報　文

553.54 : 552.522 (52)

An Outline of Expanded Shale Resources in Japan

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Abstract

The present condition of expanded shale resources in Japan is briefly introduced in the present paper.

Six companies are producing the coated type expanded shale presently. The raw materials are argillaceous rocks of marine origin ranging from Cretaceous to Miocene in age. Most of them were deposited on shelves or slopes of basins, with an exception of lagoonal sediments of Palaeogene. They are processed mainly for unpelletized aggregate. But raw materials with significant sandy intercalations and slaty rocks are used for pelletized aggregate

Some raw material shales in the Cretaceous are composed mainly of quartz, feldspar, Fe-rich chlorite and illite-montmorillonite interstratification. Also, a raw material mudstone in the Miocene, which is somewhat tuffaceous, consists mainly of quartz, feldspar, montmorillonite, Fe-rich chlorite and illite with a small amount of expandable layer, and is accompanied by a few % calcite. These raw materials contain considerable amounts of organic matter. It is considered to be a significant gas source for them.

1. Introduction

Lightweight aggregates are materials weighing less than the common concrete aggregates of sand, gravel and crushed rock. And they can be divided into three divisions; natural materials such as pumice and diatomite, processed natural materials such as expanded shale and perlite, and by-products like slag and fly ash.

Among them, production of expanded shale and perlite started during the 1960s in Japan. Expanded shale is manufactured by heating treatment of common argillaceous rocks of shale, clay and slate, and is mainly used as structural concrete aggregate. It is almost the same in compressive strength with the common concrete aggregates, and is much higher in refractory property. And the use of expanded shale is very effective to save steel materials for construction of building and others.

Output of expanded shale increased steadily in Japan, although it has decreased temporarily because of "Oil Crisis" of 1974 (Table 1). It is evident that construction of more multistory buildings, high-ways, etc. stimulated the increase. Also, differing from other resources such as pumice and perlite, raw materials of expanded shale are almost inexhaustible in quantity. Such a situation suggests that an importance of expanded shale among lightweight aggregates would increase still more in future.

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Table 1 Output of Expanded Shale in Japan.

Fiscal years	Production (cu.m.)	Ratios to the year before
1965	42, 196	
1966	207, 770	492
1967	275, 594	133
1968	580, 650	211
1969	1, 017, 700	175
1970	1, 261, 275	124
1971	1, 344, 959	107
1972	1, 487, 491	111
1973	1, 746, 840	117
1974	1, 665, 887	95
1975	1, 275, 740	77
1976	1, 259, 381	98

After statistics by ALA Association

However, since Okano (1966) summarized the lightweight aggregates in Japan, no scientific examination has been done on expanded shale resources. The writers, by chance, had an opportunity to look round some of its factories and mines recently. In view of the above situation, it is considered to be worthwhile to introduce the present condition of the expanded shale resources in Japan. The above subject will be briefly summarized focusing on geologic features of the shale deposits in the present paper.

The writers sincerely thank to Mr. T. Okano, Drs. J. Hirayama, O. Fukuda, Y. Teraoka and T. Nakajima, Geological Survey of Japan, for their kind suggestion. Also, they are deeply indebted to the Artificial Lightweight Aggregate Association of Japan, ALAA, and its member companies for their kind supports.

2. Technical setting

Expanded shale is divided into two types; coated and crushed. And all of expanded shales produced in Japan are of the coated type fired by rotary kiln, and the crushed type one manufactured by sintering furnace has never been produced. Because, the latter is much higher in water absorption ability and much lower in compressive strength than the former. In this paper, therefore, only the coated type one is described.

Expanded shale is characterized by its high porosity, high compressive strength and low bulk specific gravity. Such products are made by adequate heating treatment of crushed shale fragments or pellets (Plate 9–1, 9–2). Generally speaking, most of argillaceous rocks such as shale and clay contain some amount of gas sources like carbon and carbonate. And when they are heated into somewhat soft and viscous state, they are bloated with expansion of gaseous materials. At that time, their crusts must be viscous and compact enough to trap gaseous materials.

So far, a large number of investigation was carried out to clarify what kind of shales are expandable but it has not yet been settled that a certain factor is the most significant (Bush, 1973). The writers also can not offer any conclusive opinion relating to what causes bloating. However, in view of technical experience on expanded shale manufacture in Japan, properties necessary at least for its raw material are considered to be as follows;

1) It is to expand at as the lowest possible temperature. The maximum heating temperature is to be under 1,250°C.

2) It is desirable the temperature range between softening and melting of raw material shale is more than 60°C.

3) Raw material deposits are to be capable of a large quantity mining, and the processing plant must be located near a big consumption area.

The first condition suggests that rocks containing significant amounts of highly refractory minerals such as quartz and kaolinite are not suitable for the raw material. Sandstone, for example, is generally predominated by quartz grains, and is too porous to trap gaseous materials when it is heated. Also, kaolinitic shale and clay beds are mostly developed in terrestrial sediments. These facts show that marine argillaceous sediments with few sandstone intercalations are more suitable for the raw material.

Among the three conditions, the second seems to be the most important for expanded shale processing (Plate 10–1). Because, shale fragments or pellets of a small temperature range between softening and melting are easily sintered into massive clinkers in the rotary kiln. Such a clinker can not be used as the coated type aggregate. For example, shales containing a considerable amount of alkalies and alkalin earths must have a tendency toward a massive clinker. It is very difficult to control successfully the heating process of such a raw material.

The last condition is very natural from an economical point of view. Since expanded shale is a bulky material of low unit value, it is very necessary to be mined in a large quantity and processed in the vicinity of a big consumption area.

The above consideration suggests that the raw material shale deposits are to be rather homogeneous argillaceous rocks of marine origin and to be suitable for a large scale mining. But, in fact, most of argillaceous rocks are accompanied more or less by sandy intercalations. Also, slates have a tendency to be splitted into platy fragments, and fired platy fragments are not always suitable for concrete aggregate. Because, concrete aggregate made with such a shape materials is not so stable in compressive strength.

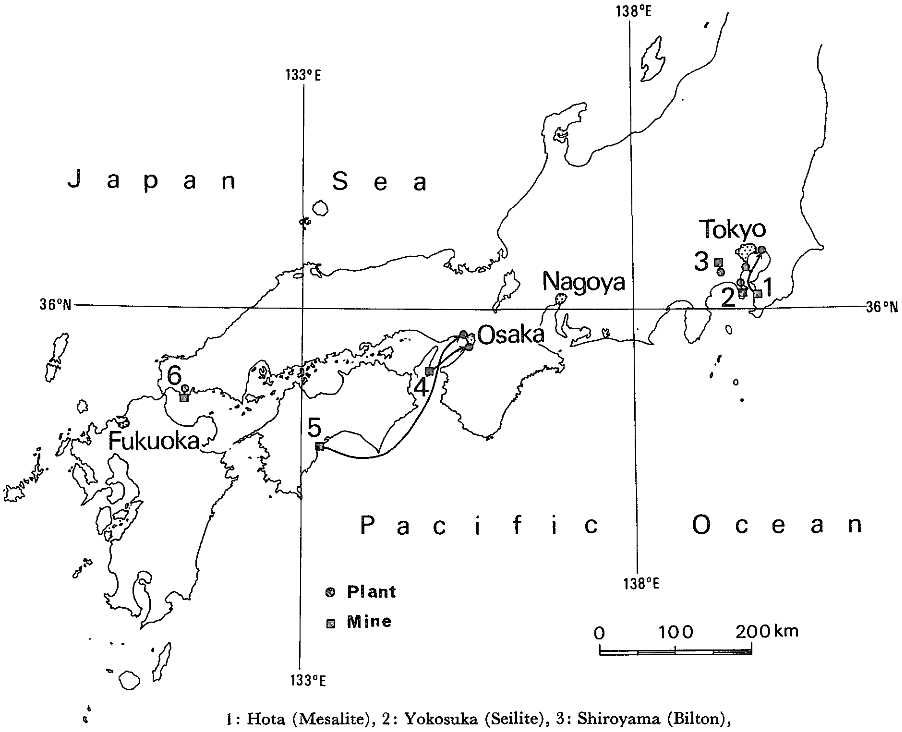
Therefore, raw materials such as argillaceous rocks with significant sandy intercalations and slates are usually crushed and pelletized, and then fired for pelletized type aggregate. Pelletization is very effective to reduce qualitative fluctuation of raw materials and make adequate shape of aggregates.

3. General features of expanded shale industry

3.1 Processing plants

In Japan, six companies have been manufacturing expanded shale since 1964 or 1965. They are listed in Table 2. Also, locations of the plants and the mines of raw material are illustrated in Fig. 1.

Besides them, there is a company that stopped the work recently because of continuing



1: Hota (Mesalite), 2: Yokosuka (Seilite), 3: Shiroyama (Bilton), 4: Sumoto (Asanolite), 5: Susaki (Lionite), 6: Ube (Ube-keikotsu).

Fig. 1 Localities of expanded shale plants and mines.

depression. That partly might have been caused by cost-up from establishment of more facilities for polution prevention.

These processing plants are located being restricted in the vicinity of big cities such as Tokyo and Osaka with an exception of Ube-Kosan Co., which is situated in a factory zone developed along the coast of the Seto Inner Sea, west Japan. Since bulky materials such as expanded shale can not be transported far and still remain a low cost, it is natural that processing plants for expanded shale were built around large consumption areas. But workings of raw material shale are not always adjacent to the plants. Of seven plants shown in Table 2, only three factories have their mining pits within 10 kilometers from them. But the other four are processing the raw materials transported by ship from distant lands, and one of the mining pits, Susaki, is located at more than 200 kilometers far from the factory (Fig. 1).

These plants are mainly producing unpelletized aggregates and only two produce pelletized ones. That depends on the properties and mode of occurrence of raw material shale as explained previously. Total capacity of production for each type aggregate is approximately 4,000 cu.m./day of unpelletized type and 2,700 cu.m./day of pelletized one (Table 2).

3.2 Manufacturing process

As described previously, all of expanded shales produced in Japan are of the coated type. And they are classified into unpelletized and pelletized aggregates. Examples of manufacturing process for each are shown in Fig. 2. General explanation for manufacturing process of each

Table 2 Producers List.

Names of company (Commercial name of products)	Location		Capacity of production	Type of product
	Workings of raw material	Processing plant		
Ube-Kosan Co. (Ube-keikotsu)	Ube, Yamaguchi Pref.	Ube, Yamaguchi Pref.	430 cu.m./day	Unpelletized
Osaka Cement Co. (Lionite)	Susaki, Kochi Pref.	Osaka city	1,600 〃	Pelletized
Sumitomo Metal Mining Co. (Bilton)	Shiroyama, Kanagawa Pref.	Aikawa, Kanagawa Pref.	1,100 〃	Pelletized
Nihon Cement Co. (Asanolite)	Sumoto, Hyogo Pref.	Osaka city	1,200 〃	Unpelletized
Mitsui Mining and Smelting Co. (Mesalite)	Hota, Chiba Pref.	Funabashi, Chiba Pref. Kawasaki, Kanagawa Pref.	2,000 〃	Unpelletized (Partly pelletized)
Mitsubishi Coal Mining & Cement Co. (Seilite)	Yokosuka, Kanagawa Pref.	Yokosuka, Kanagawa Pref.	500 〃	Unpelletized

type is briefly described below refering to the examples.

Unpelletized aggregate (Example 1 in Fig. 2)

Firstly, shales are crushed and then sized into two parts, less than 5 milimeters and 5 to 15 milimeters, and both the fine and coarse green materials are fed into a rotary kiln for each

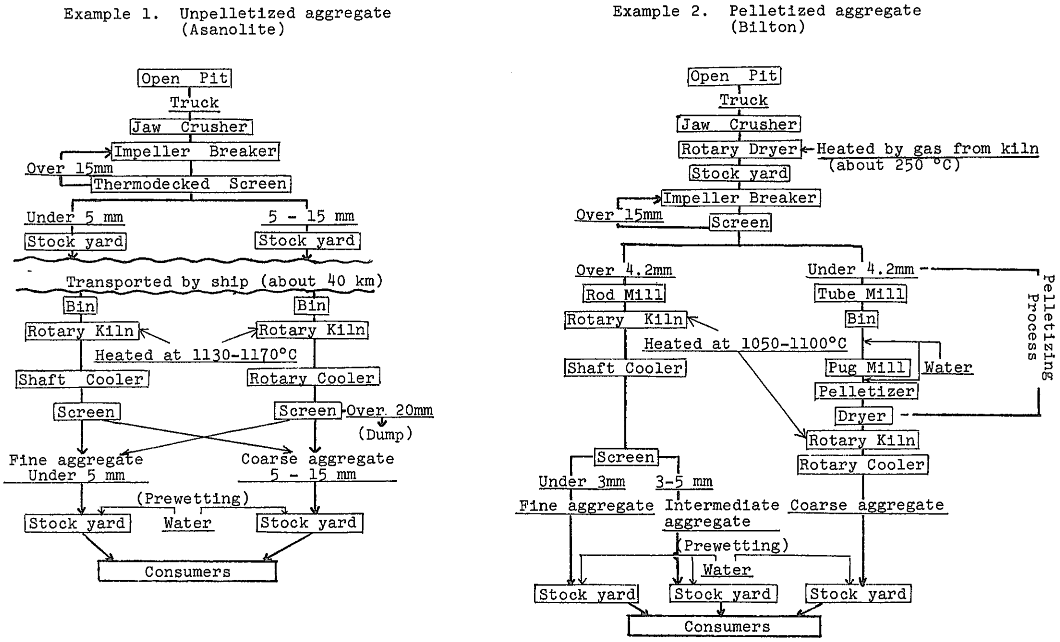


Fig. 2 Manufacturing processes of expanded shale.

Table 3 Physical properties of expanded shales.

Items	Unpelletized aggregate		Pelletized aggregate
	Coarse	Fine	Coarse
Bulk specific gravity	1. 20–1. 30	1. 65–1. 75	1. 20–1. 30
Unit weight (kg/l)	0. 75–0. 85	1. 05–1. 15	0. 75–0. 80
Water absorption (wt.%)	7–9	6–8	5–8

respectively. The maximum temperature of heating usually ranges from 1,100 to 1,200°C, and it takes about 40 minutes to pass through the kiln. The expanded fragments are conveyed on to screen through cooler and then separated into fine aggregate of less than 5 milimeters and coarse one of 5 to 20 milimeters. Each product is piled at stockyard and prewetted by water-sprinkler. Prewetting is indispensable to make consistency of concrete or mortar homogeneous. In addition, it is useful to prevent the segregation and lost of fine-grain aggregates depending on wind.

Pelletized aggregate (Example 2 in Fig. 2)

The process for pelletized aggregate also is almost similar with that for unpelletized one. It is characterized by pelletization and some additional crushing and drying processes. That is, the green materials ground in tube mill are kneaded with an adequate amount of water in pug mill and then pelletized. The heating and cooling processes for the green pellet are almost the same as for unpelletized aggregate excluding lower heating temperature of pelletized one. The process for finegrain aggregate also is the same with that of Example 1.

By the way, Mitsui Mining and Smelting Co. of Mesalite mostly produces unpelletized aggregate and partly pelletized one made with dusty materials collected by electric precipitater.

Generally speaking, the above additional processes for pelletized aggregate necessarily cause some amount of cost-up of the product. However, as described previously, pelletization is very useful to reduce the fluctuation in quality of raw materials and consequently make the heating control easy. Example 2 shows that not only the heating range for pelletized aggregate is larger than for unpelletized one but also the heating temperature is lower (Fig. 2).

There are few differences in physical properties between unpelletized and pelletized aggregates as shown in Table 3.

4. Geologic features

There occur a large amount of sedimentary rocks predominated by argillaceous facies, which ranges in age from late Paleozoic to Quarternary, in Japan. Probably, considerable parts of them might be suitable for the raw material of expanded shale. But in fact, shale deposits worked presently are from Cretaceous to Miocene in age.

4.1 Shale deposits in the Cretaceous

In Cretaceous, the Pacific Ocean side, the Outer Zone, of Southwest Japan was an extensive sea region, wherein very thick eugeosynclinal sediments consisting mainly of sandstone-shale alternation were deposited. They are called the Shimanto Supergroup generically. The Susaki mine is mining a shale predominating part of the Supergroup.

The Kobotoke Group of the Shiroyama mine also belongs to the Supergroup and consists mainly of sandstone and alternation of sandstone and shale or sandy shale (Makino, 1973). The Shiroyama mine is working a slaty black shale-rich part of the lower part of the Group.

These raw material shales in the Shimanto Supergroup are generally accompanied by some sandstone intercalations, and are somewhat slaty. Therefore, they are used for the pelletized aggregate raw material.

In the same time, a long and narrow miogeosynclinal basin formed in the Inner Zone of Southwest Japan. It extended from the southeast of Osaka to the northwestern end of Shikoku island. The shale mine at Sumoto is mining a exclusively shale predominating part of the miogeosynclinal sediments, the Izumi Group. The raw material shale is black colored, massive and conchoidally fractured.

According to Tanaka (1965), Teraoka (1977), etc., the Izumi Group forms a synclinorium structure with axes dipping to the east, and it covers the basement granite unconformably at the northern margin, and its southern margin is bordered by faults relating with the Median Tectonic Line. In the central axial parts, the Group consists exclusively of thick sequences of turbidite, sandstone-shale alternation, and it grades into basal conglomerates through black shale facies northward without exception. These facts show that the black shale facies were deposited mainly on the shelf of basin.

4.2 Shale deposits in the Palaeogene

During the Palaeogene, almost all of the Japanese Islands was emergent. And paralic basins were formed mainly in the inner side of the Japanese Islands, and coal-bearing

Table 4. Geologic features of the raw material argillaceous rocks.

Location of workings	Names of Formations and Groups	Geologic age	Rock facies	Sedimentary environment
1. Hota	Amatsu Formation, Sakuma Group	Middle Miocene	*Massive mudstone*, Tuffaceous sandstone, Sandstone, Tuff.	Marine Slope of basin.
2. Yokosuka	Zushi Formation, Miura Group	Late Miocene	Ditto	Ditto
3. Shiroyama	Kobotoke Group	Cretaceous	*Slaty shale*, Sandstone, *Alternation of sandstone and slate.*	Marine. Shelf or slope of eugeosynclinal basin.
4. Sumoto	Izumi Group	Cretaceous	*Massive shale*, Sandstone, Alternation of sandstone and shale.	Marine. Shelf of miogeosynclinal basin.
5. Susaki	Shimanto Supergroup	Cretaceous	*Shale*, Sandstone, *Alternation of shale and sandstone.*	Marine. Shelf or slope of eugeosynclinal basin.
6. Ube	Ube Group	Palaeogene	*Shale*, Sandstone. Coal. Coaly shale.	Marine. Lagoonal basin.

Note: Underlined are raw materials.

formations were deposited in northern Kyushu, west end of Honshu island, etc. (YOSHIDA ed., 1975). The Ube Group is one of the above coal-bearing formations and is composed mainly of conglomerate, sandstone and shale. A comparatively shale predominating part is worked at Ube for the expanded shale raw material. Another factory that already stopped the production had produced the pelletized aggregate made with wastes of coal mines at northeast Kyushu.

These raw material shales are lagoonal sediments of marine origin.

4.3 Shale deposits in the Miocene

Two shale mines, Hota and Yokosuka, are working the Miocene mudstones at the south of Tokyo (Fig. 1). According to the Geological Map of Tokyo Bay and adjacent areas (MITSUNASHI *et al.*, 1976), these mudstones occur in the middle Miocene Amatsu Formation and the late Miocene Zushi Formation respectively.

During Miocene, an irregularly shaped big open bay extended in the northwest to southeast direction in the region surrounding Tokyo, and two small mountain lands were emergent near the above two mines (FUKUDA, 1964). These mudstone Formations were thickly deposited on the slopes around them.

These raw material mudstones are poorly laminated, grey to dark grey colored and accom-

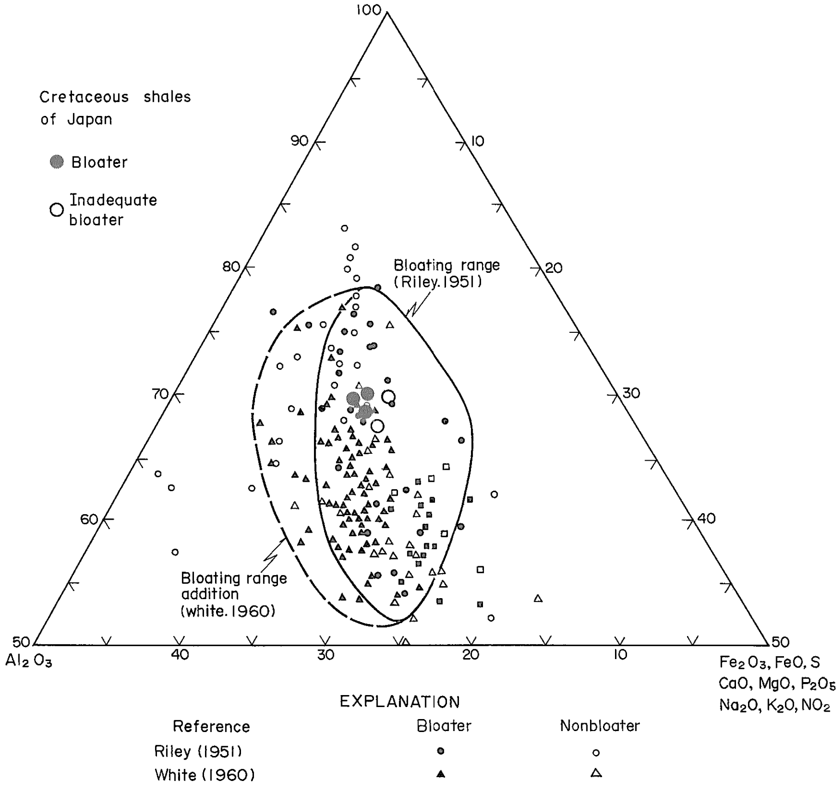


Fig. 3 Comparative composition of bloating and nonbloating argillaceous rocks (After Bush, 1973).

panied in places by intermediate to basic tuff intercalations.

All of the shale deposits described thus are thick enough for a large quantity mining (Plate 10–2). And it is noticeable that excluding the Ube mine of lagoonal sediments they were deposited on shelves or slopes of marine basins. Their geologic features presented above are summarized in Table 4.

5. Petrography of expandable shales

5.1 Chemical composition

So far, a lot of investigation was carreid out relating to what factor is the most important for bloating of argillaceous rocks. And the significance of the chemical composition of argillaceous rocks has been discussed very often. For example, Fig. 3 shows the distribution of chemical composition of some bloatable and nonbloatable materials in terms of SiO_2, Al_2O_3 and combined flux constituents content. Based on the diagram, RILEY (1951) tried to define a range of composition of expandable materials. In addition, WHITE (1960) proposed to extend the range toward higher Al_2O_3 area. Certainly, most of expandable argillaceous rocks seem to be plotted in the range. But it is noted that some nonbloatable materials also are plotted in the same range (Fig. 3).

In general, the raw material argillaceous rocks used for expanded shale in Japan are 62 to 70% in SiO_2, 14 to 18% Al_2O_3, 3 to 6% Fe_2O_3, 0.2 to 3% CaO, 1.2 to 2.0% MgO, 3 to 6% in alkalies and 3.5 to 6% Ig.loss, and sometimes contain a small amount of CO_2, C, SO_3 and free sulfur. Such a composition materials evidently fall in the range shown in Fig. 3. However, some inadequately expandable materials also were found to fall in the same range. The above facts indicate that chemical composition is not always sufficient to distinguish expandable materials from inadequately expandable or unexpandable ones.

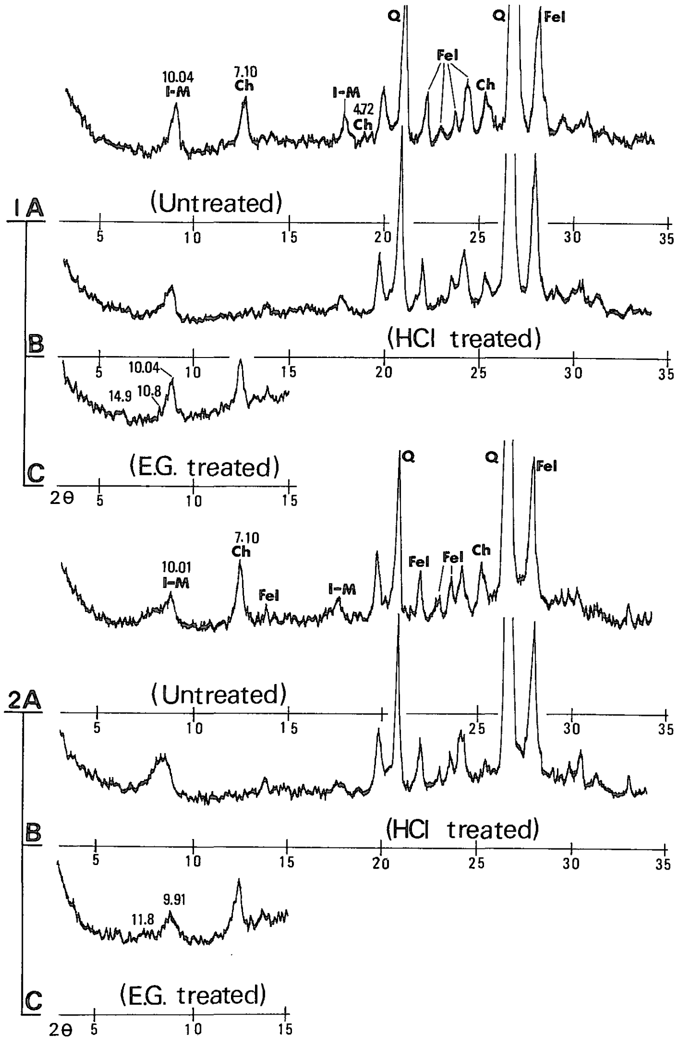
5.2 Mineralogical features

So far, few mineralogical data on the raw materials of expanded shale was available in Japan. The results that the writers investigated on mineral composition of some raw materials will be presented below. The investigated samples are the raw material shales of Bilton and Asanolite from the Cretaceous and the mudstone for Mesalite from the Miocene.

X-ray diffraction data

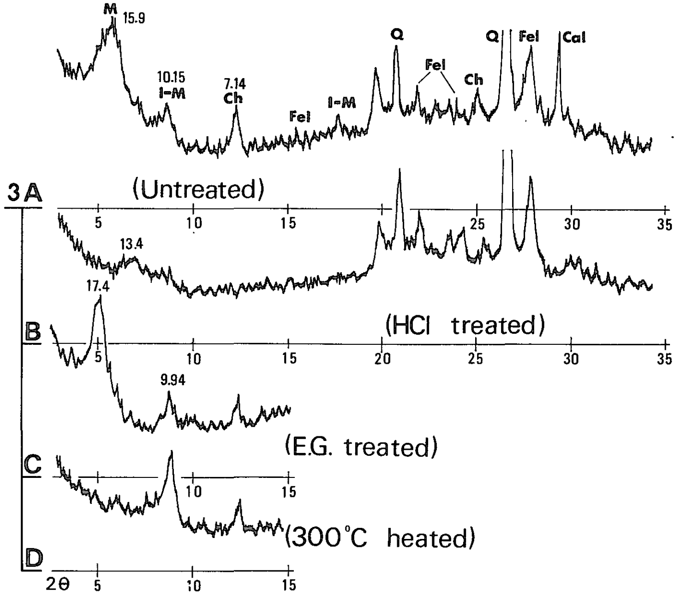
The above three samples were investigated by X-ray powder diffraction. The results are shown in Fig. 4–A and –B.

Both the shales for Bilton and Asanolite showed almost similar powder patterns as shown in Fig. 4–A. They are composed mainly of quartz, feldspar, chlorite and illite. Since the 7.10 Å peaks disappeared after HCl treatment, it is considered that they hardly contain kaolinite. In view of the remarkably enhanced 7 Å reflections comparing with 14 Å ones, which are almost indistinguishable, the chlorites are Fe-rich ones (OINUMA *et al.*, 1972). Next, the existence of illite is indicated by the characteristic 10 Å basal reflection in these patterns. They are accompanied by broad diffusion bands at lower angle position, and after Ethylene glycol treatment they were



1: Bilton, 2: Asanolite.

Fig. 4–A X-ray powder patterns of some shales in the Cretaceous.
Noto: Scanning conditions and mineral symbols are shown in Fig. 4–B



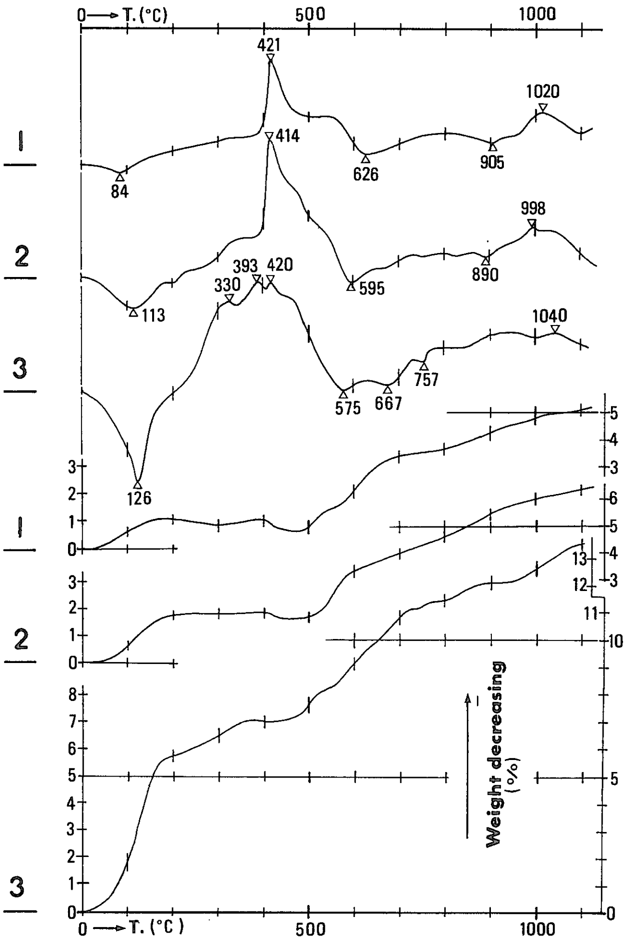
3: Mesalite
Instrument: Guigerflex, Target: Cu, Filter: Ni, Voltage: 30 kV, Current: 15 mA, Ratemeter: 8, Multiplier: 0.8, Time const.: 2, Scanning sp.: 2 °/min., Chart sp.: 2 cm/min.
I-M: Random interstratification of illite and montmorillonite, Ch: Chlorite, Q: Quartz, Fel: Feldspar, M: Montmorillonite.

Fig. 4–B X-ray powder patterns of a mudstone in the Miocene.

separated into two peaks, 10 Å and 11 Å. Though more precise examination is necessary to identify them, the above facts suggest some illites are accompanied by some amount of expandable layer, probably montmorillonite. That is, they are considered to be random interstratification of illite and montmorillonite.

The mudstone for Mesalite is characterized by a considerable amount of montmorillonite (Fig. 4–B). Excluding montmorillonite, it is composed of quartz, feldspar, chlorite and illite as well. Since the 10 Å basal reflection of illite removed toward higher angle position by Ethylene glycol treatment, it is considered to be random interstratification of illite and a small amount of montmorillonite (MacEvan *et al.*, 1961). Montmorillonite probably was derived from volcanic glass by diagenetic alteration. Also, the mudstone contains a small amount of calcite, which was formed by disintegration of volcanic glass. In fact, the mudstone bed is intercalated by tuff in places.

Thermal analysis



1 : Bilton, 2 : Asanolite, 3 : Mesalite.
Instrument: Differencial Thermal Balance, Weight of samples: 300 mg, Heating rate: 10 °C/min., Sensitivity of DTA: 50 μv, Sensitivity of TG: 50 mg.

Fig. 5 DTA and TG curves of the raw material samples.

The same samples were examined by DTA and TG as shown in Fig. 5.

Endothermic peaks of around 400°C are very outstanding in their DTA curves. They were derived from combustion of organic matters such as coaly material. In TG curves, they seem to correspond to temporary weight increase. That might have been caused by change of thermal convection in the sample holder.

As for the shales of Bilton and Asanolite, No. 1 and 2 in Fig. 5, several endothermic and exothermic peaks are found in their DTA curves. But it is difficult to determine the significance of each because they are mixture of chlorite and illite-montmorillonite interstratification.

The DTA curve of the mudstone for Mesalite, No. 3 in Fig. 5, shows very conspicuous endothermic reaction of 126°C depending on dehydration of montmorillonite. In addition, a small endothermic peak of 757°C is found in it. It probably depends on disintegration of calcite, though the temperature is rather lower than that of common calcite. The weight loss corresponding to the peak suggests it contains a few % calcite.

Consideration

The above results indicate these investigated samples are rather common in mineral composition as marine argillaceous sediments. Particularly, it is noted that all of them contain considerable amounts of clay minerals.

The writers recently pointed the following three conditions as to the significant petrographical features of expandable shales in Iran (Fujii *et al.*, 1977).

(1) The expandability firstly depends on particle size component. The rocks predominated by sandy particles do not show sufficient expandability.

(2) The expandability depends on clay mineral contents. Fine-grained rocks containing little clay minerals do not have adequate expandability.

(3) The expandable shales are composed mainly of quartz, chlorite and illite, and do not contain a considerable amount of kaolinite. In addition, shales containing a significant amount of carbonate, probably more than 10%, melted immediately after expansion. They are inadequately expandable.

The petrographical features of the raw material rocks studied in this investigation meet the above conditions except for the existence of montmorillonite in the mudstone for Mesalite. Since montmorillonite minerals are much diversified in chemical composition, it is unknown whether rocks containing montmorillonite are adequately expandable without exception. And it is noticeable that the raw materials contain a considerable amount of organic matter. It is considered to be a significant gas source.

6. Summary

The present condition of expanded shale resources in Japan is summarized as follows.

(1) Six companies are producing expanded shale presently. Their production capacity totals about 6,700 cu.m./day.

(2) The raw material shales are marine argillaceous rocks of Cretaceous to Miocene. Most of them were deposited on shelves or slopes of basins, and another one occurs in a lagoonal coal-

bearing formation of Palaeogene.

(3) These raw materials are mainly used for unpelletized aggregate. And some of them are processed for pelletized aggregate because of their significant sandy intercalation and slaty structure.

(4) Some raw material shales in the Cretaceous are composed mainly of quartz, feldspar, Fe-rich chlorite and illite with montmorillonite layer. Such a composition is very common as marine argillaceous sediments.

(5) A raw material mudstone in the Miocene consists mainly of quartz, feldspar, montmorillonite, Fe-rich chlorite and illite with expandable layer, and is accompanied by a small amount of calcite. But it is unknown whether rocks containing a considerable amount of montmorillonite always have an adequate expandability or not.

(6) The investigated raw material rocks contain significant amounts of organic matter. It is considered to be a significant gas source.

7. Future prospects

As mentioned first, the output of expanded shale in Japan steadily increased in the last decade. But since 1974, it has decreased drastically because of recession of Japanese economy. The decrease probably was accelerated by some cost-up from the rise of fuel price and the additional investment for facilities for pollution prevention. In fact, most of markets for concrete aggregate are occupied by natural heavy weight aggregates because of higher price of expanded shale.

However, use of expanded shale for concrete aggregate gives rise to saving of steel materials for construction of building, high-way and others. Moreover, it can offer a long term saving of energy for heating and cooling a building through its high insulating property. It is expected that use of expanded shale will increase gradually with expansion of construction industry.

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日本の膨張頁岩資源の概要

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要旨

日本の膨張頁岩資源の現状について紹介する．膨張頁岩は現在6社7工場によって生産されており，その原料は白亜紀から中新世の海成泥質岩である．その大部分は，地向斜などの陸棚あるいは傾斜面の堆積物であり，一部では古第三紀の夾炭層中の泥質部を採掘している．これらの原料は主に非造粒型骨材に加工されるが，砂岩の夾みに富むものや粘板岩状のものは，粉砕，成形後造粒型骨材に加工される．

白亜系中の頁岩のあるものは，主として石英，長石，鉄に富む緑泥石およびイライトとモンモリロナイトの不規則混合層鉱物からなる．また中新統の泥岩の一つは，この他にモンモリロナイトを多く含み，少量の方解石を伴っている．

これらの原料はいずれも，相当量の有機物を含んでおり，有機物が重要な気体発生源となり加熱による膨張を生ぜしめたものと考えられる．

〔地名索引〕

Hota…保田； Shiroyama…城山； Sumoto…洲本； Susaki…須崎； Ube…宇部； Yokosuka…横須賀

（受付：1977年8月10日；受理：1977年9月1日）

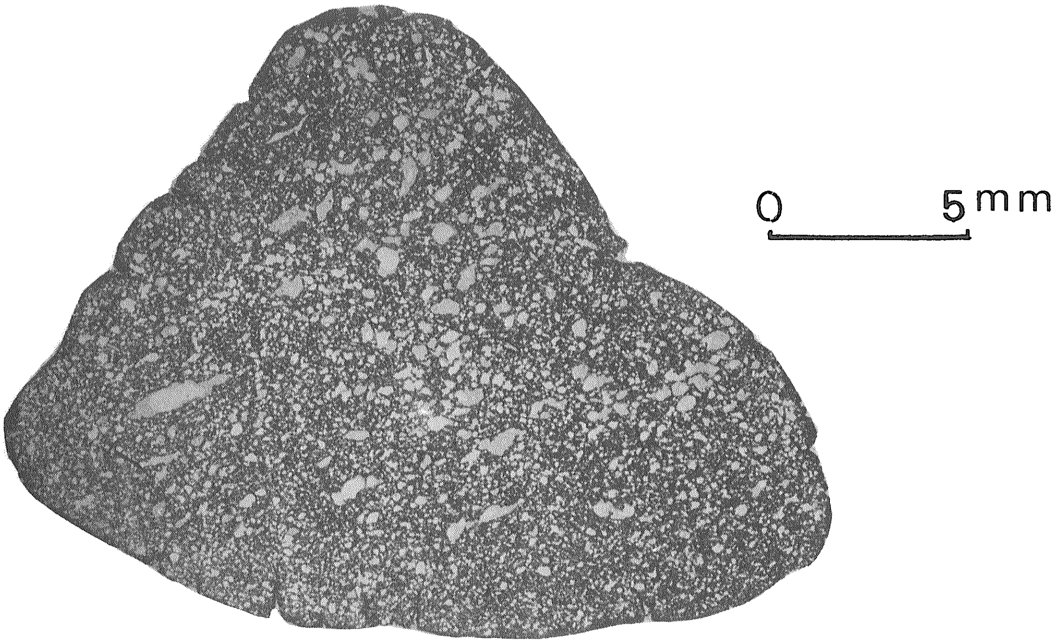


Plate 9–1 Photomicrograph of unpelletized aggregate, Asanolite.

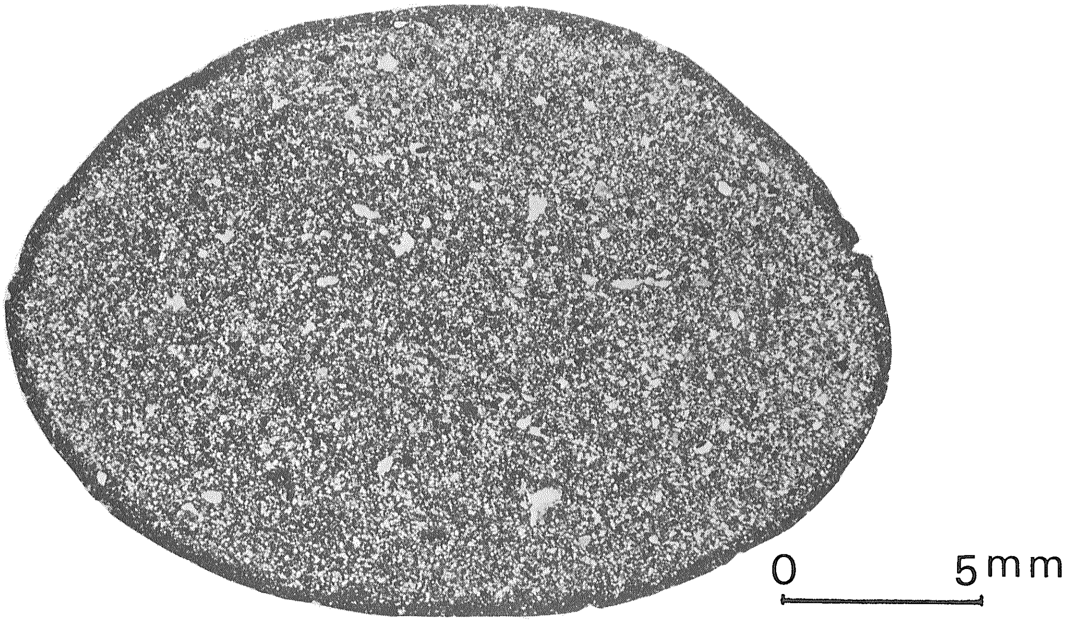
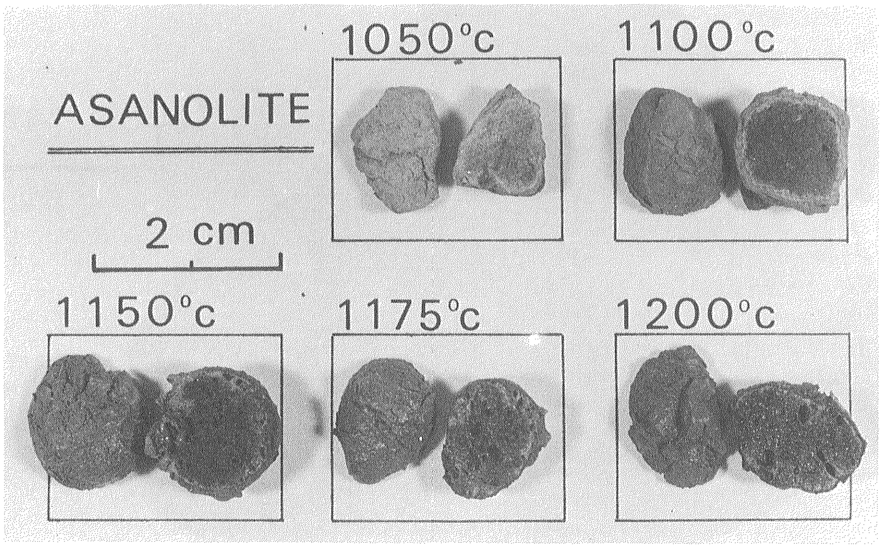


Plate 9–2 Photomicrograph of pelletized aggregate, Bilton.



Note: 1,050°C—not expanded, 1,100–1,175°C—expanded, 1,200°C—melted.

Plate 10–1 Expansion effect at various temperatures.

Plate 10–2 Workings of raw material shale of Bilton.