Chapter 2
World phosphate deposits

Phosphate rock (PR) is a general term that describes naturally occurring mineral assemblages containing a high concentration of phosphate minerals. The term refers to both unbeneficiated phosphate ores and concentrated products. Sedimentary deposits have provided about 80–90 percent of world production in the last ten years. They occur in formations of widely varying geological ages, exhibit a range of chemical compositions and physical forms, often occur as relatively flat-lying thick beds, and may underlie shallow overburden. The deposits that account for most of world PR production are in Morocco and other African countries, the United States of America, the Near East and China. Most sedimentary deposits contain the carbonate-fluorapatite called francolite (McConnell, 1938). Francolites with high carbonate for phosphate substitution are the most highly reactive and are the most suitable for direct application as fertilizers or soil amendments (Chapter 3).

Igneous deposits have provided about 10–20 percent of world production in the last ten years. They are exploited in the Russian Federation, Canada, South Africa, Brazil, Finland and Zimbabwe but also occur in Uganda, Malawi, Sri Lanka and several other locations. These deposits usually contain varieties of fluorapatite that are relatively unreactive and are the least suitable for direct application. The weathering products of igneous and sedimentary apatites (iron and aluminium phosphate minerals) are generally not useful for direct application in agriculture in their natural state.

Phosphate is the component of agronomic interest in these rocks. The higher the phosphate (P_2O_5) content as apatite, the greater the economic potential of the rock. Factors that are important in the chemical conversion of PRs to fertilizer (free carbonates, iron (Fe), aluminium (Al), magnesium (Mg) and chloride) are often not important where the rock is to be used for direct application (Gremillion and McClellan, 1975; McClellan and Gremillion, 1980; Van Kauwenbergh and Hellums, 1995).

World phosphate rock production

Table 1 lists world PR production for 1999, the most recent year for which firm figures are available. The main four producers of PR (the United States of America, China, Morocco and Western Sahara, and the Russian Federation) produced about 72.0 percent of the world total. The leading 12 producers accounted for more than 93 percent of the world total. Twenty other countries produced the remaining 6–7 percent of world production.

On a worldwide basis, the production and consumption of direct application phosphate rock (DAPR) are very limited, and reliable data are often difficult to obtain and evaluate. Many countries do not classify DAPR as a fertilizer and consumption statistics may not include it. Information may have to be obtained through unofficial channels, and its quality may be highly variable. It may be necessary to estimate DAPR by subtracting the amount of PR used for other purposes from the total amount of PR imported or used within a country. The figures presented in this chapter for DAPR are indicative rather than firm figures.

TABLE 1
World phosphate rock production, 1999

	Product (1 000 tonnes)	World total %
United States of America	40 867	28.1
China	30 754	21.1
Morocco and Western Sahara	21 986	15.1
Russian Federation	11 219	7.7
Subtotal top four	**104 826**	**72.0**
Tunisia	8 006	5.5
Jordan	6 014	4.1
Brazil	4 301	2.9
Israel	4 128	2.8
South Africa	2 941	2.0
Syrian Arab Republic	2 084	1.4
Senegal	1 879	1.3
Togo	1 715	1.2
Subtotal top twelve	**135 894**	**93.4**
India	1 623	1.1
Algeria	1 093	0.8
Egypt	1 018	0.7
Mexico	955	0.7
Kazakhstan	900	0.6
Finland	734	0.5
Viet Nam	710	0.5
Christmas Island	683	0.5
Nauru	604	0.4
Iraq	415	0.3
Venezuela	366	0.3
Canada	350	0.3
Australia	145	0.1
Uzbekistan	139	< 0.1
Zimbabwe	124	< 0.1
Democratic People's Republic of Korea	70	< 0.1
Sri Lanka	30	< 0.1
Peru	15	< 0.1
Colombia	4	< 0.1
World total	**145 472**	**100.0**

Source: Mew, 2000.

TABLE 2
World consumption of direct application phosphate rock

	World phosphate consumption (nutrient basis) %	Approximate tonnage (million tonnes at 30% P_2O_5)
1975	5.6	4.8
1980	4.9	5.2
1985	4.0	4.5
1990	3.0	3.6
1991	1.7	2.0
1995	1.5	1.5
1998	1.4	1.5

Source: Van Kauwenbergh, 2003.

One estimate of world DAPR consumption from 1975 to 1998 (Table 2) shows a fall in consumption from 5.6 to 1.4 percent of total P_2O_5 consumption. This is equivalent to about 1.5 million tonnes of product averaging about 30 percent P_2O_5. Another source (Maene, 2003) indicates a drop in consumption of DAPR from 1.66 million tonnes P_2O_5 in 1980 to 0.57 million tonnes P_2O_5 in 1998. This is equivalent to a consumption of about 1.9 million tonnes of product in 1998 at 30 percent P_2O_5. While the exact current amount of DAPR consumption is difficult to determine, it appears that world consumption is less than 2.0 million tonnes of product per year. In the former Soviet Union (FSU), consumption of DAPR decreased from about 900 000 tonnes P_2O_5 to about 350 000 tonnes in 1991; its use had previously been government mandated on collective farms. In China, DAPR consumption fell from about 300 000 tonnes P_2O_5 in the early to mid-1980s to less than 30 000 tonnes P_2O_5 in 1995 (Rong, 1995). In China, DAPR is in use only near mines in areas with acid soils.

PR from Tunisia, China, Christmas Island, Egypt, Israel, Jordan, Morocco and Peru continues to be produced and used for direct application. Colombia, India, Sri Lanka and Venezuela also produce DAPR. Sales of North Carolina DAPR were once approximately 250 000–300 000 tonnes/year; however, this marketing activity has been suspended and North Carolina PR is not currently available for direct application.

WORLD PHOSPHATE ROCK RESERVES AND RESOURCES

There is no accepted worldwide system for classifying PR reserves and resources. A system developed in the United States of America (U.S. Bureau of Mines and U.S. Geological Survey,

FIGURE 1
Economic and potentially economic phosphate deposits of the world

1981; U.S. Geological Survey, 1982) defines reserves as "identified resources of a mineral that can be extracted profitably with existing technology and under present economic conditions" (Brobst and Pratt, 1973). Reserve estimates may be stated as the total amount of minable rock in the ground or as the amount of recoverable product. Many authors do not distinguish between reserves and non-economic resources when reporting the size of deposits. Thus, substantial differences in reserve and/or resource estimates may exist between various sources. It is prudent to acknowledge that such discrepancies exist and that such figures should serve only as order-of-magnitude estimates.

Figure 1 shows a map of PR deposits currently being mined, those that have been mined in the recent past, and those that have been shown to be potentially economic. A tabulation (Table 3) of the ten main producing countries and their reserve bases shows that these countries possess about 90 percent of the world's phosphate reserves. Based on current extraction rates and economic conditions in the 1990s, more than half of these countries will have exceeded the life of their reserves in less than 20 years.

Sheldon (1987) categorized phosphate reserves and resources according to continents and regions (Table 4). At first glance, each main

TABLE 3
World phosphate rock reserves and reserve base

	Reserves[a]	Reserve base[b]
	(1 000 tonnes)	
United States of America	1 000 000	4 000 000
China	500 000	1 200 000
Israel	180 000	180 000
Jordan	900 000	1 700 000
Morocco and Western Sahara	5 700 000	21 000 000
Senegal	150 000	1 000 000
South Africa	1 500 000	2 500 000
Togo	30 000	60 000
Tunisia	100 000	600 000
Russian Federation	150 000	1 000 000
Other countries	1 200 000	4 000 000
World total	**12 000 000**	**37 000 000**

a. Cost less than US$40/tonne. Cost includes: capital, operating expenses, taxes, royalties, and a 15-percent return on investment f.o.b. mine.

b. Criteria for reserve base established by a joint U.S. Bureau of Mines and U.S. Geological Survey working group.

Source: US Bureau of Mines, 2001.

TABLE 4
World economic identified phosphate concentrate resources

Continent and country	Reserves	Inferred reserve base and reserve base
	(million tonnes)	
North America		
United States of America	1 260	22 587
Canada	37	37
Mexico	208	2 416
	1 505	25 040
South America		
Brazil	551	558
Peru	428	1 353
Other	120	211
	1 099	2 122
Africa		
Algeria	250	435
Morocco and Western Sahara	2 100	62 575
Senegal	155	200
South Africa	1 800	6 781
Tunisia	70	1 021
Other	82	1 216
	4 457	72 228
Asia		
China	170	1 000
Iraq	296	296
Israel	70	449
Jordan	530	1 542
Other	241	807
	1 307	4 094
Oceania		
Australia	340	850
Other	51	51
	391	901
Europe		
Former Soviet Union	6 500	8 000
Finland	-	46
	6 500	8 046
World total	**15 259**	**112 431**

Source: Sheldon, 1987.

continent/region has ample 'reserves' of phosphate, with the possible exception of Oceania (391 million tonnes). However, regionally, a few countries, or even one country, may dominate. In North America, the United States of America possesses 84 percent of the reserves. In Europe, the FSU countries possess 99 percent of the reserves. Within Africa, Morocco, South Africa, Algeria, Senegal and Tunisia possess 98 percent of the reserves. The South American reserves lie mainly in Brazil and Peru (97 percent). In Asia, 88 percent of the reserves occur in Iraq, Israel, Jordan and China. Australia possesses 87 percent of the reserves of Oceania.

As it is difficult to assign firm figures for current DAPR production and consumption, it is also difficult to estimate world resources of PR most suitable for direct application. The criterion that a high-solubility DAPR must have more than 5.9 percent P_2O_5 soluble in neutral ammonium citrate (NAC) (Hammond and Leon, 1983) limits the number of deposits to be considered. Using this criterion, the North Carolina, Peru and Tunisia deposits may be considered as containing the most significant world resources of the most highly reactive PR. Although there are a number of small deposits, or portions of deposits, that may contain PR with relatively high solubility, this analysis does not consider these deposits because resource estimates are not available for many of them.

Using the inferred reserve base and reserve base figures in (Table 4) for Peru and Tunisia and a figure of 730 million tonnes for the resources of the North Carolina deposits (Stowasser, 1991) (producible at less than US$60/tonne), the total resources of DAPR with an NAC solubility of more than 5.9 percent P_2O_5 amount to 3 100 million tonnes.

Using Sheldon's figure of a total world inferred reserve base of 112 431 million tonnes, world resources of high-solubility DAPR amount to about 2.8 percent of total world resources.

Considering the more conservative reserve base figure for the Tunisian deposits from the United States Geological Survey (USGS) (600 million tonnes) (Table 3), the resource estimates of Sheldon (1987) and Stowasser (1991) for Peru and North Carolina, respectively, and the total

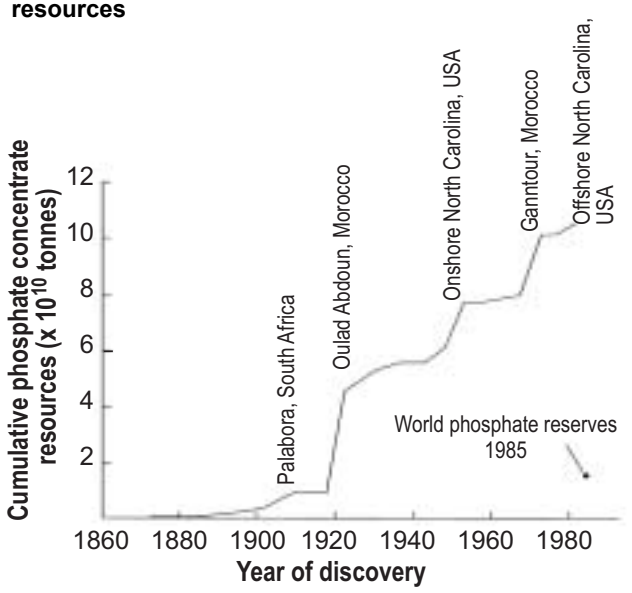
world reserve base of the USGS (37 000 million tonnes), world resources of high-solubility DAPR may amount to about 7.2 percent of total world resources.

Although detailed consideration of small deposits and portions of large deposits containing highly soluble PR or redefining the solubility level of the PR chosen to perform the analysis may serve to increase the amount of potential world resources of the most suitable DAPR, it is apparent that the potential world resources of the most suitable DAPRs are limited and that these represent only a fraction of total world PR resources.

Future trends in world phosphate rock production

Among the current leading four PR-producing countries, Morocco is in the most advantageous position and may possess over half of the world's phosphate reserves. In the last 12 years, China has approximately doubled its production, and Tunisia has increased its production by about 2 million tonnes. In 1999, two new phosphate mines opened in Canada and Australia. Increased future production may also come from Australia, Jordan, Iraq and South Africa.

Figure 2
History of the discovery of world phosphate resources



Source: Sheldon, 1987.

In 1999, production in the FSU countries was approximately one-third of 1988 levels. Recovery from the political changes and economic collapse of the FSU has been slow and may continue to be so in the foreseeable future. Production at current or declining levels is expected for Tunisia, Togo, Algeria, India, Israel, Senegal, Syrian Arab Republic, Brazil and Nauru. Production could come from new mines in Peru, Saudi Arabia, Mauritania and Guinea-Bissau.

There is also potential to discover new deposits. In the past 100 years, phosphate has been discovered at a rate (Figure 2) that exceeds the rate of consumption (Sheldon, 1987).

One source of future phosphate production is offshore deposits. Deposits of this type occur along the southeast coast of the United States of America, on the Peru-Chile shelf, off the coast of Namibia, on the Chatham Rise off New Zealand, off the coast of Baja California, Mexico, and off the Congo River delta. None of these offshore deposits is being mined, and they will probably not be mined while ample reserves exist onshore.