

Zeitschrift: Eclogae Geologicae Helvetiae
Band: 87 (1994)
Heft: 3: Concepts and controversies in phosphogenesis : proceedings of the symposium and workshop held on 6-10 September 1993

Artikel: Phosphorite geochemistry : state-of-the-art and environmental concerns
Bibliographie: References
Autor: [s.n.]
DOI: <https://doi.org/10.5169/seals-167474>

Nutzungsbedingungen

Die ETH-Bibliothek ist die Anbieterin der digitalisierten Zeitschriften. Sie besitzt keine Urheberrechte an den Zeitschriften und ist nicht verantwortlich für deren Inhalte. Die Rechte liegen in der Regel bei den Herausgebern beziehungsweise den externen Rechteinhabern. [Siehe Rechtliche Hinweise.](#)

Conditions d'utilisation

L'ETH Library est le fournisseur des revues numérisées. Elle ne détient aucun droit d'auteur sur les revues et n'est pas responsable de leur contenu. En règle générale, les droits sont détenus par les éditeurs ou les détenteurs de droits externes. [Voir Informations légales.](#)

Terms of use

The ETH Library is the provider of the digitised journals. It does not own any copyrights to the journals and is not responsible for their content. The rights usually lie with the publishers or the external rights holders. [See Legal notice.](#)

Download PDF: 22.11.2024

ETH-Bibliothek Zürich, E-Periodica, <https://www.e-periodica.ch>

enthusiasm and support during the meeting. Kingston University funded IJ during his attendance at the symposium. WB acknowledges the financial support of the Florida Institute of Phosphate Research (FIPR#90-05-035) for the phosphogypsum studies. The manuscript benefited greatly from critical reviews by Drs Peter Cook (British Geological Survey), Yoshua Kolodny (Hebrew University of Jerusalem), John McArthur (University College London) and Arthur Notholt (Mineral Resources Consultant, Uxbridge). This is a contribution to IGCP Project 325, Palaeogeography of Authigenic Minerals.

REFERENCES

- ABU MURRY, O.S. 1993: Distribution of rare earth elements in Jordanian phosphate. Concepts and Controversies in Phosphogenesis. Int. Symp. and Workshop, Matten, 6-10 September, 1993.
- ALTSCHULER, Z.S. 1973: The weathering of phosphate deposits – geochemical and environmental aspects. In: Environmental Phosphates Handbook (Ed. by GRIFFITH, D., BEETON, A., SPENCER, J.M. & MITCHELL, D.T.). Wiley & Sons, New York, 33–96.
- 1980: The geochemistry of trace elements in marine phosphorites. Part I: Characteristic abundances and enrichment. In: Marine Phosphorites (Ed. by BENTON, Y.K.). Soc. Econ. Paleont. Miner. Spec. Publ. 29, 19–30.
- ALTSCHULER, Z.S., CISNEY, E.A. & BARLOW, I.H. 1952: X-ray evidence of the nature of carbonate apatite. Geol. Soc. Am. Bull. 63, 1230–1231.
- ALTSCHULER, Z.S., CLARKE, R.S. & YOUNG, E.Y. 1958: Geochemistry of uranium in apatite and phosphorite. US Geol. Surv. Prof. Pap. 314-D, 45–90.
- ALTSCHULER, Z.S., BERMAN, S. & CUTTITI, F. 1967: Rare earths in phosphorites – geochemistry and potential recovery. US Geol. Surv. Prof. Paper 575(B), B1–B9.
- ANON 1989: Cadmium in phosphates: one part of a wider environmental problem. Phosphorus Potassium 162, 23–30.
- 1993: Phosphate Rock helps feed the world. Engineer. Min. Jour. 194, 2, 73.
- ATLAS, E.L. 1975: Phosphate equilibria in seawater and interstitial waters. PhD Dissert. Oregon State University, Corvallis.
- ATLAS, E.L. & PYTKOWICZ, R.M. 1977: Solubility behaviour of apatites in seawater. Limnol. Oceanogr. 22, 290–300.
- AVITAL, Y., STARINSKY, A. & KOLODNY, Y. 1983: Uranium geochemistry and fission track mapping of phosphorites, Zefa Field, Israel. Econ. Geol. 78, 121–131.
- BACHRA, B.N., TRAUTZ, O.R. & SIMON, S.L. 1965: The effect of magnesium and fluoride ions on the spontaneous precipitation of calcium carbonates and phosphates. Arch. Oral Biol 10, 731–738.
- BACQUET, G., VO QUANG, T., BONEL, G. & VIGNOLES, M. 1980: Résonance paramagnétique électronique du centre F dans les fluorapatites carbonatées de type B. J. Solid State Chem. 33, 189–195.
- BAECHLE, H.-T. & WOLSTEIN, F. 1984: Cadmium compounds in mineral fertilisers. Proc. Fertil. Soc. London 226, 1–18.
- BAROLE, D.V., RAJAGOPALAN, G. & SOMAYAJULU, B.L.K. 1987: Radiometric ages of phosphorites from the west coast of India. Mar. Geol. 78, 161–165.
- BATURIN, G.N. 1978: Phosphorites on the Ocean Floor (in Russian). Izdat. Nauka, Moscow.
- BATURIN, K.N. & KOCHENOV, A.V. 1974: Uranium content of oceanic phosphorites (in Russian). Litologia I Poleznye Iskopaemye 1, 124–129.
- BATURIN, G.N. & ORESHKIN, V.N. 1984: Behaviour of cadmium in ocean-floor bone phosphate. Geochem. Int. 35, 69–74.
- BATURIN, G.N., KOCHENOV, A.V. & PETELIN, V.P. 1970: Phosphorite formation on the shelf of SW Africa. Lithol. Min. Res. 3, 266–276.
- BATURIN, G.N., MERKULOVA, K.I. & CHALOV, P.I. 1972: Radiometric evidence for recent formation of phosphatic nodules in marine shelf sediments. Mar. Geol. 13, M37–M41.
- 1974: Absolute dating of oceanic phosphorites by disequilibrium uranium. Geochemistry 11, 568–574.
- BECKER, P. 1989: Phosphogypsum: expensive waste or profitable by-product. Phosphates and Phosphoric Acid. Marcel Dekker Inc. 537–569.
- BENMORE, R.A., COLEMAN, M.L. & MCARTHUR, J.M. 1983: Origin of sedimentary francolite from its sulphur and carbon isotope composition. Nature 302, 516–518.
- BENMORE, R.A., MCARTHUR, J.M. & COLEMAN, M.L. 1984: Stable isotopic composition of structural carbonate in sedimentary francolite. Spec. Publ. Geol. Surv. India 17, 35–40.

- BENTOR, Y.K. 1980: Phosphorites – the unsolved problems. In: *Marine Phosphorites* (Ed. by BENTOR, Y.K.). Soc. Econ. Paleont. Mineral. Spec. Publ. 29, 3–18.
- BERNAT, M. 1975: Les isotopes de l'uranium et du thorium et les terres rares dans l'environnement marin. *Cah. ORSTOM Série Géol.* 7, 65–83.
- BERNER, R.A., RUTTENBERG, K.C., INGALL, E.D. & RAO, J.-L. 1993: The nature of phosphorus burial in modern marine sediments. In: *Interactions of C, N, P and S Biogeochemical Cycles and Global Change* (Ed. by WOLLAST, R., MACKENZIE F.T. & CHOU, L.). Springer-Verlag, Berlin, 365–378.
- BERTRAM, C.J. & ELDERFIELD, H. 1993: The geochemical balance of the rare earth elements and neodymium isotopes in the oceans. *Geochim. Cosmochim. Acta* 57, 1957–1986.
- BERTRAND-SARFATI, J., MOUSSINE-POUCHKINE, A., FLICOTEAUX, R. & AIT KACI, A. 1993: Minstromatolites phosphatés liés à la transgression glacio-eustatique d'âge Cambrien Inférieur (Sahara, Algérie). Abstract, 4th. French Congress of Sedimentology, Villeneuve d'Asq, 16–18 November 1993.
- BIRCH, G.F., THOMSON, J., MCARTHUR, J.M. & BURNETT, W.C. 1983: Pleistocene phosphorites off the west coast of South Africa. *Nature* 302, 601–603.
- BLISKOVSKIY, V.Z. 1976: On kurskite and francolite. *Lithol. Miner. Resour.* 11, 332–341.
- BLISKOVSKIY, V.Z., YEFIMOVA, V.A. & ROMANOVA, L.V. 1967: The strontium contents of phosphorites. *Geochem. Internat.* 4, 1186–1190.
- BLISKOVSKIY, V.Z., GRINENKO, V.A., MIGDISOV, L.I. & SAVINA, L.I. 1977: Sulphur isotopic composition of the minerals of phosphorites. *Geochem. Internat.* 14, 148–155.
- BONEL, G., LABARTHE, J.C. & VIGNOLES, C. 1973: Contribution à l'étude structurale des apatites carbonatées de type B. *Compt. Rend. Coll. Internat. Physico-Chimie et la Cristallographie des apatites d'intérêt biologique*, Paris. 230, 117–125.
- BONNOT-COURTOIS, C. & FLICOTEAUX, R. 1989: Distribution of rare-earth and some trace elements in Tertiary phosphorites from the Senegal Basin and their weathering products. *Chem. Geol.* 75, 311–328.
- BORNEMAN-STARINKEVICH, I.D. & BELOV, N.V. 1940: Isomorphic substitution in carbonate-apatite. *Compt. Rend. Dokl. Acad. Sci. USSR XXVI*, 18, 804–806.
- 1953: Carbonate-apatites. *Dokl. Akad. Nauk. SSSR* 90, 89–92.
- BOYLE, E.A. 1981: Cadmium, zinc, copper and barium in foraminiferal tests. *Earth Planet. Sci. Lett.* 53, 11–35.
- BOYLE, E.A., SCLATER, F. & EDMOND, J.M. 1976: On the marine geochemistry of cadmium. *Nature* 263, 42–44.
- BROWN, L.R., CHANDLER, W.C., FLAVIN, C., JACOBSON J., POLLOCK, C., POSTEL S., STARKE, L. & WOLF, E.C. 1987: *State of the World*. New York, W.W. Norton.
- BRULAND, K.W. 1983: Trace elements in seawater. In: *Chemical Oceanography Volume 8* (Ed. by RILEY, J.P. & CHESTER, R.), Academic Press, London, 157–220.
- BURKE, W.H., DENISON, R.E., HETHERINGTON, E.A., KOEPNICK, R.B., NELSON, H.F. & OTTO, J.B. 1982: Variation of $^{87}\text{Sr}/^{86}\text{Sr}$ throughout Phanerozoic time. *Geology* 10, 516–519.
- BURNETT, W.C. 1977: Geochemistry and origin of phosphorite deposits from off Peru and Chile. *Geol. Soc. Amer. Bull.* 88, 813–823.
- BURNETT, W.C. & GOMBERG, G.N. 1977: Uranium oxidation and probable subaerial weathering of phosphatized limestone from the Pourtales Terrace. *Sedimentology* 24, 291–302.
- BURNETT, W.C. & VEEH, H.H. 1977: Uranium-series disequilibrium studies in phosphorite nodules from the West Coast of South America. *Geochim. Cosmochim. Acta* 41, 755–764.
- BURNETT, W.C., VEEH, H.H. & SOUTAR, A. 1980: U-series, oceanographic and sedimentary evidence in support of recent formation of phosphate nodules off Peru. In: *Marine Phosphorites* (Ed. by BENTOR, Y.K.). Soc. Econ. Paleont. Mineral. Spec. Publ. 29, 61–71.
- BURNETT, W.C., BEERS, M.J. & ROE, K.K. 1982: Growth rates of phosphate nodules from the continental margin off Peru. *Science* 215, 1616–1618.
- BURNETT, W.C., ROE, K.K. & PIPER, D.Z. 1983: Upwelling and phosphorite formation in the ocean. In: *Coastal Upwelling – its Sedimentary Record, Part A: Responses of the Sedimentary Regime to Present Coastal Upwelling* (Ed. by SUSS, E. & THIEDE, J.). Plenum, New York, 377–397.
- BURNETT, W.C., COWART, J.B. & CHIN, P.A. 1987: Polonium in the surficial aquifer of west central Florida. *NWWA Conference, Somerset, NJ.* (Ed. by GRAVES, B.). 251–269.
- BURNETT, W.C., BAKER, K.B., CHIN, P.A., MCCABE, W. & DITCHBURN, R. 1988: Uranium-series and AMS ^{14}C studies of modern phosphatic pellets from Peru Shelf muds. In: *The Origin of Marine Phosphorite. The Results of the R.V. Robert D. Conrad Cruise 23-06 to the Peru Shelf* (Ed. by BURNETT, W.C. & FROELICH, P.N.). *Marine Geol.* 80, 215–230.
- BURNETT, W.C., LAROCK, P.A., COWART, J.B. & HULL, C.D. 1992: *Microbiology and Radiochemistry of Phosphogypsum. Year 2 Report to the Florida Institute of Phosphate Research, Bartow, FL.*

- BURNETT, W.C., HULL, C.D., CABLE P., CHERRIER, J., LAROCK, P.A. & HYUN J. 1993: Radionuclides in phosphogypsum: migration and bacterial control. Proc. Fourth Int. Conf. on the Chemistry and Migration Behavior of Actinides, Abstract, Charleston, S.C.
- CAPO, C. & DEPAULO, D.J. 1990: Seawater strontium isotope variation from 2.5 million years to the present. *Science* 249, 51–55.
- CARSON, G.A. & CROWLEY, S.F. 1993: The glauconite-phosphate association in hardgrounds: examples from the Cenomanian of Devon, southwest England. *Cret. Res.* 14, 69–89.
- CATHCART, J.B. 1978: Uranium in phosphate rock. US Geol. Surv. Prof. Pap. 988-A, 1–6.
- 1992: Uranium in phosphate rock with special reference to the Central Florida deposits. US Geol. Surv. Circ. 1069, 32–35.
- CHERRIER, J., LAROCK P.A. & BURNETT, W.C. (in press): Uptake and cellular distribution patterns of polonium by a phosphogypsum bacterial isolate. *Jour. Appl. Environ. Microbiology*.
- CHIEN, S.H. & BLACK, C.A. 1976: Free energy of formation of carbonate apatites in some phosphate rocks. *Soil Sci. Soc. Amer. Proc.* 40, 234–239.
- CLAYPOOL, G.E., HOLZER, W.T., KAPLAN, I.R., SAKAI, H. & ZAK, I. 1980: The age curve of sulphur and oxygen isotopes in marine sulphates and their mutual interpretation. *Chem. Geol.* 28, 199–260.
- COLLEY, S & THOMSON, J. 1985: Recurrent uranium relocations in distal turbidites emplaced in pelagic conditions. *Geochim. Cosmochim. Acta* 49, 2339–2348.
- COMPTON, J.S., SNYDER, S.W. & HODELL, D.A. 1990: Phosphogenesis and weathering of shelf sediments from the south-eastern United States: Implications for Miocene $\delta^{13}\text{C}$ excursions and global cooling. *Geology* 18, 1227–1230.
- COMPTON, J.S., HODELL, D.A., GARRIDO, J.R. & MALLINSON, D.J. 1993: Origin and age of phosphorite from the south-central Florida Platform: Relation of phosphogenesis to sea-level fluctuations and $\delta^{13}\text{C}$ excursions. *Geochim. Cosmochim. Acta* 57, 131–146.
- COOK, P.J. 1972: Petrology and geochemistry of the phosphate deposits of Northwest Queensland, Australia. *Econ. Geol.* 67, 1193–1213.
- 1984: Spatial and temporal controls on the formation of phosphorite deposits – a review. In: *Phosphate Minerals* (Ed. By NRIAGU, J.O. & MOORE, P.B.). Springer, Heidelberg, 242–274.
- COOK, P.J. & McELHINNY, M.W. 1979: A reevaluation of the spatial and temporal distribution of phosphate deposits in the light of plate tectonics. *Econ. Geol.* 74, 315–330.
- COOK, P.J., SHERGOLD, J.H., BURNETT, W.C. & RIGGS, S.R., 1990: Phosphorite research: a historical overview. In: *Phosphorite Research and Development* (Ed. by NOTHOLT A.J.G. & JARVIS, I.). *Geol. Soc. Spec. Publ.* 52, 1–22.
- COSSA, 1878: Sur la diffusion de cerium, du lanthane et du didyme, extract of a letter from Cossa to Sella, presented by Frény. *Compt. Rend. Acad. Sci. Paris* 87, 378–388.
- CULLEN, D.J. & BURNETT, W.C. 1986: Phosphorite associations on seamounts in the tropical south-west Pacific. *Mar. Geol.* 71, 215–236.
- DAR'IN, A.V. & ZANIN, YU. N. 1990: Rare-earth elements in a series of supergene transformations of phosphorites (in Russian). *Geologiya i Geofizika* 31, 89–97.
- DA ROCHA ARAUJO, P.R., FLICOTEAUX, R., PARRON, C. & TROMPETTE, R., 1992: Phosphorites of Rocinha Mine – Patos de Minas (Minas Gerais, Brazil): Genesis and evolution of a Middle Proterozoic deposit tectonized by the Brasiliano Orogeny. *Econ. Geol.* 87, 332–351.
- DENISON, R.E., KOEPNICK, R.B., FLETCHER, A., HOWELL, M.W. & CALLAWAY, W.S. 1994a: Criteria for the retention of original seawater $^{87}\text{Sr}/^{86}\text{Sr}$ in ancient shelf limestones. *Chem. Geol.* 112, 131–143.
- DENISON, R.E., KOEPNICK, R.B., BURKE, W.H., HETHERINGTON, E.A. & FLETCHER, A. 1994b: Construction of the Mississippian, Pennsylvanian and Permian seawater $^{87}\text{Sr}/^{86}\text{Sr}$ curve. *Chem. Geol.* 112, 145–167.
- DEPAULO, D.J. & INGRAM, B. 1985: High-resolution stratigraphy with strontium isotopes. *Science* 227, 938–941.
- DEPAULO, D.J. & WASSERBURG, G.J. 1976: Nd isotopic variations and petrogenetic models. *Geophys. Res. Lett.* 3, 249–252.
- ELDERFIELD, H. 1986: Strontium isotope stratigraphy. *Palaeogeog. Palaeoclimatol. Palaeoecol.* 57, 71–90.
- ELDERFIELD, H. & GREAVES, M.J. 1982: The rare earth elements in seawater. *Nature* 296, 214–219.
- ELDERFIELD, H. & PAGETT, R. 1986: REE in ichthyoliths: variations with redox conditions and depositional environment. *Sci. Total Environ.* 49, 175–197.
- ELDERFIELD, H. & SHOLKOVITZ, E.R. 1987: Rare earth elements in the pore waters of reducing nearshore sediments. *Earth Planet. Sci. Lett.* 82, 280–288.
- EL-KAMMAR, A.M., ZAYED, M.A. & AMER, S.A. 1979: Rare earths of the Nile Valley phosphorites, Upper Egypt. *Chem. Geol.* 24, 69–81.

- EMERY, D. & ROBINSON, A. 1993: Inorganic Geochemistry: Applications to Petroleum Geology. Blackwell, Oxford.
- EPSTEIN, S., BUCHSBAUM, R., LOWENSTAM, H.A. & UREY, H.C. 1953: Revised carbonate-water temperature scale. *Geol. Soc. Amer. Bull.* 62, 417–426.
- FLICOTEAUX, R., 1982: Genèse des phosphates alumineux de Sénégal occidental étapes et guides de l'altération. *Sci. Géol. Mém.* 67.
- FLICOTEAUX, R. & LUCAS, J., 1984: Weathering of phosphate minerals. In: *Phosphate Minerals* (Ed. by NRIAGU, J.O. & MOORE, P.B.). Springer-Verlag, Berlin, 292–317.
- FLICOTEAUX, R., WALTER A.-V., BONNOT-COURTOIS, C. & TOLEDO-GROKE, M.-C., 1990: Transformation and precipitation of phosphates during weathering: characterization by REE distributions. *Geochemistry of the Earth's Surface and of Mineral Formation*, 2nd Int. Symp, Aix-en-Provence, 365–367.
- FLICOTEAUX, R., PANNATIER, Y. & BONNOT-COURTOIS, C. 1993: Palaeoceanographic conditions of phosphate precipitation in the western part of the Palaeogene Senegal Basin. *Contribution of geochemical data. Concepts and Controversies in Phosphogenesis*. Int. Symp. and Workshop, Matten, 6–10 September, 1993.
- FROELICH, P.N., KLINKHAMMER, G.P., BENDER, M.L., LUETKE, N.A., HEATH, G.R., CULLEN, D., DAUPHIN, P., HAMMOND, D., HARTMAN, B. & MYNARD, V. 1979: Early oxidation of organic matter in pelagic sediments of the eastern equatorial Atlantic: suboxic diagenesis. *Geochim. Cosmochim. Acta* 43, 1075–1090.
- FROELICH, P.N., KIM, K.H., JAHNKE, R., BURNETT, W.C., SOUTAR, A. & DEAKIN, M. 1983: Pore water fluoride in Peru continental margin sediments: Uptake from seawater. *Geochim. Cosmochim. Acta* 47, 1605–1612.
- FROELICH, P.N., ARTHUR, M., BURNETT, W.C., DEAKIN, M., HENSLEY, V., JAHNKE, R., KAUL, L. KIM, K., ROE, K., SOUTAR, A. & VATAKANON, C. 1988: Early diagenesis of organic matter in Peru continental margin sediments: Phosphate precipitation. In: *The Origin of Marine Phosphorite. The Results of the R.V. Robert D. Conrad Cruise 23–06 to the Peru Shelf* (Ed. by BURNETT, W.C. & FROELICH, P.N.). *Marine Geol.* 80, 309–343.
- GAVSHIN, V.M., BOBROV, V.A. & ZORKINA, L.S. 1974: Quantitative relations between uranium and phosphorus in phosphorites and phosphatic sedimentary rocks. *Lithol. Miner. Res.* 9, 740–746.
- GAUTHIER, M.J., CLEMENT, R.L., FLATAU, G.N. & AMIARD, J.C. 1986: Accumulation du cadmium par les bactéries marines à Gram négatif selon leur sensibilité au métal et leur type respiratoire. *Oceanol. Acta* 9, 333–337.
- GILINSKAYA, L.G. 1991: A new type of PO_4^{3-} centre in apatite. *J. Struct. Chem.* 31, 892–898.
- 1993: Stable paramagnetic $\text{Pb}^{3+} (^2S_{1/2})$ centers in natural $\text{Ca}_5(\text{PO}_4)_3(\text{F}, \text{Cl}, \text{OH})$ apatites. *Phys. Solid State* 35, 35–37.
- GILINSKAYA, L.G. & ZANIN, YU. N. 1983: EPR investigation of the isomorphic impurity in the form VO^{2+} in apatite from phosphorite (in Russian). *Dokl. Akad. Nauk. SSSR* 273, 1463–1467.
- GILINSKAYA, L.G., ZANIN, YU. N., KNUBOVETS, R.G., KORNEVA, T.A. & FADEEVA, V.P. 1993: Organophosphorus radicals in natural apatites ($\text{Ca}_5(\text{PO}_4)_3(\text{F}, \text{OH})$). *J. Struct. Chem.* 33, 859–870
- GIRARD, J.-P., FLICOTEAUX, R., WALTER, A.-V., SAVIN, S.M. & NAHON, D. 1993: Oxygen and carbon stable isotope composition of structural carbonate in weathering apatites from laterites, southern Brazil and western Senegal. *Appl. Geochem.* 8, 617–632.
- GLENN, C.R. 1990a: Pore water, petrologic and stable carbon isotopic data bearing on the origin of Modern Peru margin phosphorites and associated authigenic phases. In: *Phosphate Deposits of the World Volume 3: Neogene to Recent Phosphorites*. (Ed. by BURNETT, W.C. & RIGGS, S.R.). Cambridge University Press, Cambridge, 46–61.
- 1990b: Depositional sequences of the Duwi, Sibâiya and Phosphate Formations, Egypt: phosphogenesis and glauconitization in a Late Cretaceous epeiric sea. In: *Phosphorite Research and Development* (Ed. by NOTHOLT A.J.G. & JARVIS, I.). *Geol. Soc. Spec. Publ.* 52, 205–222.
- GLENN, C.R. & ARTHUR, M.A. 1988: Petrology and major element geochemistry of Peru margin phosphorites and associated diagenetic minerals: authigenesis in modern organic-rich sediments. In: *The Origin of Marine Phosphorite. The Results of the R.V. Robert D. Conrad Cruise 23-06 to the Peru Shelf* (Ed. by BURNETT, W.C. & FROELICH, P.N.). *Marine Geol.* 80, 231–267.
- GLENN, C.R., ARTHUR, M.A., YEH, H.W. & BURNETT, W.C. 1988: Carbon isotopic composition and lattice-bound carbonate of Peru-Chile margin phosphorites. In: *The Origin of Marine Phosphorite. The Results of the R.V. Robert D. Conrad Cruise 23-06 to the Peru Shelf* (Ed. by BURNETT, W.C. & FROELICH, P.N.). *Marine Geol.* 80, 287–307.
- GLENN, C.R., ARTHUR, M.A., RESIG, M.J., BURNETT, W.C., DEAN, W.E. & JAHNKE, R.A. 1994a: Are modern and ancient phosphorites really so different? In: *Siliceous, Phosphatic and Glauconitic Sediments of the Tertiary and Mesozoic* (Ed. by IJIMA, A., ABED, A.M. & GARRISON, R.E.). *Proc. 29th Int. Geol. Congr., Part C, VSP, Utrecht*, 159–188.

- GLENN, C.R., FÖLLMI, K.B., RIGGS, S.R., BATURIN, G.N., GRIMM, K.A., TRAPPE, J., ABED, A.M., GALLI-OLIVIER, C., GARRISON, R.E., ILYIN, A., JEHL, C., ROHRICH, V., SADAQAH, R.M., SCHIDLOWSKI, M., SHELDON, R.E. & SIEGMUND, H. 1994b: Phosphorus and phosphorites: Sedimentology and environments of formation. *Eclogae geol. Helv.* 87, 747–788.
- GOLDBERG, E.D., KOIDE, M., SCHMITT, R.A. & SMITH, H.V. 1963: Rare earth distribution in the marine environment. *J. Geophys. Res.* 68, 4209–4217.
- GONY, J.N. 1971: Étude cristallographique du phosphate uranifère de Bakouma (République centrafricaine). Commissariat à l'Énergie Atomique, CEN Saclay, Report CEA-R-400E.
- GRAHAM, D.W., BENDER, M.L., WILLIAMS, D.F. & KEIGWIN JR., L.D. 1982: Strontium-calcium ratios in Cenozoic planktonic foraminifera. *Geochim. Cosmochim. Acta* 46, 1281–1292.
- GRANDJEAN, P. & ALBARÈDE, F. 1989: Ion probe measurement of rare earth element in biogenic phosphates. *Geochim. Cosmochim. Acta* 53, 3179–3183.
- GRANDJEAN, P., CAPPETA, H., MICHARD, A. & ALBARÈDE, F. 1987: The assessment of REE patterns and $^{143}\text{Nd}/^{144}\text{Nd}$ ratios in fish remains. *Earth Planet. Sci. Lett.* 84, 181–196.
- GRANDJEAN, P., CAPPETA, H. & ALBARÈDE, F. 1988: The REE and ϵNd of 40–70 Ma old fish debris from the West-African platform. *Geophys. Res. Lett.* 15, 389–392.
- GRANDJEAN-LÉCUYER P., FEIST, R. & ALBARÈDE, F. 1993: Rare earth elements in old biogenic apatites. *Geochim. Cosmochim. Acta* 57, 2507–2514.
- GRUNER, J.W. & MCCONNELL, D. 1937: The problem of carbonate-apatites. The structure of francolite. *Z. Krist. Abt. A* 97, 208–215.
- GULBRANDSEN, R.A. 1966: Chemical composition of the phosphorites of the Phosphoria Formation. *Geochim. Cosmochim. Acta* 30, 769–778.
- 1970: Relation of carbon dioxide content of apatite of the Phosphoria Formation to regional facies. *US Geol. Surv. Prof. Pap.* 700-B, 9–13.
- 1975: Analytical data on the Phosphoria Formation, Western United States. *US Geol. Surv. Open-File Rep.* 75–554.
- GULBRANDSEN, R.A., KRAMER, J.R., BESTY, L.B. & MAYS, R.E. 1966: Carbonate-bearing apatite from Faraday Township, Ontario, Canada. *Amer. Mineral.* 51, 819–824.
- GULBRANDSEN, R.A., ROBERSON, C.E. & NEIL, S.T. 1984: Time and the crystallisation of apatite in seawater. *Geochim. Cosmochim. Acta* 48, 213–218.
- GUSEV, G.M., ZANIN, YU.N., KRIVOPUTSKAYA, L.M., LEMINA, N.M. & IUSUPOV, T.S. 1976: Transformation of apatite composition under conditions of weathering and leaching. *Dokl. Acad. Nauk. SSSR* 229, 971–973.
- HARADA, K., BURNETT, W.C., LAROCK, P.A. & COWART, J.B. 1989: Polonium in Florida groundwater and its relationship to the sulfur cycle and bacteria. *Geochim. Cosmochim. Acta* 53, 143–150.
- HEGGIE, D.T., SKYRING, G.W., O'BRIEN, G.W., REIMERS, C., HERCZEG, A., MORIARTY, D.J.W., BURNETT, W.C. & MILNES, A.R. 1990: Organic carbon cycling and modern phosphorite formation on the East Australian continental margin: an overview. In: *Phosphorite Research and Development* (Ed. by NOTHOLT, A.J.G. & JARVIS, I.). *Geol. Soc. Spec. Publ.* 52, 87–117.
- HEIN, J.R., YEH, H.-W., GUNN, S.H., SLITER, W.V., BENNINGER, L.M. & WANG, C.-H. 1993: Two major Cenozoic episodes of phosphogenesis recorded in Equatorial Pacific seamount deposits. *Paleoceanogr.* 8, 293–311.
- HENDERSON, G.M., COHEN, A.S. & O'NIONS, R.K. 1993: $^{234}\text{U}/^{238}\text{U}$ ratios and ^{230}Th ages for Hateruma Atoll corals: implications for coral diagenesis and seawater $^{234}\text{U}/^{238}\text{U}$ ratios. *Earth Planet. Sci. Lett.* 15, 65–73.
- HESS, J., BENDER, M.L. & SCHILLING, J.-G. 1986: Evolution of the ratio of strontium-87 to strontium-86 in seawater from Cretaceous to Present. *Science* 231, 979–984.
- HODELL, D.A., MUELLER, P.A. & GARRIDO, J.R. 1991: Variations in the strontium isotopic composition of seawater during the Neogene. *Geology* 19, 24–27.
- HOWARD, P.F. & HOUGH, M.J. 1979: On the geochemistry and origin of the D-Tree, Wonarah and Sherrin Creek phosphorite deposits of the Georgina Basin, Northern Australia. *Econ. Geol.* 74, 260–284.
- HOYLE, J., ELDERFIELD, H., GLEDHILL, A. & GREAVES, M. 1984: The behaviour of rare earth elements during mixing of river and seawaters. *Geochim. Cosmochim. Acta* 48, 143–149.
- HUDSON, J.D. 1977: Stable isotopes and limestone lithification. *J. Geol. Soc.* 133, 637–660.
- ILYIN, A.V. & RATNIKOVA, G.I. 1976: Rare-earth element distribution in the Hobso Gol phosphorites (Mongolia). *Geochem. Int.* 13, 53–56.
- ILYIN, A.V., ZAITSEV, N.S. & BJAMBA, Z. 1986: Proterozoic and Cambrian phosphorites deposits: Khubsugul, Mongolian People's Republic. In: *Phosphate Deposits of the World Vol. 1, Proterozoic and Cambrian Phosphorites* (Ed. by COOK, P.J. & SHERGOLD, J.H.). 162–174.

- INGRAM, B.L., COCCIONI, R., MONTANARI, A. & RICHTER, F.M. 1994: Strontium isotopic composition of mid-Cretaceous seawater. *Science* 264, 546–550.
- IRWIN, H., CURTIS, C. & COLEMAN, M. 1977: Isotopic evidence for source of diagenetic carbonates formed during burial of organic rich sediments. *Nature* 269, 209–213.
- ISHERWOOD, K. F. 1992: Phosphate Industry and the Environment. In: *Phosphate Fertilizers and the Environment* (Ed. by SCHULTZ, J. J.). Tampa FL, 115–124.
- JACOB, K.D., HILL, W.L., MARSHALL, M.R. & REYNOLDS, D.S. 1933: The composition and distribution of phosphate rock with special reference to the United States. US Dept. Agric. Techn. Bull. 364.
- JACOBSEN, S.B. & WASSERBURG, G.J. 1980: Sm-Nd isotopic evolution of chondrites. *Earth Planet. Sci. Lett.* 50, 139–155.
- JAHNKE, R.A. 1984: The synthesis and solubility of carbonate fluorapatite. *Am. J. Sci.* 284, 58–78.
- JAHNKE, R.A., EMERSON, S.R., ROE, K.K. & BURNETT, W.C. 1983: The present day formation of apatite in Mexican continental margin sediments. *Geochim. Cosmochim. Acta* 47, 259–266.
- JALLAD, I.S., ABU MURREY, O.S. & SADAQAH, R.M. 1989: Upper Cretaceous phosphorites of Jordan. In: *Phosphate Deposits of the World Volume 2: Phosphate Rock Resources* (Ed. by NOTHOLT, A.J.G., SHELDON, R.P. & DAVIDSON, D.F.). Cambridge University Press, Cambridge, 344–351.
- JARVIS, I. 1984: Rare-earth element geochemistry of late Cretaceous chalks and phosphorites from northern France. *Spec. Publ. Geol. Surv. India* 17, 179–190.
- 1992: Sedimentology, geochemistry and origin of phosphatic chalks, the Upper Cretaceous deposits of NW Europe. *Sedimentology* 39, 55–97.
- JARVIS, I. & JARVIS, K.E. 1991: Geochemical variation in phosphorite nodules: a study using laser ablation inductively coupled plasma-mass spectrometry. In: *First Gentner Symposium on Geoscience. Phosphorites and Black Shales*. Jerusalem, September 1991, Program with Abstracts, 22.
- JEANDEL, C. 1993: Concentration and isotopic composition of Nd in the South Atlantic Ocean. *Earth Planet. Sci. Lett.* 117, 581–591.
- JEANMAIRE, J.-P. 1985: Répartition de l'uranium dans les niveaux phosphatés Maestrichtien supérieur – Éocène inférieur du secteur de Benguerir (Bassin des Ganntour, Maroc occidental). *Sci. Géol. Mém.* 77, 53–68.
- JOHNSON, A.K.C. 1987: Le bassin côtier à phosphates du Togo (Maestrichtien-Eocène moyen). Thèse Univ. Dijon.
- JOHNSTON, A.E. & JONES, K.C. 1992: The cadmium issue – long-term changes in the cadmium content of soils and the crops grown on them. In: *Phosphate Fertilizers and the Environment, Proc. Int. Workshop, IFDC, March 1992 Tampa, Florida*, 255–269.
- JONES, E.J.W. 1989: Radioactivity of the ocean floor and marine phosphorite deposits: observations with a new deep-towed scintillometer. *Geophys. Res. Lett.* 16, 123–126.
- KAPLAN, I.R. 1983: Stable isotopes of sulphur, nitrogen and deuterium in Recent marine environments. In: *Stable Isotopes in Sedimentary Geology, SEPM Short Course 10*, 2.1–2.108.
- KARHU, J. & EPSTEIN, S. 1986: The implication of the oxygen isotope records in coexisting cherts and phosphates. *Geochim. Cosmochim. Acta* 50, 1745–1757.
- KASTNER, M., GARRISON, R.E., KOLODNY, Y., REIMERS, C.E. & SHEMAH, A. 1990: Coupled changes of oxygen isotopes in PO_4^{3-} and CO_3^{2-} in apatite, with emphasis on the Monterey Formation, California. In: *Phosphate Deposits of the World Volume 3: Neogene to Modern Phosphorites* (Ed. by BURNETT, W.C. & RIGGS, S.R.). Cambridge University Press, Cambridge, 312–324.
- KAUFMAN, A.J., JACOBSEN, S.B. & KNOLL, A.H. 1993: The Vendian record of Sr and C isotopic variations in seawater: implications for tectonics and paleoclimate. *Earth Planet. Sci. Lett.* 120, 409–430.
- KAZAKOV, A.V. 1937: The phosphorite facies and the genesis of phosphorites. In: *Geological Investigations of Agricultural Ores. Trans. Sci. Inst. Fertil. Insecto-Fungicides* 142, 93–113.
- KETO, L.S. & JACOBSEN, S.B. 1987: Nd and Sr isotopic variations in Early Paleozoic oceans. *Earth Planet. Sci. Lett.* 84, 27–41.
- 1988: Nd isotopic variations of Phanerozoic paleoceans. *Earth Planet. Sci. Lett.* 90, 395–410.
- KIM, K.H. & BURNETT, W.C. 1986: Uranium-series growth history of a Quaternary phosphatic crust from the Peruvian continental margin. *Chem. Geol.* 58, 227–244.
- KOEPNICK, R.B., BURKE, W.H., DENISON, R.E., HETHERINGTON, E.A., NELSON, H.F., OTTO, J.B. & WAITE, L.E. 1985: Construction of the seawater $^{87}\text{Sr}/^{86}\text{Sr}$ wave for the Cenozoic and Cretaceous: supporting data. *Chem. Geol. (Iso. Geosci. Sect.)* 58, 55–81.
- KOLODNY, Y. 1969: Are marine phosphorites forming today? *Nature* 244, 1017–1019.
- 1981: Phosphorites In: *The Sea Volume 7* (Ed. by EMILIANI, C.). Wiley Interscience, New York, 981–1023.

- KOLODNY, Y. & KAPLAN, I.R. 1970a: Uranium isotopes in sea floor phosphorites. *Geochim. Cosmochim. Acta* 34, 3–24.
- 1970b: Carbon and oxygen isotopes in apatite CO₂ and co-existing calcite from sedimentary phosphorite. *J. Sediment. Petrol.* 40, 954–959.
- KOLODNY, Y. & LUZ, B. 1992a: Isotope signatures in phosphate deposits; Formation and diagenetic history. In: *Isotopic Signatures and Sedimentary Records, Lecture Notes in Earth Sciences No. 43* (Ed. by CLAUER, N. & CHAUDHURI, S.). Springer-Verlag, Berlin, Heidelberg, 69–121.
- 1992b: Oxygen isotopes in phosphates of fossil fish – Devonian to Recent. In: *Stable Isotope Geochemistry: A Tribute to Samuel Epstein* (Ed. by TAYLOR, H.P., O-NEIL, J.R. & KAPLAN, I.R.). *Geochem. Soc. Spec. Publ.* 3, 105–119.
- KOLODNY, Y. & RAAB, M. 1988: Oxygen isotopes in phosphatic fish remains from Israel: Paleothermometry of tropical Cretaceous and Tertiary shelf waters. *Palaeogeog. Palaeoclimatol. Palaeoecol.* 64, 59–67.
- KOLODNY, Y., LUZ, B. & NAVON, O. 1983: Oxygen isotope variations in phosphate of biogenic apatite. I: Fish bone apatite – rechecking the rules of the game. *Earth Planet. Sci. Lett.* 64, 398–404.
- KOULOHERIS, A. P. 1980: Chemical nature of phosphogypsum as produced by various wet process phosphoric acid processes. *Proc. Int. Symp. Phosphogypsum*. (Ed. by BORRIS, D. P. & BODY, P. W.). Florida Institute of Phosphate Research 8–35.
- KRAJEWSKI, K.P., VAN CAPPELLEN, P., TRICHET, J., KUHN O., LUCAS, J., MARTIN-ALGARRA, A., PRÉVÔT, L., TEWARI, V.C., GASPAR, L., KNIGHT, R.I. & LAMBOY, M. 1994: Biological processes and apatite formation in sedimentary environments. *Eclogae geol. Helv.* 87, 701–745.
- KRESS, A.G. & VEEH, H.H. 1980: Geochemistry and radiometric ages of phosphatic nodules from the continental margin of northern New South Wales, Australia. *Mar. Geol.* 36, 143–157.
- LEHR, J.R., MCCLELLAN, G.H., SMITH, J.P. & FRAZIER, A.W. 1968: Characterisation of apatites in commercial phosphate rock. *Coll. int. Phosphates Minéraux Solides, Toulouse 1967 2, Soc. Chim. Fr., Paris* 29–44.
- LINDEKEN C.L. 1980: Radiological considerations of phosphogypsum utilization in agriculture. *Proc. Second Int. Symp. on Phosphogypsum*. (Ed. by BORRIS, D.P. & BODY, P.W.). Florida Institute of Phosphate Research, 459–80.
- LINDEKEN, C.L. & COLES, D.G. 1978: The radium-226 content of agricultural gypsums. *Radioactivity in Consumer Products*. (Ed. by MOGHISSI, A., PARAS, P., CARTER, M. & BARKER, R.). 369–75.
- LONGINELLI, A. & NUTI, S. 1968: Oxygen isotopic composition of phosphorites from marine formations. *Earth Planet. Sci. Lett.* 5, 13–16.
- 1973a: Revised phosphate-water isotopic temperature scale. *Earth Planet. Sci. Lett.* 19, 373–376.
- 1973b: Oxygen isotope measurements of phosphate from fish teeth and bones. *Earth Planet. Sci. Lett.* 20, 337–340.
- LUCAS, J. & ABBAS, M. 1989: Uranium in natural phosphorites: the Syrian example. *Sci. Géol. Bull.* 42, 223–236.
- LUCAS, J. & PRÉVÔT, L. 1981: Synthèse d'apatite à partir de matière organique phosphate (ARN) et de calcite par voie bactérienne. *Compt. Rend. Acad. Sci. Paris* 292, 1203–1208
- 1984: Synthèse d'apatite par voie bactérienne à partir de matière organique phosphatée et de divers-carbonates de calcium dans des eaux douce et marine naturelles. *Chem. Geol.* 42, 101–118.
- 1985: The synthesis of apatite by bacterial activity: mechanism. In: *Phosphorites* (Ed. by LUCAS, J. & PRÉVÔT, L.). *Sci. Géol. Mém.* 77, 83–92.
- LUCAS, J., PRÉVÔT, J. & LAMBOY, M. 1978: Les phosphorites de la marge norde de l'Espagne. *Chimie, minéralogie, genèse. Oceanol. Acta* 1, 55–72.
- LUCAS, J., FLICOTEAUX, R., NATHAN, Y., PRÉVÔT, L. & SHAHAR, Y. 1980: Different aspects of phosphorite weathering. In: *Marine Phosphorites – Geochemistry, Occurrence, Genesis*. (Ed. by BENTON, Y.K.). *Soc. Econ. Paleontol. Mineral.* 29, 41–51.
- LUCAS, J., ILYIN, A.V. & KUHN, A. 1986: Proterozoic and Cambrian phosphorites deposits: Volta basin, West Africa. In: *Phosphate Deposits of the World Vol. 1, Proterozoic and Cambrian Phosphorites* (Ed. by COOK, P.J. & SHERGOLD, J.H.). 235–243.
- LUCAS, J., EL FALEH, E. M. & PRÉVÔT, L. 1990: Experimental study of the substitution of Ca by Sr and Ba in synthetic apatites. In: *Phosphorite Research and Development* (Ed. by NOTHOLT, A.J.G. & JARVIS, I.). *Geol. Soc. Spec. Publ.* 52, 33–47.
- MALONE, P.H.G. & TOWE, K.M. 1970: Microbial carbonate and phosphate precipitates from seawater cultures. *Mar. Geol.* 9, 301–309.
- MANHEIM, F.T., ROWE, G.T. & JIPPA, D. 1975: Marine phosphorite formation off Peru. *J. Sed. Petrol.* 45, 243–251.
- MARSHALL, J.F. & COOK, P.J. 1980: Petrology of iron- and phosphorus-rich nodules from the Eastern Australian continental shelf. *J. Geol. Soc.* 137, 765–771.

- MARTENS, C.S. & HARRIS, R.C. 1970: Inhibition of apatite precipitation in the marine environment by magnesium ions. *Geochim. Cosmochim. Acta* 34, 621–625.
- MARTIN, J.H. & KNAUER, G.A. 1973: The elemental composition of plankton. *Geochim. Cosmochim. Acta* 37, 1639–1653.
- MARTIN-ALGARRA, A., SANCHEZ-NAVAS, A. & VERA, J.A. 1993: Phosphate stromatolites in the pelagic Mesozoic record of the Betic Cordillera (southern Spain). *Concepts and Controversies in Phosphogenesis. Int. Symp. and Workshop, Matten, 6–10 September, 1993.*
- MATTHEWS, A. & NATHAN, Y. 1977: The decarbonation of carbonate fluorapatite (francolite). *Amer. Mineral.* 62, 565–573.
- MAY, A. & SWEENEY, J. W. 1982: Assessment of environmental impacts associated with phosphogypsum in Florida. US Bureau of Mines Report 8639, 1–19.
- MCARTHUR, J.M. 1978a: Systematic variations in the contents of Na, Sr, CO₂ and SO₄ in marine carbonate fluorapatite and their relation to weathering. *Chem. Geol.* 21, 41–52.
- 1978b: Element partitioning in ferruginous and pyritic phosphorite from the continental margin off Morocco. *Mineral. Mag.* 42, 221–228.
- 1980: Post-depositional alteration of the carbonate-fluorapatite phase of Moroccan Phosphates. In: *Marine Phosphorites – Geochemistry, Occurrence, Genesis.* (Ed. by BENTOR, Y.K.). *Soc. Econ. Paleontol. Mineral.* 29, 53–60.
- 1985: Francolite geochemistry – compositional controls during formation, diagenesis, metamorphism and weathering. *Geochim. Cosmochim. Acta* 49, 23–35.
- 1990: Fluorine-deficient apatite. *Min. Mag.* 54, 508–510.
- 1994: Recent trends in strontium isotope stratigraphy. *Terra Nova* 6, 331–358.
- MCARTHUR, J.M. & HERCZEG, A. 1990: Diagenetic stability of the isotopic composition of phosphate oxygen: paleoenvironmental implications. In: *Phosphorite Research and Development* (Ed. by NOTHOLT, A.J.G. & JARVIS, I.). *Geol. Soc. Spec. Publ.* 52, 119–124.
- MCARTHUR, J.M. & WALSH, J.N. 1984: Rare-earth geochemistry of phosphorites. *Chem. Geol.* 47, 191–220.
- MCARTHUR, J.M., COLEMAN, M.L. & BREMNER, J.M. 1980: Carbon and oxygen isotopic composition of structural carbonate in sedimentary francolite. *J. Geol. Soc.* 137, 669–673.
- MCARTHUR, J.M., BENMORE, R.A., COLEMAN, M.L., SOLDI, C., YEH, H.-W. & O'BRIEN, G.W. 1986: Stable isotope characterisation of francolite formation. *Earth Planet. Sci. Lett.* 77, 20–34.
- MCARTHUR, J.M., HAMILTON, P.J., GREENSMITH, J.T., BOYCE, A.J., FALICK, A.E., BIRCH, G., WALSH, J.N., BENMORE, R.A. & COLEMAN, M.L. 1987: Phosphorite geochemistry: isotopic evidence for meteoric alteration of francolite on a local scale. *Chem. Geol. (Isotope Geosci. Sect.)* 65, 415–425.
- MCARTHUR, J.M., THOMSON, J., JARVIS, I., FALICK, A.E. & BIRCH, G.F. 1988: Eocene to Pleistocene phosphogenesis off western South Africa. *Mar. Geol.* 85, 41–63.
- MCARTHUR, J.M., SAHAMI, A.R., THIRLWALL, M., HAMILTON, P.J. & OSBORN, A.O. 1990: Dating phosphogenesis with strontium isotopes. *Geochim. Cosmochim. Acta* 54, 1343–1351.
- MCARTHUR, J.M., THIRLWALL, M.F., CHEN, M., GALE, A.S. & KENNEDY, W.J. 1993a: Strontium isotope stratigraphy in the Late Cretaceous: numerical calibration of the Sr isotope curve and intercontinental correlation for the Campanian. *Paleoceanography* 8, 859–873.
- MCARTHUR, J.M., THIRLWALL, M.F., GALE, A.S., KENNEDY, W.J., BURNETT, J.A., MATTEY, D. & LORD, A.R. 1993b: Strontium isotope stratigraphy for the Late Cretaceous: a new curve based on the English Chalk. In: *High Resolution Stratigraphy* (Ed. by HAILWOOD, E.A. & KIDD, R.B.). *Geol. Soc. Spec. Publ.* 70, 195–209.
- MCCONNELL, D. 1973: *Apatite – Its Crystal Chemistry, Mineralogy, Utilization, and Geologic and Biologic Occurrences.* Springer Verlag, Vienna–Heidelberg–New York.
- MCCLELLAN, G.H. 1980: Mineralogy of carbonate fluorapatites. *J. Geol. Soc. London* 137, 675–681.
- MCCLELLAN, G.H. & LEHR, J.R. 1969: Crystal chemical investigations of natural apatites. *Amer. Mineral.* 54, 1374–1391.
- MCCLELLAN, G.H. & SAAVEDRA, F.N. 1986: Chemical and mineral characteristics of some Cambrian and Precambrian phosphorites. In: *Phosphorite Deposits of the World Volume 1, Precambrian and Cambrian Phosphorites* (Ed. by COOK, P.J. & SHERGOLD, J.H.). Cambridge University Press, Cambridge 244–267.
- MCCLELLAN, G.H. & VAN KAUWENBERGH, S.J. 1990: Mineralogy of sedimentary apatites. In: *Phosphorite Research and Development* (Ed. by NOTHOLT A.J.G. & JARVIS, I.). *Geol. Soc. Spec. Publ.* 52, 23–31.
- McFARLIN, R. F. 1992: Current and anticipated research priorities for the utilization and management of phosphate process by-products and wastes. *Phosphate Fertilizers and the Environment* (Ed. by SCHULTZ, J. J.). Tampa, FL., 179–184.

- MCKELVEY, V.E. 1950: Rare earths in western phosphate rocks. US Geol. Surv. Trace Element Mem. Rept 194.
- 1956: Uranium in phosphate rock. US Geol. Surv. Prof. Pap. 300, 477–481.
- 1967: Phosphate deposits. US Geol. Surv. Bull. 1252-D, 1–21.
- MCKELVEY, V.E., SWANSON, R.W. & SHELDON, R.P. 1953: The Permian phosphorite deposits of the Western United States. In: *Compt. Rend. Congr. Geol. Int. 19th Algiers 1952*, 21, 45–64.
- MCKELVEY, V.E., STROBELL, J.D. JR. & SLAUGHTER, A.I. 1986: The vanadiferous zone of the Phosphoria Formation in western Wyoming and southeastern Idaho. US Geol. Surv. Prof. Pap. 1465.
- MCMURTRY, G.M., VON DER HAAR, D.L., YEH, H.-W., MAHONEY, J.J. & EISENHAUER, A. 1994: Cenozoic accumulation history of a Pacific ferromanganese crust. *Earth Planet. Sci. Lett.* 125, 105–118.
- MENOR, E. 1975: *Pétrographie, minéralogie et géochimie des gisements de phosphates de Taïba (Sénégal) et d'Olinda (Brésil)*. Thèse Doct. Ing. Strasbourg.
- MIDDELBURG, J.J. & COMANS, R.N.J. 1991: Sorption of cadmium on hydroxyapatite. *Chem. Geol.* 90, 45–53.
- MILLER, R. L. & SUTCLIFFE, H. 1984: Effects of three phosphate industrial sites on ground-water quality in central Florida, 1979 to 1980. US Geol. Surv. Water Resour. Investi. Report 83–4256, 160–84.
- MINSTER, T. & FLEXER, A. 1991: Cadmium-bearing sphalerite in the Senonian section, northern Negev – remarks on its formation and technological implications. In: *First Gentner Symp. on Geoscience. Phosphorites and Black Shales*. Jerusalem, September 1991, Program with Abstracts, 35.
- MORTVEDT, J.J. 1992: The radioactivity issue – effects on crops grown on mined phosphate lands, P-fertilized soils, and phosphogypsum-treated soils. In: *Phosphate Fertilizers and the Environment*, Proc. Int. Workshop, IFDC, March 1992 Tampa, Florida, 271–278.
- NATHAN, Y. 1984: The mineralogy and geochemistry of phosphorites. In: *Phosphate Minerals* (Ed. by NRIAGU, J.O. & MOORE, P.B.). Springer Verlag, Berlin, 275–291.
- NATHAN, Y. & LUCAS, J. 1976: Expériences sur la précipitation directe de l'apatite dans l'eau de mer: implications dans la genèse des phosphorites. *Chem. Geol.* 18, 181–186.
- NATHAN, Y. & NIELSEN, H. 1980: Sulfur isotopes in phosphorites. In: *Marine Phosphorites* (Ed. by BENTOR, Y.K.). Soc. Econ. Paleont. Miner. Spec. Publ. 29, 73–78.
- NATHAN, Y., SHILONI, Y., RODED, R., GAL, I. & DEUTSCH, Y. 1979: The geochemistry of the northern and central Negev phosphorites (southern Israel). *Geol. Surv. Israel Bull.* 73, 1–41.
- NATHAN, Y., SOUDRY, D. & AVIGOUR, A. 1990: Geological significance of carbonate substitution in apatites: Israeli phosphorites as an example. In: *Phosphorite Research and Development* (Ed. by NOTHOLT, A.J.G. & JARVIS, I.) Geol. Soc. Spec. Publ. 52, 179–191.
- NATHAN, Y., SOUDRY, D., DORFMAN, E., LEVY, Y. & SHITRIT, D. 1991: The geochemistry of cadmium in the Negev phosphorites. In: *First Gentner Symp. on Geoscience. Phosphorites and Black Shales*. Jerusalem, September 1991, Program with Abstracts, 35.
- NATHAN, Y., WATKINS, R.T. & BREMNER, J.M. 1993: Rare earth elements from phosphatic-rich sediments off the South African continental shelf. *Concepts and Controversies in Phosphogenesis*. Int. Symp. and Workshop, Matten, 6–10 September, 1993.
- NIFONG, G. D. 1988: Environmental aspects of phosphogypsum. Unpublished Florida Institute of Phosphate Research (FIPR) Manuscript.
- NOTHOLT, A.J.G., SHELDON, R.P. & DAVIDSON, D.F. 1989: *Phosphate Deposits of the World Volume 2: Phosphate Rock Resources*. Cambridge University Press, Cambridge.
- O'BRIEN, G.W. & VEEH, H.H. 1980: Holocene phosphorite on the east Australian continental margin. *Nature* 288, 690–692.
- O'BRIEN, G.W., VEEH, H.H., CULLEN, D.J., & MILNES, A.R. 1986: Uranium-series isotopic studies of marine phosphorites and associated sediments from the East Australian continental margin. *Earth Planet. Sci. Lett.* 80, 19–35.
- O'BRIEN, G.W., VEEH, H.H., MILNES, A.R. & CULLEN, D.J. 1987: Sea-floor weathering of phosphorite nodules off East Australia: Its effect on uranium oxidation state and isotopic composition. *Geochim. Cosmochim. Acta* 51, 2051–2064.
- O'BRIEN, G.W., MILNES, A.R., VEEH, H.H., HEGGIE, D.T., RIGGS, S.R., CULLEN, D.J., MARSHALL, J.F. & COOK, P.J. 1990: Sedimentation dynamics and redox iron-cycling: controlling factors for the apatite-glauconite association on the East Australian continental margin. In: *Phosphorite Research and Development* (Ed. by NOTHOLT, A.J.G. & JARVIS, I.) Geol. Soc. Spec. Publ. 52, 61–86.
- PACEY, N.R. 1985: The mineralogy, geochemistry and origin of pelletal phosphates in the English Chalk. *Chem. Geol.* 48, 243–256.
- PALMER, M.R. & ELDERFIELD, H. 1985: Sr isotope composition of sea water over the past 75 Myr. *Nature* 314, 526–528.

- PANCZER, G., NATHAN, Y. & SHILONI, Y. 1989: Trace element characterisation of phosphate nodules in Israel. *Sci. Geol. Bull.* 42, 173–184.
- PARKER, R.J., 1975: The petrology and origin of some glauconitic and glauco-conglomeratic phosphorites from the South African continental margin. *J. Sediment. Petrol.* 45, 230–242.
- PARKER, R.J. & SIESSER, W.G. 1972: Petrology and origin of some phosphorites from the South African continental margin. *J. Sediment. Petrol.* 42, 434–440.
- PETERMAN, Z.E., HEDGE, C.E. & TOURTELOT, H.A. 1970: Isotopic composition of strontium in seawater throughout Phanerozoic time. *Geochim. Cosmochim. Acta* 34, 105–120.
- PIEPGRAS, D.J. & WASSERBURG, G.J. 1980: Neodymium isotopic variation in seawater. *Earth Planet. Sci. Lett.* 50, 128–138.
- PIEPGRAS, D.J., WASSERBURG, G.J. & DASCH, E.J. 1979: The isotopic variations in seawater. *Earth Planet. Sci. Lett.* 45, 223–236.
- PIPER, D.Z. 1991: Geochemistry of a Tertiary sedimentary phosphate deposit: Baja California Sur, Mexico. *Chem. Geol.* 92, 283–316.
- 1994: Seawater as a source of minor elements in black shales, phosphorites and other sedimentary rocks. *Chem. Geol.* 114, 95–114.
- PIPER, D.Z. & ISAACS, C.M. 1994: Geochemistry of minor elements in the Monterey Formation, CA: seawater chemistry of deposition. In: *Analogy of a Source Rock: The Cooperative Monterey Organic Geochemistry Study* (Ed. by ISAACS, C.M. & RULLKÖTTER, J.). *Am. Assoc. Pet. Geol. Stud. Geol.* (in press).
- PIPER, D.Z. & KOLODNY, Y. 1987: The stable isotopic composition of a phosphate deposit: $\delta^{13}\text{C}$, $\delta^{34}\text{S}$ and $\delta^{18}\text{O}$. *Deep Sea Res.* 34, 897–911.
- PIPER, D.Z. & MEDRANO, M.D. 1994: The geochemistry of the Phosphoria Formation at Montpelier Canyon, Idaho: The environment of deposition. *US Geol. Surv. Bull.* 2023B (in press).
- PIPER, D.Z., BAEDECKER, P.A., CROCK, J.G., BURNETT, W.C. & LOEBNER, B.J. 1988: Rare earth elements in the phosphatic-enriched sediments of the Peru Shelf. In: *The Origin of Marine Phosphorite. The Results of the R.V. Robert D. Conrad Cruise 23–06 to the Peru Shelf* (Ed. by BURNETT, W.C. & FROELICH, P.N.). *Marine Geol.* 80, 269–285.
- POTTS, P.J., HAWKESWORTH, C.J., VAN CALSTEREN, P. & WRIGHT, I.P. 1993a: Advances in analytical technology and its influence on the development of modern inorganic geochemistry: a historical perspective. In: *Magmatic Processes and Plate Tectonics* (Ed. by PRICHARD, H.M., ALABASTER, T., HARRIS N.B.W. & NEARY, C.R.). *Geol. Soc. Spec. Publ.* 76, 501–520.
- POTTS, P.J., TINDLE, A.G. & WEBB, P.C. 1993b: *Geochemical Reference Material Compositions*. CRC Press, Boca Raton FL.
- PRÉVÔT, L. 1990: Geochemistry, petrography, genesis of Cretaceous – Eocene phosphorites. *Mém. Soc. Géol. Fr.* 158.
- PRÉVÔT, L. & LUCAS, J. 1979: Comportement de quelques éléments traces dans les phosphorites. *Sci. Géol. Bull.* 32, 91–105.
- 1980: Behaviour of some trace elements in phosphatic sedimentary formations. In: *Marine Phosphorites* (Ed. by BENTON, Y.K.). *Soc. Econ. Paleont. Miner. Spec. Publ.* 29, 31–39.
- 1985: Utilization of geochemistry to explain the setting of the phosphatic series of the Ganntour Basin (Morocco). *Sci. Géol. Mém.* 77, 45–51.
- 1986: Microstructure of apatite – replacing carbonate in synthesized and natural samples. *J. Sed. Petrol.* 56, 153–159.
- PRÉVÔT, L., EL FALEH, E.M. & LUCAS, J. 1989: Details on synthetic apatites formed through bacterial mediation. Mineralogy and chemistry of the products. *Sci. Geol. Bull.* 42, 237–254.
- PRICE, N.B. & CALVERT, S.E. 1978: The geochemistry of phosphorites from the Namibian Shelf. *Chem. Geol.* 23, 151–170.
- PRICE, N.M. & MOREL, F.M.M. 1990: Cadmium and cobalt substitution for zinc in a marine diatom. *Nature* 344, 658–660.
- RICHTER, F.M. & TUREKIAN, K.K. 1993: Simple models for the geochemical response of the ocean to climatic and tectonic forcing. *Earth Planet. Sci. Lett.* 119, 121–131.
- ROE, K.K. & BURNETT, W.C. 1985: Uranium geochemistry and dating of Pacific island apatite. *Geochim. Cosmochim. Acta* 49, 1581–1592.
- ROE, K.K., BURNETT, W.C., KIM, K.H. & BEERS, M.J. 1982: Excess protactinium in phosphate nodules from the coastal upwelling zone. *Earth Planet. Sci. Lett.* 60, 39–46.
- ROESSLER, C. E. 1984: The radiological aspects of phosphogypsum. *Proc. Seminar on Phosphogypsum*. Florida Institute of Phosphate Research 11–36.

- 1988: Radiological assessment of the application of phosphogypsum to agricultural land. Proc. Second Int. Symp. on Phosphogypsum. (Ed. by LLOYD, G. M.). Florida Institute of Phosphate Research 5–23.
- ROLLINSON, H. 1993: Using Geochemical Data: Evaluation, Presentation, Interpretation. Longman, Burnt Mill, Harlow.
- ROMANKEVICH, Y.A. & BATURIN, G.N. 1972: Composition of the organic matter in phosphorites from the continental margin off southwest Africa. *Geochem. Int.* 9, 464–470.
- RUTTENBERG, K.C. 1993: Reassessment of the oceanic residence time of phosphorus. *Chem. Geol.* 107, 405–409.
- RUTTENBERG, K.C. & BERNER, R.A. 1993: Authigenic apatite formation and burial in sediments from non-upwelling, continental margin environments. *Geochim. Cosmochim. Acta* 57, 991–1007.
- SANDELL, E.B., HEY, M.H. & MCCONNELL, D. 1939: The composition of francolite. *Mineral. Mag.* 25, 395–401.
- SAVENKO, V.S. 1978: Experimental studies on the conditions of chemical precipitation of calcium phosphates from seawater. *Dokl. Akad. Nauk. SSSR* 243, 1302–1305.
- SCHMITZ, B., ABERG, G., WERDELIN, L., FORY, P. & BENDIX-ALMGREEN, S.E. 1991: $^{87}\text{Sr}/^{86}\text{Sr}$, Na, F, Sr and La in skeletal fish debris as a measure of the paleosalinity of fossil-fish habitats. *Geol. Soc. Am. Bull.* 103, 786–794.
- SCHULTZ, J. J. 1992: An examination of the environmental issues facing the phosphate fertilizer production sector – indicated cost of environmental compliance. *Phosphate Fertilizers and the Environment*, Tampa, FL, (Ed. by SCHULTZ, J.J.). 283–309.
- SCHUFFERT, J.D., KASTNER, M., EMANUELE, G. & JAHNKE, R.A. 1990: Carbonate-ion substitution in francolite: A new equation. *Geochim. Cosmochim. Acta* 54, 2323–2328.
- SCHWAB, R.G. & OLIVEIRA, N.P. DA 1981: The influence of phosphorus during lateritic weathering. *Zentralbl. Geol. Paläont. Teil 1* 3/4, 419–436.
- SEMENEV, E.I., KHOLODOV, V.N. & BARINSKII, R.L. 1962: Rare earths in phosphorites. *Geochemistry* 5, 501–507.
- SHAW, H.F. & WASSERBURG, G.J. 1985: Sm-Nd in marine carbonates and phosphorites: Implications for Nd isotopes in seawater and crustal ages. *Geochim. Cosmochim. Acta* 49, 503–518.
- SHELDON, R.P. 1964: Paleolatitudinal and paleogeographic distribution of phosphorite. *US Geol. Surv. Prof. Pap.* 501-c, 106–113.
- SHEMESH, A., KOLODNY, Y & LUZ, B. 1983: Oxygen isotope variations in phosphate of biogenic apatites. II. Phosphorite rocks. *Earth Planet. Sci. Lett.* 64, 405–416.
- SHEMESH, A., KOLODNY, Y & LUZ, B. 1988: Isotope geochemistry of oxygen and carbon in phosphate and carbonate of phosphorite francolite. *Geochim. Cosmochim. Acta* 52, 2565–2572.
- SHOLKOVITZ, E.R., PIEPGRAS, D.J. & JACOBSEN, S.B. 1989: The pore water chemistry of rare earth elements in Buzzard Bay sediments. *Geochim. Cosmochim. Acta* 53, 2847–2856.
- SLANSKY, M. 1979: Nomenclature et classification des phosphates sédimentaires. *Bull. BRGM*, IV, 2, 153–156.
- 1980: Géologie des Phosphates Sédimentaires. *Mém. BRGM* 114.
- 1986: *Geology of Sedimentary Phosphates*. Elsevier, New York.
- 1989: Nomenclature descriptive des phosphorites. *Sci. Géol. Bull.* 42, 255–266.
- SMALLEY, P.C., HIGGINS, A.C., HOWARTH, R.J., NICHOLSON, H., JONES, C.E., SWINBURNE, N.H.M. & BESSA, J. 1994: Seawater Sr isotope variations through time: a procedure for constructing a reference curve to date and correlate marine sedimentary rocks. *Geology* 22, 431–434.
- SMIRNOV, A.I., IVNITZKAYA, R.B. & ZALAVINA, T.P. 1962: Experimental data on the possibility of the chemical precipitation of phosphate from seawater. In: *Geology of Phosphorite Deposits*. State Sci. Res. Inst. Chem. Raw Mater. 7, 289–302.
- SMITH, J.P. & LEHR, J.R. 1966: An X-ray investigation of carbonate apatite. *J. Agric. Food Chem.* 14, 342–349.
- STARINSKY, A., KATZ, A. & KOLODNY, Y. 1982: The incorporation of uranium into diagenetic phosphorite. *Geochim. Cosmochim. Acta* 46, 1365–1374.
- STAUDIGEL, H., DOYLE, P. & ZINDLER, A. 1985: Sr and Nd isotope systematics in fish teeth. *Earth Planet. Sci. Lett.* 76, 45–56.
- STILLE, P., CHAUDHURI, S., KHARAKA, Y.K. & CLAUER, N. 1992: Neodymium, strontium, oxygen and hydrogen isotope compositions of waters in present and past oceans: a review. In: *Isotopic Signatures and Sedimentary Records*, Lecture Notes in Earth Sciences No. 43 (Ed. by CLAUER, N. & CHAUDHURI, S.). Springer-Verlag, Berlin, Heidelberg, 389–410.
- STILLE, P., RIGGS, S., CLAUER, N., AMES, D., CROWSON, R. & SYNDER, S.W. 1994: Sr and Nd isotopic analysis of phosphorite sedimentation through one Miocene high-frequency depositional cycle on the North Carolina continental shelf. *Marine Geol.* 117, 253–273.

- SUMMERHAYES, C.P. & MCARTHUR, J.M. 1990: Moroccan offshore phosphorite deposits. In: *Phosphate Deposits of the World Volume 3: Genesis of Neogene to Recent Phosphorites*. (Ed. by BURNETT, W.C. & RIGGS, S.R.). Cambridge University Press, Cambridge 159–166.
- TLIG, S., SASSI, A., BELAYOUNI, H. & MACHEL, D. 1987: Distribution de l'uranium, du thorium, du zirconium, du hafnium et des terres rares (TR) dans les grains de phosphates sédimentaires. *Chem. Geol.* 62, 209–221.
- TOOMS, J.S., SUMMERHAYES, C.P. & CRONAN, D., D.S. 1969: Geochemistry of marine phosphate and manganese deposits. *Oceanogr. Marine Biol. Ann. Rev.* 1, 49–100.
- TRAVI, Y. 1988: Hydrogéochimie et hydrologie isotopique des aquifères fluorures du bassin du Sénégal – origine et conditions de transport du fluor dans les eaux souterraines. Thèse d'état, Université de Paris–Sud, France.
- TUCKER, M.E. & WRIGHT, V.P. 1990: *Carbonate Sedimentology*. Blackwell, Oxford.
- TUREKIAN, K.K. & WEDEPOHL, K.H. 1961: Distribution of some major elements of the Earth's crust. *Geol. Soc. Am. Bull.* 72, 175–192.
- UREY, H.C., LOWENSTAM, H.A., EPSTEIN, S. & MCKINNEY, U. 1951: Measurements of paleotemperatures and temperatures of the Upper Cretaceous of England, Denmark and the south-eastern US. *Geol. Soc. Amer. Bull.* 62, 399–416.
- VAN CAPELLEN, P. & BERNER, R. A. 1988: A mathematical model for the early diagenesis of phosphorus and fluorine in marine sediments: apatite precipitation. *Amer. J. Sci.* 288, 289–333.
- 1991: Fluorapatite crystal growth from modified seawater solutions. *Geochim. Cosmochim. Acta* 55, 1219–1234.
- VEEH, H.H. 1982: Concordant ^{230}Th and ^{231}Pa ages of marine phosphorites. *Earth Planet. Sci. Lett.* 57, 278–284.
- VEEH, H.H. & BURNETT, W.C. 1982: Carbonate and phosphate sediments. In: *Uranium-Series Disequilibrium: Application to Environmental Problems* (Ed. by IVANOVICH, M. & HARMON, R.S.). Clarendon Press, Oxford, 459–480.
- VEEH, H.H., BURNETT, W.C. & SOUTAR, A. 1973: Contemporary phosphorites on the continental margin off Peru. *Science* 181, 844–845.
- VEEH, H.H., CALVERT, S.E. & PRICE, N.B. 1974: Accumulations of uranium in sediments and phosphorites on the south-west African shelf. *Mar. Chem.* 2, 188–202.
- VEIZER, J. 1989: Strontium isotopes in seawater through time. *Ann. Rev. Earth Planet. Sci.* 17, 141–167.
- 1992: Depositional and diagenetic history of limestones: stable and radiogenic isotopes. In: *Isotopic Signatures and Sedimentary Records, Lecture Notes in Earth Sciences No. 43* (Ed. by CLAUSER, N. & CHAUDHURI, S.). Springer-Verlag, Berlin, Heidelberg, 13–48.
- VIGNOLES, M., BONEL, G. & BACQUET, G. 1982: Étude physico-chimique des apatites carbonatées phospho-calciques semblables à la francolite. *Bull. Minéral.* 105, 307–311.
- WRIGHT, J., SEYMOUR, R.S. & SHAW, H.F. 1984: REE and Nd isotopes of conodont apatite: variations with geological age and depositional environment. *Geol. Soc. Am. Spec. Pap.* 196, 325–340.
- WRIGHT, J., SCHRADER, H. & HOLSER, W.T. 1987: Paleoredox variations in ancient oceans recorded by rare earths in fossil apatite. *Geochim. Cosmochim. Acta* 51, 631–644.
- ZANIN, YU. N. 1968: Zones of lateritic weathering of secondary phosphorites of Altay-Sayan region. *Int. Geol. Rev.* 10, 1119–1127.
- ZANIN, YU. N. & KRIVOPUTSKAYA, L.M. 1976: Transformation of apatite material of phosphorite in catagenesis. *Dokl. Acad. Sci. USSR Earth Sci. Sect.* 230, 200–202.
- ZANIN, YU. N., GILINSKAYA, L.G., KRASIL'NIKOVA, N.A., KRIVOPUTSKAYA, L.M., MIRTOV, YU. V. & STOLPOVSKAYA, V.N. 1985: Calcium phosphates in phosphorites of different types. *Int. Geol. Rev.* 27, 1212–1229.

Manuscript received April 4, 1994

Revision accepted July 15, 1994