rotation area appeared. The tenfold rotation resulted in a large, well defined rotation area and several points of symmetry. In picture magnified for 5 million the peculiarities of this kind of rotation are well illustrated. Around the rotation center there are several dark points of symmetry which are arranged to form regular pentagons. Two circles of ten regular pentagons were established. These may be the components of the quasi-crystalloid skeleton. The inner globular biopolymer units of the outer pentagons are connected with six other units making connection with both the inner and the outer pentagonal units.

Biopolymer B (Plate 11.1., figs. 3,6)

The fivefold rotation reinforced the regular pentagon and resulted in a characteristic rotation area of pentagonal form. Several secondary points of symmetry appeared at this method also. Five relatively large biopolymer units form a large pentagon around the original biopolymer structure. At the border of the rotation area there are five groups of biopolymer units which may be a pentagon-dodecahedrane unit. After tenfold rotation (Plate 11.1., fig. 6) around the rotation center, a characteristic circle of dark globular biopolymer units appeared which may be useful for further secondary rotations. The border of the rotation area is characteristic.

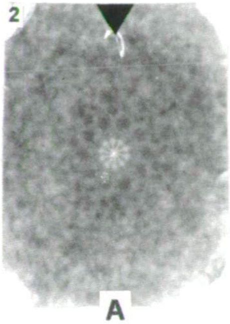
Biopolymer H (Plate 11.1., figs. 4, 7-9)

The sixfold rotation resulted in characteristic rotation area composed of two borders which may be the components of a bordering three dimensional pattern (Plate 11.1., fig. 4). There are six characteristic globular biopolymer units at the inner bordering area which may be useful for further secondary symmetry operations. The twelvefold rotations (Plate 11.1., fig. 7) resulted in several secondary points of symmetry around the rotation center and a characteristic rotation area. The dimensions of the dark globular biopolymer units are different. The twelve globular biopolymer units of the outermost circle are the largest. Different biopolymer networks are shown around the rotation area (Plate 11.1., fig. 7). Incomplete rotations (Plate 11.1., figs. 8,9) show several globular biopolymer units without characteristic arrangement. There are some differences between the two incomplete rotations, namely the rotation in fig. 8 shows regular arrangement of globular units forming a hexagon.



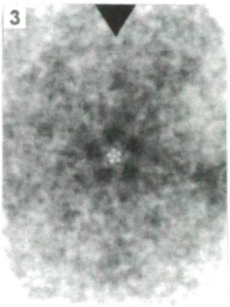
A

C.P.5.A.5.5.



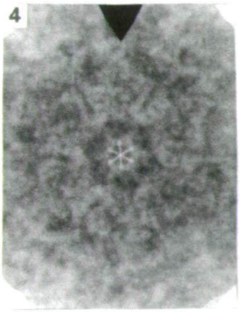
A

C.P.5.A.5.10.



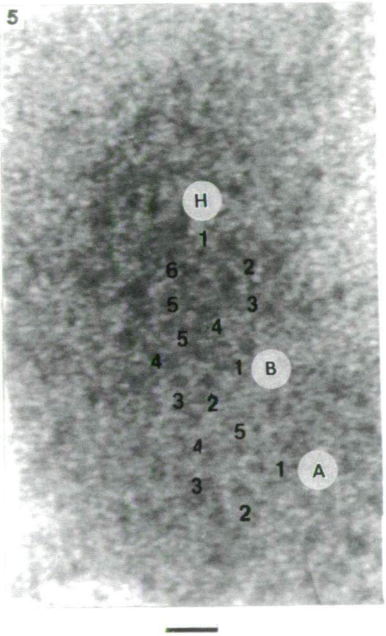
B

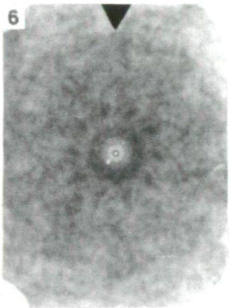
C.P.5.A.5.5.



H

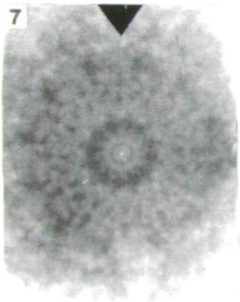
C.P.6.A.6.6.





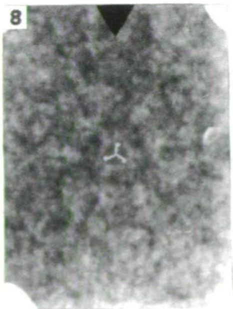
B

C.P.5.A.5.10.



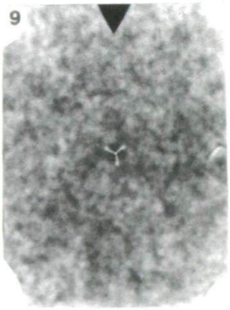
H

C.P.6.A.6.12.



H

I.P.6.A.6.3$_{1,3,5}$



H

I.P.6.A.6.3$_{2,4,6}$

Plate 11.1.

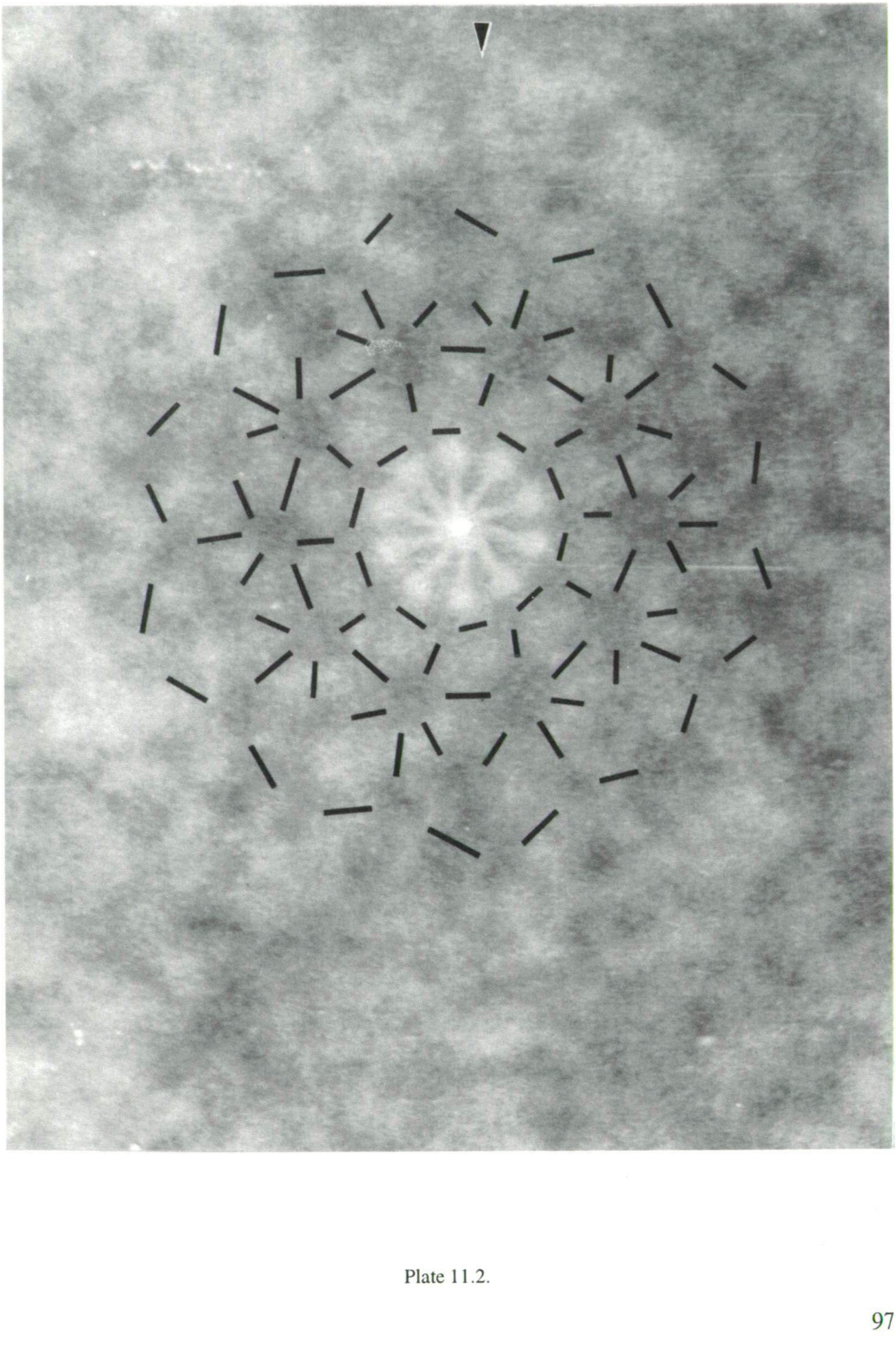


Plate 11.2.

Discussion and Conclusions

The discovery of the quasicrystals was made by SHECHTMAN, BLECH, GRATIAS and CAHN (1984), but the nomination was introduced by LEVINE and STEINHARDT (1984). Four years later, in the partially degraded ectexines of the pollen grains of *Pinus griffitithii*, the quasi-crystalloid biomacromolecular system was discovered (KEDVES, 1988). This biopolymer organization was investigated extensively in our laboratory. Several results and multidisciplinary contacts of the quasicrystals were shortly reviewed for the 10th anniversary of the discovery of the quasicrystals by KEDVES (1994). We cite again the most important establishments concerning our investigations: MACKAY (1976, 1981), PENROSE (1979), BURSILL and PENG JU LIN (1985), AUDIER and GUYOT (1986), NELSON (1986), SCHNEER (1988) and HARGTITAI (1990).

In the Materials and Methods part we reviewed the data referring to the different experimental methods. It is interesting that recently we have had to turn back to the two dimensional symmetry operations and, based on our recent investigations, we obtained several unexpected new results. During these symmetry operations the biopolymer network of the tenfold rotation of the biopolymer "A" is interesting. The surrounding ten regular pentagons may be modelled with the three dimensional Penrose unit of KEDVES (1992), p. 74, fig. 1.

Recently we have started to include C60 fullerene/benzol solution also in the partial degradation of the plant cell wall. For the symmetry operations of the sixfold biomacromolecular structures the incomplete rotation method may be useful. In this way the recently introduced index system seems to be important.

Finally, these new data support again the concept that the biomacromolecular system of the plant cell wall, especially of the sporoderm, is much more complicated than we believed earlier.

Acknowledgements

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Plate 11.1.

Phoenix dactylifera L. Biopolymer structure of the partially degraded ectexine and symmetry operations of two regular pentagons and a hexagon.

1,2. Regular pentagon biomacromolecule "A", 1. fivefold, 2. tenfold rotation pictures.
3,6. Regular pentagon biomacromolecule "B", 3. fivefold, 6. tenfold rotation pictures.
4. Sixfold rotation picture of the hexagonal biomacromolecule.
5. Ultrastructure of the partially degraded ectexine. The investigated biomacromolecular units are marked. A and B are regular pentagons, H is a regular hexagon.
7. Twelvefold rotation picture of the hexagonal biomacromolecular system.
8,9. Incomplete rotation picture of the regular hexagonal biolpolymer unit. Bar scale: 0.01.

Plate 11.2.

Phoenix dactylifera L. Magnified picture of the tenfold rotation picture, illustrated in Plate 11.1., fig. 2. Ten regular pentagons appeared around the rotation center in consequence of the symmetry operation. Globular biomacromolecular units in the center of the pentagons may be the components of the pentagon-dodecahedrane bipolymer structures.
Bar scale: 0.002.

References

AUDIER, M. and GUYOT, P. (1986): Al_4Mn quasicrystal atomic structure, diffraction data and Penrose tiling. - Phil. Mag. Letters, *B*, *53*, L43-L51.

BURSILL, L.A. and PENG JU LIN (1985): Penrose tiling observed in quasi-crystal. - Nature *316*, 50-51.

FLYNN, J.J. and ROWLEY, J.R. (1971): Wall Microtubules in Pollen Grains. - Zeiss. Inform. *18*, 40-45.

HARGITTAI, I. (1990): Quasicrystals, Networks, and Molecules of Fivefold Symmetry. - VCH Publishers, Inc., New York

KEDVES, M. (1988a): Quasi-crystalloid basic molecular structure of the sporoderm. - 7 Internat. Palynol. Congr. Brisbane, Abstracts, 82.

KEDVES, M. (1988b): About the symmetry of the pentagonal basic biopolymer units of the pollen wall. - Acta Biol. Szeged. *34*, 157-159.

KEDVES, M. (1989a): Méthode d'étude des biopolymères de la paroi pollinique à structure quasi-cristalloïde. A method of investigation of the quasi-crystalloid structure of pollen wall biopolymers. - Rev. de Micropaléontologie *32*, 226-234.

KEDVES, M. (1989b): Quasi-crystalloid biopolymer structures of the sporoderm and its highly organized degrees. - Acta Biol. Szeged. *35*, 59-70.

KEDVES, M. (1990a): Experimental investigations on recent *Selaginella* spores. - Taiwania *35*, 240-252.

KEDVES, M. (1990b): Quasi-crystalloid basic molecular structure of the sporoderm. - Rev. Palaeobot. Palynol. *64*, 181-186.

KEDVES, M. (1991a): First observations on the biopolymer organization of the intine. - Plant Cell Biology and Development (Szeged) *1*, 15-27.

KEDVES, M. (1991b): TICOS polyhedra as a model in the pentasporan organization. - Plant Cell Biology and Development (Szeged) 2, 43-48.

KEDVES, M. (1991c): Three dimensional modelling of the biopolymer structure of the plant cell wall I. - Plant Cell Biology and Development (Szeged) 2, 63-74.

KEDVES, M. (1992): Three dimensional modelling of the biopolymer structure of the plant cell wall II. - Plant Cell Biology and Development (Szeged) *3*, 67-87.

KEDVES, M. (1994): To the tenth anniversary of the discovery of quasicrystals. - Plant Cell Biology and Development (Szeged) *5*, 9-10.

KEDVES, M., BÉRES, O., JACSÓ, D., KOCSICSKA, I. and VARGA, B. (2003). Symmetry operations on the C60 fullerene/benzol solution revealed biopolymer structures. - Plant Cell Biology and Development (Szeged) *15*, 93-95.

KEDVES, M. and BORBOLA, A. (1998): Biopolymer structure and symmetry operations in partially dissolved and fragmented sclereids of *Armeniaca vulgaris* LAM. - Plant Cell Biology and Development (Szeged) 9, 64-75.

KEDVES, M. and FARKAS, E. (1991): Basis of the tertiary rotation and TICOS modelling of the quasi-crystalloid biopolymer skeleton of the plant cell. - Plant Cell Biology and Development (Szeged) 2, 36-42.

KEDVES, M., FARKAS, E., MÉSZÁROS, K., TÓTH, A. and VÉR, A. (1991): Investigations on the basic biopolymer structure of the ectexine of *Alnus glutinosa* (L.) GAERTN. - Plant Cell Biology and Development (Szeged) 2, 49-58.

KEDVES, M., HORVÁTH, A., TRIPATHI, S.K.M. and MADHAV KUMAR (2001): Symmetry operations on the quasi-crystalloid biopolymer system of the sporopollenin of *Phoenix sylvestris* LINN. from India. - Plant Cell Biology and Development (Szeged) *13*, 76-86.

KEDVES, M. and JACSÓ, D. (2003): Symmetry operations on octagonal biopolymer structure of partially degraded ectexine of *Ginkgo biloba* L. - Plant Cell Biology and Development (Szeged) *15*, 96-98.

KEDVES, M. and KEDVES, L. (1995): Computer modelling of the quasi-crystalloid biopolymer structure I. - Plant Cell Biology and Development (Szeged) *6*, 68-77.

KEDVES, M. and KEDVES, L. (1996): Computer modelling of the quasi-crystalloid biopolymer structure II. - Plant Cell Biology and Development (Szeged) 7, 82-88.

KEDVES, M. and KEDVES, L. (1997): Computer modelling of the quasi-crystalloid biopolymer structure III. - Plant Cell Biology and Development (Szeged) *8*, 100-105.

KEDVES, M. and KEDVES, L. (1999): Computer modelling of the quasi-crystalloid biopolymer structure IV. - Plant Cell Biology and Development (Szeged) *10*, 91-97.

KEDVES, M. and PÁRDUTZ, Á. (1993): Negative quasi-crystalloid biopolymer network from the exospore of *Equisetum arvense* L. - Plant Cell Biology and Development (Szeged) *4*, 78-80.

KEDVES, M., PÁRDUTZ, Á., BORBOLA, A. and PRISKIN, K. (2003): LM and TEM investigations on experimentally altered pollen grains of *Phoenix dactylifera* L. - Plant Cell Biology and Development (Szeged) *15*, 81-92.

KEDVES, M., PÁRDUTZ, Á., FARKAS, E. and VÉR, A. (1991): Basic establishments of the biological objects molecular structure containing quasi-crystalloid skeleton. - Plant Cell Biology and Development (Szeged) *1*, 35-37.

KEDVES, M., PÁRDUTZ, Á. and MADARÁSZ, M. (2000): New data on the molecular symmetry and organization of the quasi-crystalloid skeleton of the sporoderm. - Plant Cell Biology and Development (Szeged) *11*, 184-192.

KEDVES, M., PRISKIN, K., TRIPATHI, S.K.M. and MADHAV KUMAR (2003): Biopolymer structure of the partially degraded cuticles of *Cycas rumphii* MIQ.: A preliminary report. - Plant Cell Biology and Development (Szeged) *15*, 43-47.

KEDVES, M., SASHALMI, J. and SZÉCSÉNYI, A. (2002): Symmetry operations on the quasi-periodic biopolymer structures on the wall of *Botryococcus braunii* KÜTZ. I. - Plant Cell Biology and Development (Szeged) *14*, 85-91.

KEDVES, M. and TÓTH, A. (1994): Premiers résultats du système de biopolymère stabilisateur du squelette quasi-cristalloïde de l'exine. - Plant Cell Biology and Development (Szeged) *5*, 79-86.

KEDVES, M., TÓTH, A. and FARKAS, E. (1993): An experimental investigation of the biopolymer organization of both recent and fossil sporoderm. - Grana Suppl. *1*, 40-48.

KEDVES, M., TÓTH, A., FARKAS, E., BELLON, A. and SCHMÉL, Á. (1992): Methodical problems of the biopolymer organization of partially degraded ectexine. - Ann. Univ. Sci. Budapestinensis de R. Eötvös Nom. Sect. Geol. *29*, 263-279.

KEDVES, M., TÓTH, A. and GOTTL, E. (1994): Incomplete and non-fivefold rotation of the basic biopolymer unit of the exine of *Pinus griffithii* MCCLELL. - Plant Cell Biology and Development (Szeged) *5*, 67-78.

KEDVES, M., TÓTH, A. and VÉR, A. (1995): Radial fivefold rotation: A new method in the study of the biopolymer organization of the sporoderm. - Plant Cell Biology and Development (Szeged) *6*, 44-59.

KEDVES, M., TRIPATHI, S.K.M., VÉR, A., PÁRDUTZ, Á. and ROJIK, I. (1998): Experimental studies on *Botryococcus* colonies from Hungarian Upper Tertiary oil shale. - Plant Cell Biology and Development (Szeged) *9*, 43-63.

LEVINE D. and STEINHARDT, P.J. (1984): Quasicrystals.: A new class of ordered structures. - Phys. Rev. Lett. *63*, 2477-2480.

MACKAY, A.L. (1976): Crystal symmetry. - Physics Bull. Nov., 495-497.

MACKAY, A.L. (1981): De Nive Quinquangula: On the pentagonal snowflake. - Sov. Phys. Crystallogr. *26*, 517-522.

MADDOX, J. (1989): Quasicrystals stabilized by entropy. - Nature *340*, 261.

MARKHAM, R., FREY, S. and HILLS, G.J. (1963): Methods for the enhancement of image detail and accentuation of structure in electron microscopy. - Virology *22*, 88-162.

NELSON, D.R. (1986): Quasicrystals. - Sci. Amer. *254*, 43-51.

PENROSE, R. (1979): A Class of Non-Periodic Tilings of the Plane. - Math. Intelligencer 2, 32-37.

ROWLEY, J.R. (1967): Fibrils, mikrotubules and lamellae in pollen grains. - Rev. Palaeobot. Palynol. *3*, 213-226.

SCHNEER, C.J. (1988): Symmetry and morphology of snowflakes and related forms. - Canadian Mineralogist *26*, 391-406.

SHECHTMAN, D., BLECH, L., GRATIAS, D. and CAHN, J.W. (1984): Metallic phase with long-range orientational order and no traditional symmetry. - Phys. Rev. Lett. *53*, 1951-1953.