Introduction

This work is essentially a collection of about 550 known Phanerozoic ooidal ironstone occurrences, deposits and districts in the world, stated in 366 brief stratigraphic and petrologic records. Unfortunately, a very few others were unknown to us.

The compilation of the world-wide directory of Phanerozoic ooidal ironstones has been made possible thanks to fruitful cooperation with numerous geologists from the world over who most generously supplied descriptions of ooidal ironstones, mostly of their native countries. Yet, in a few countries, no correspondents were found to submit the needed information and the present writers then had to supply it themselves.

The ooidal ironstones are distinctive non-cherty sandy, clayey siliciclastic or siliciclastic-carbonate sedimentary rocks with more than 5 % of ferruginous ooids and more than 15 % of iron. They are composed mainly of oxidic-iron minerals and/or iron-rich clay minerals, but they include a wide variety of textures, mineralogy, and composition in detail. For those features the origin of ferruginous ooids, the origin of clay minerals, and the origin of iron-rich sediments will be involved (Young, 1993, p. 481–483). Research of them has continued for at least 150 years, and in earlier times they were the principal ore in the industrial world.

Table 1. Official and a few common names of countries with Phanerozoic ooidal ironstones

EUROPE	Belgium, Bulgaria, Czech Rep., Denmark, Estonia, France, Germany, Hungary, Ireland, Italy, Luxembourg, Macedonia, Norway, Poland, Portugal, Romania, Russia (European, Asian), Slovakia, Spain, Sweden, Switzerland, Turkey, Ukraine, United Kingdom (England, Wales, Scotland), Yugoslavia
ASIA	China, India, Iraq, Israel, Kazakhstan, Lebanon, Malaysia, Nepal, Oman, Pakistan, Philippines, Saudi Arabia, Syria
AFRICA	Algeria, Egypt, Guinea, Libya, Malgash Rep., Mali, Mauritania, Morocco, Niger, Nigeria, Sudan, Tunisia
NORTH AMERICA	Canada (Alberta, Can. Arctic Archipelago, Manitoba, New Brunswick, Newfoundland, Nova Scotia, Saskatchewan, Yukon Territory), United States (Alabama, Alaska, Arizona, Georgia, Illinois, Indiana, Iowa, Kansas, Kentucky, Louisiana, Maryland, Michigan, Minnesota, Missouri, Montana, Nebraska, New Jersey, New Mexico, New York, North Dakota, Ohio, Oklahoma, Pennsylvania, South Dakota, Tennessee, Texas, Utah, Virginia, West Virginia, Wisconsin, Wyoming)
SOUTH AMERICA	Argentina, Bolivia, Brazil, Colombia, Venezuela
AUSTRALIA	Northern Territory, Queensland, Western Australia

Now the ooidal ironstones are main source of iron in a very few countries, and research has been largely discontinued. Nevertheless, their origins are intriguing, and recently progress has been made. In fact, a conference on Phanerozoic Ironstones in 1987 (Young and Taylor, 1989) and an International Geological Correlation Programme-Project 277 (Phanerozoic Ooidal Ironstones, 1988–1992) were convened with field trips to Ordovician and Silurian ironstones in Georgia and northern Alabama, to Ordovician ones in Wales and Jurassic ones in England, to Silurian and Devonian ironstones in Pennsylvania, to Ordovician ones in

Table 2. Iron ore in the Phanerozoic ooidal ironstones

Currently or until recently exploited	
Argentina	Rosales (Silurian)
Colombia	Paz de Rio (Eocene)
Macedonia	Taymishte (Devonian)
Spain	Coto Wagner, Coto Vivaldi (Ordovician)
Russia (European)	Lipetsk (Jurassic)
Ukraine	Kerch-Taman (Pliocene)
United Kingdom	Frodingham (Jurassic)
United States (Texas)	Lone Star (Eocene)
Future potential	
Algeria	Atafaitafa, Gara Djebilet, Oguilet Laroussi, Mecheri Abdelaziz, Talus a Tigillites, Trottoirs, Orsine, Zemila
Argentina	Alfaro, Pachaco, Talacasto, Villicum, Zapla and others
Australia	Robe River
Canada	Clear Hills
China	deposits in Guangxi, Guizhou, Hunan, Jiangxi, Sichuan and Yunnan provinces
Israel	Ramim
Kazakhstan	Ayat, Dzhalsky Klysch, Kara Sandyk, Kok Bulak, Kutan Bulak, Kirov, Lisakovsk, Shiyelya, Taldy-Espe
Libya	Wadi Shatti
Macedonia	Rzhanovo
Morocco	Ait Amar, Bou-Kerzia, Khaloua, Mellet, Oumjerane, Satour, Siguenite, Taklimt, Tourza
Niger	Say
Poland	Konskie, Starachowice
Russia (Asian)	Bakhchar, Chigorin, Kolpashevo, Loshchinsk, Marsyat, Mugay, Narym, Serov, Zhigansk region
Syria	Zabadany, Radjou
Turkey	Çamdag
Venezuela	Arriba

Morocco, and Oligocene ironstones in Kazakhstan. In hope of encouraging this effort we have now recorded the Phanerozoic ooidal ironstones around the globe, from eastern Australia, Asia, Europe, Africa, North America, to southern South America (Table 1), in terms of brief stratigraphic occurrence and sedimentary petrology. Most of these 58 countries include ironstones which had, or have, or probably will have economic iron ore (Table 2).

First we define the ooidal ironstones and speculate about their origin of accumulation. Then we collect the Phanerozoic ooidal ironstones around the world. In most instances the terminologies of Young (1989a) is followed, and the stratigraphic names and correlation should be checked with most recent publications.

Definition

Stratigraphic record

Banded ironstones were common during Precambrian time, but they were nearly absent in the Phanerozoic Eon. In contrast, only a few ooidal ironstones (for example, Transvaal in South Africa, The Roper Bar and Constance Range in northern Australia, the Sinian System in Northern China, the Gunflint in the Mesabi Range in North America, and the Sokoman in the Labrador trough; Taylor, 1969, p. 175) occurred during the earlier Proterozoic Eon, and none apparently developed in the later Proterozoic or early Cambrian ages – about 1000 to 570 Ma. Then more than 400 ooidal ironstones accumulated throughout most of the Phanerozoic Eon, from Middle Cambrian to Recent (Figure 1; Table 3). An increase and decrease in the number of ironstones through time resemble the warm and cool modes (Frakes et al., 1992, Fig. 11.1) and the higher and lower level of atmospheric CO_2 (Berner, 1990, Fig. 5) in the Phanerozoic Eon. These, in turn, are related to the varied amount of heat given off by the planet.

Phanerozoic ironstones were present in both low and high latitudes. They were especially common in the Ordovician and Devonian (45 degrees north to 65 degrees south of the paleoequator) and again in Jurassic and Cretaceous (10 degrees south to 70 degrees north to the paleoequator) times, when the greenhouse stage (Fischer, 1981) was marked by a high relative rate of marine sedimentation on the continents (Ronov and others, 1980, Fig. 4) and generally mild climate. In contrast, only a few occurred in the Cambrian, Carboniferous, Permian, Triassic, or in the late Cenozoic. Yet one of the richest ooidal ironstones developed in the Middle Pliocene sequence of Crimea in southern Ukraine.

Although most of the ironstones accumulated in warm climate some were deposited in a cooler mode, as in the Late Ordovician time of northern (marginal) Gondwana. Two ironstones also accumulated in cool temperate, humid climate in Late Permian time in eastern Gondwana. Here, however, the setting was a progressive warming from Early Permian glacial phase to latest Permian warm temperate to tropical conditions (Fawcett et al., 1994, p. 150–151).

Table 3. Stratigraphic record of Phanerozoic ooidal ironstones (numbers in parentheses are the numbers of deposits in the directory)

CAMBRIAN	Canada (47), Morocco (187), United States (316–324)
ORDOVICIAN	Algeria (1–6), Australia (29), Bolivia (40), Canada (48–52), China (63–65), Czech Republic (75–86), Estonia (93), France (94–98), Germany (110–111), Libya (164–166), Malaysia? (180), Morocco (188–204), Norway (219), Poland (225), Portugal (233–234), Russia – European (236) and Asian part (241), Spain (257–260), Sweden (269–272), Tunisia (278–280), Turkey (283), United Kingdom (289–292), United States (325–335)
SILURIAN	Algeria (7–8), Argentina (25–27), Bolivia (41), Brazil (42), Canada (53–54), Guinea (144), Italy (157), Libya (167–168), Mauritania (185), Morocco (205), Spain (261), Turkey (284–285), United Kingdom (293–294), United States (336–341)
DEVONIAN	Algeria (9–22), Argentina (28), Belgium (33–38), Brazil (43), Canada (55), China (66–67), Czech Republic (87–88), France (99–100), Guinea (145), Kazakhstan (158), Libya (169–172), Macedonia (177), Mali (183), Mauritania (186), Morocco (206–209), Nepal (211), Poland (226–227), Russia – European part (237) and Asian part (242), Saudi Arabia (249), Spain (262–263), Turkey (286), United States (342–348)
CARBONIFEROUS	Czech Republic (89), Ireland (152), Libya (173–174), Morocco (210), United Kingdom (295–296), United States (349)
PERMIAN	Australia (30), India (147)
TRIASSIC	Canada (56), India (148–149), Nepal (212), Saudi Arabia (250), Slovakia (256), United States (350)
JURASSIC	Algeria (23), Australia (31), Belgium (39), Bulgaria (44–46), Canada (57–59), China (68–69), France (101–108), Germany (112–138), Hungary (146), India (150), Iraq (151), Luxembourg (176), Malgash Republic (182), Nepal (213), Norway (220), Pakistan (222), Poland (228–231), Russia – European (238–239) and Asian part (243), Saudi Arabia (251), Slovakia (256), Spain (264–265), Sweden (273), Switzerland (274), Tunisia (281), United Kingdom (297–309), Yugoslavia (363–364)
CRETACEOUS	Canada (60–62), Colombia (70–71), Egypt (91–92), France (109), Germany (139–142), Israel (153–156), Kazakhstan (159), Lebanon (163), Libya (175), Macedonia (178), Nigeria (217), Oman (221), Poland (232), Russia – European (240) and Asian part (244–247), Saudi Arabia (252–254), Sudan (266–268), Syria (276–277), United Kingdom (310–315), United States (351–354), Venezuela (357–358), Yugoslavia (365–366)
CENOZOIC	Algeria (24), Australia (32), Colombia (72–74), Denmark (90), Germany (143), Kazakhstan (160–162), Malaysia (181), Mali (184), Niger (214–216), Nigeria (218), Pakistan (223), Philippines (224), Romania (235), Russia – Asian part (247–248), Saudi Arabia (255), Switzerland (275), Tunisia (282), Ukraine (287–288), United States (355–356), Venezuela (359–362)
RECENT	Chad, Indonesia, Malawi, Venezuela