HYDROCHEMICAL MODEL IN KARST WATER AND THE EVALUATION OF THE CORROSION FEATURE FOR THE MID-ORDOVICIAN LIMESTONE IN FENG-FENG COALFIELD

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ABSTRACT

The paper makes exposition of the hydrochemical action and model of karstic water from the shallow to the deep within a complete hydrogeological unit, the determination of the corrosion equilibrium boundary condition of carbonatite and sulfate rock and the calculation for the corrosion quantity. The hydrochemical model of karst water has been verified basic tally with actual situation by means of the data of the karstic development feature obtained by prospecting, tests and mining in the region. This provides theory basis for the correct planning of the coalfield development and control.

Feng-Feng coalfield is one old mine areas earlier developed coal in Carboniferous-Permian system (CP). The development of coal has been carried out from the shallower part to the deeper and from the upper to the lower coal formation in Carboniferous-Permian system close to rich aquifers of the Mid-Ordovician limestone (O_2) for years. Because the impermeable bed between the coal formation and the limestone is thinner (15-25 m) and water pressure and quantity in the lower formation, water intrusion from the bottom of the shaft has become one of major problems influenced the further development of the coalfield and the tap of potentialities of the old mine area. Since the quantity of water intrusion in the mine pits is closely related to the karst developing feature in O_2 limestone in the region, the investigation of karst developing law in O_2 limestone aquifers will be one way to correctly plan the coalfield development and to present from floor water invasion. This paper discusses chemical action and variation of karstic water, and karst developing feature from karst hydrochemical point.

I. THE HYDROCHEMICAL MODEL OF KARST WATER IN MID-ORDOVICIAN LIMESTONE IN FENG-FENG COALFIELD

In a given hydrogeological unit, the recharge and discharge areas are easily determined, while karst hydrochemical action, the type of corroded minerals and the corroded quantity are different due to the variation of burried depth and hydrodynamic conditions. The karst developing characteristics is alsc different. This problem will be discussed below.

Generally Geological and Hydrogeological Situation of the Mine Area

The mine area is located at the middle section of the east flank of Zanhuang anticline stretching in NNE direction which was dissected by faults in NW and nearly EW direction and which suffered from folds and intrusive body to form an independently hydrogeological unit in rhombus range with recharge, runoff and discharge areas. The total area of the region is 2686 km^2 and area cf exposed limestone is 1295.7 km^2. Annually average rainfall is 554 mm and annual evaporation is 1664-2231 mm. All of the rivers are the seasonal streams except the rivers near southern boundary of the region, and the density of the river network in exposed limestone area is 0.414 m/km^2. The largest runoff length of karst groudwater is about 45 km and the elevation of the largest circulation depth is about -500 m. The elevation of the discharge point is +122.8 m. The annual average discharge of the spring mass is 7-9 m^3/s and steady coefficient and the variable ratio of the springs are 2.23 and 84%, respectively. The ratio of underground runoff is 0.0054-0.00695 $m^3/s\ km^2$.

The thickness of O_2 limestone, which is underlying main aquifers, is about 584 m in the region. The limestone is a set of carbonatite-sulfate formation which is subdivided into three large groups according to rock facies. The lower parts of each group is much of dolomite breccia limestone and thin layer marlite, dolomite, calcareous shale and gypsum etc. The middle part of the layer is tidal interval and low tidal zone facies which is much of pelitic crystal limestone, bright crystal granular limestone and pelitic crystal stain limestone in which karstic fissures and holes are intensively developed and which is one of main richment sections in each group. The discharge of single well is generally 3.6-7.26 m^3/h m. The top section strata are much of earth crystal and stain limestone and earth crystal limestone, in addition, thin layer marlite, dolomite limestone and some layers of dolomite breccia limestone. In some drill holes, gypsum layers were found. In the group of strata, karstic fissures and karstic holes are mainly developed which form richment zones of ground water in the section of advantageous structure and good runoff conditions. In the lower coal layers in late carboniferous system, main aquifers are Daqing limestone with thickness of 5-7 m. The steady drainage rate from the mine pit is generally 360-600 m^3/h.

Hydrochemical Action of Karstic Water in Water-rock System.

In the regional interval from exposed carbonatite region to the hidden region of occurrence of $CaCO_3$ settlement, limestone and dolomite is mainly distributed. Because total trend of groundwater circulation and exchange becomes more intensive, the most of easily soluble sulfate has been dissolved away for long geological history, and there mainly exists calcite and dolomite in carbonatite of ground surface and the shallow. Therefore, the carbonatite rock in the region is continuously dissolved by aggressive CO_2 in groundwater. Aggressive CO_2 decreases until equilibrium state is reached as burried depth of carbonatite rock increases. Thus, in the regional interval the main chamical reaction is as follows:

$$CO_2 + H_2O \rightleftharpoons H_2CO_3 \qquad K_H \qquad (1)$$

$$H_2CO_3 \rightleftharpoons H^+ + HCO_3^- \qquad K_1 \qquad (2)$$

$$mCaCO_3 \rightleftharpoons mCa^{2+} + mCO_3^{2-} \qquad K_{sp_1} \qquad (3)$$

$$nCaMg(CO_3)_2 \rightleftharpoons nCa^{2+} + nMg^{2+} + 2nCO_3^{2-} \qquad K_{sp_2} \qquad (4)$$

$$CO_3^{2-} + H^+ \rightleftharpoons HCO_3^- \qquad K_2^{-1} \qquad (5)$$

The above five reaction equations are combined and proper coefficients are given to obtain

$$mCaCO_3 + nCaMg(CO_3)_2 + (2n+m)CO_2 + (2n+m)H_2O \rightleftharpoons (n+m)Ca^{2+} + nMg^{2+} + (2m+4n)HCO_3^- \qquad (6)$$

According to physical-chemical basic law, the balance constant of the reaction equation is

$$K = K_H\, K_1\, K_{sp_1}\, K_{sp_2}\, K_2^{-1} \qquad (7)$$

From the equilibrium theory of chemical reaction, representation of the balance constant is obtained

$$K = \frac{[HCO_3^-]^{4n+2m}\,[Ca^{2+}]^{m+n}\,[Mg^{2+}]^{n}}{P_{CO_2}^{2n+m}} \qquad (8)$$

It is know from Eq.(8) that in the regional interval to take corroded carbonatite as the dominant rock, the factors controling Ca^{2+} and Mg^{2+} content in groundwater is concentration of HCO_3^- and the component pressure of CO_2. In fact, CO_2 and CO_3^{2-} are continuously transformed into HCO_3^-, so HCO_3^- is key ion for determination of karstic chemical reaction and dissolved content in the regional interval of the interest. In the exposed area of limestone, since CO_2 of the various cause of formation replenishes into groundwater to change componet pressure of CO_2 in water and circulation and exchange of groundwater become much more intensive, water continuously dissolves carbonatite rock. Also, since the solubility of calcite and dolomite is different, calcite whose solubility is relative larger is mainly corroded on ground surface and chemical type of karstic water is properly fresh water with the type of HCO_3-Ca. The aggressive CO_2, the saturation deficiency of $Ca^{2+}(Ca)$ and saturation index (SI_c) in water are determined by using the following equations. Since temperature of water samples is much 17°-$18^{\circ}C$, the constant with $20^{\circ}C$ is taken as the chemical constant.

$$I = \frac{1}{2}\sum CiZi^2 \tag{A}$$

$$-lgf_{HCO_3} = \frac{0.5046\sqrt{I}}{1+1.47\sqrt{I}}, \quad (HCO_3) = f_{HCO_3}\left[HCO_3^-\right] \tag{B}$$

$$-lgf_{Ca} = \frac{2.0184\sqrt{I}}{1+1.97\sqrt{I}}, \quad (Ca) = f_{Ca}\left[Ca^{2+}\right] \tag{C}$$

$$\begin{aligned}\left[H_2CO_3\right]_{aggressive} &= \left[H_2CO_3\right]_{free} - \left[H_2CO_3\right]_s \\ &= \frac{(H^+)}{K_1}(KCO_3) - \frac{K_2}{K_1K_s}(HCO_3^-)^2(Ca^{2+})\end{aligned} \tag{D}$$

$$-lgP_{CO_2} = (H^+) + (HCO_3^-) + IS_c - 7.8 \tag{E}$$

$$\alpha_0 = \left(1+4.15x10^{PH-7} + 1.74x10^{2PH-17}\right)^{-1} \tag{F}$$

$$\alpha_2 = \left(1+2.38x10^{10-PH} + 5.74x10^{16-2PH}\right)^{-1} \tag{G}$$

$$\left[Ca^{2+}\right]_s = \left(\frac{\alpha_2}{K_H P_{CO_2}}\right)\left(\frac{K_s}{2}\right) \tag{H}$$

$$\Delta Ca = (Ca^{2+})_{real} - (Ca)_s \qquad (I)$$

$$SI_c = \frac{(Ca)_{real}}{(Ca)_s} \qquad (J)$$

The analysis data of water in the water supply well of "Yijing" at the recharge region of Gushan. Feng-Feng are

PH	watertemperature	Na^+	Ca^{2+}	Mg^{2+}	Cl^{-1}	SO_4^{2-}	HCO_3^-	NO_3^-	unit
7.25	18.5°C	2.967 0.129	74.168 3.701	15.893 1.307	15.566 0.493	27.159 0.565	244.278 4.004	8 0.129	mg/l me/l

According to the above calculation formulas, we obtain:

$$I = 0.0079235,\ f_{HCO_3} = 0.913,\ (HCO_3) = 3.654;$$

$$f_{Ca} = 0.703,\ (Ca) = 2.603;$$

$$[H_2CO_3]_{free} = 4.943 \times 10^{-4},\ [H_2CO_3]_s = 3.388 \times 10^{-4},$$

$$[H_2CO_3]_{ag} = (4{,}943 - 3.388) \times 10^{-4} = 1.555 \times 10^{-4}.$$

Thus aggressive $CO_2 = 1.555 \times 4.4 = 6.842$ mg/l

$$P_{CO_2} = 10^{-1.927},\ \alpha_0 = 10^{-0.924},\ \alpha_2 = 10^{-3.182}$$

$$[Ca]_s = \frac{10^{-0.924} \times 10^{-8.28}}{10^{-1.41} \times 10^{-1.927} \times 10^{-3.182}} = 10^{-2.685} = 2.065 \times 10^{-3}$$

$$[Ca]_s = 2.065 \times 40.08 = 82.78 \text{ mg/l}$$

$$\Delta Ca = 74.168 - 82.78 = -8.612 \text{ mg/l}$$

$$SI_c = \frac{74.168}{82.78} = 0.896$$

The above calculated results, $SI_c<1$, $Ca<C$ and aggressive CO_2 is 6.842 mg/l. These indexes show that the groundwater at the place has disclubile capacity for carbonatite rock; Every water sample point distributed in the whole recharge region has been calculated and the average value of each index in the whole recharge region has been obtained as aggressive CO_2 = 2.99 mg/l, ΔCa = -36.98 mg/l, and $SI_c = 0.35$. In confined aquifer section from the hidden section of the limestone aquifer to the lower limit of $CaCO_3$ settlemet, since the aquifer does not directly contact with the atmosphere and CO_2 in the atmosphere can not replenish the aquifer, these sections are taken as the regional section with no CO_2 replenishment.

From the section on, CO_2 solved in the groundwater in the exposed region of the limestone (i.e. water table) is consumed. As the depth increases until the aggressive CO_2 exhausts and the index SI_c of $CaCO_3$ is equal to 1, water flowing velocity and circulation and exchange are less than those in the recharge area. Time of water-rock interreaction also increases as the depth, the dissolved content of dolomite increases, Mg^{2+} content in water becomes more, so HCO_3-CaMg water is formed; Corresponding with the behavior that water movement becomes slow and the content of the material in the water increases as the depth and flow path increase, it can form water with HCO_3SO_4-Ca type in the deeper section. In the regional section, the method and formula for the calculation of the parameters (aggressive CO_2, ΔCa, SI_c etc) are the same as the above, but since it is more difficult to obtain directly CO_2 from the atmosphere, the formula for calculation of $\left[Ca^{2+}\right]_s$ is:

$$\left[Ca^{2+}\right]_s = \sqrt{K_s/\alpha_2} \qquad (X)$$

For example, hydrochemical data in No. 643 drill hole in the hidden limestone section in which the elevation of the top surface of the limestone is +134.879 m, is

PH	watertemperature	Na^+	Ca^{2+}	Mg^{2+}	Cl^{-1}	SO_4^{2-}	HCO_3^-	NO_3^-	unit
7.3	17°	$\frac{7.29}{0.317}$	$\frac{79.499}{3.967}$	$\frac{15.03}{1.236}$	$\frac{15.459}{0.436}$	$\frac{41.15}{0.857}$	$\frac{247.082}{4.05}$	$\frac{11}{0.177}$	$\frac{mg/l}{me/l}$

action of karstiv water, water chemical type becomes SO_4 HCO_3-Ca or SO_4 HCO_3-CaMg together with SO_4 HCO_3-CaNa types as the burried depth of the aquifer and flow path increase. At futher deeper part, the content of Ca^{2+} and SO_4^{2-} approaches the balance and water type gradually becomes Cl SO_4-Ca Na type water. As the depth increases from the place of Ca^{2+} and SO_4^{2-} balance along the slant direction of the layers, in the case of the existence of gypsum, dolomite limestone and dolomite, water movement further becomes slow and Ca^{2+} and SO^{2-} reaches saturation to settle. The replacement between Ca^{2+} in water and Mg^{2+} in dolomite forms calcite to settle, resulting in the increase of Mg^{2+} in water to form high mineralization Cl-Mg type water.

Simmarizing the above karst water chemical action and the change in their corresponding hydrochemical type from the shallow part to the deep in the whole unit, we obtain the following hydrochemical model of karst water.

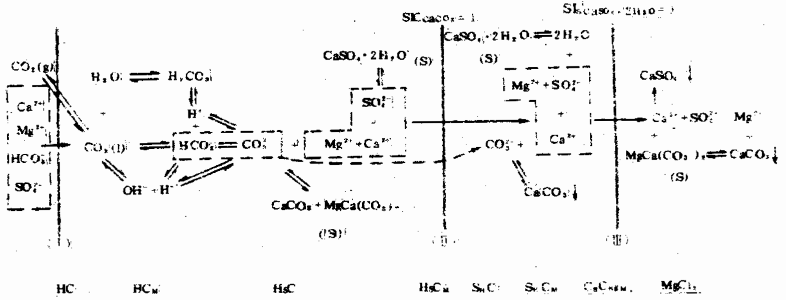

Fig. 1. Model of karst water chemical action in Carbonatite-sulfate rock

The Characteristics and Determination of the Boundary

It is know from karst water chemical action and the change in karstic water types in every regional zone that several important boundaries exist in the whole region. Boundary I is the "entry" received recharge of precipitation, surface water and groundwater from other insoluble rock regions. The sufficient exchange and balance between CO_2 in groundwater and CO_2 in the atmosphere or CO_2 from the various formation cause occur in the region. Because groundwater in the region mainly depends on the recharge from the precipitation in the exposed limestone region, the influence of P_{CO_2} can not be ignored and P_{CO_2} carbonate equilibrium theory need to be considered when calculated in the water samples from the recharge region in region I, i.e. the content of the balance Ca^{2+} is calculated using Eq.(H). Boundary I is easily determined in the field, that is the phreatic water region receiving recharge in exposed limestone.

Boundary II is located in the flow region of the confined aquifer when the carbonate rock is hidden underground. Its upper limit is the line in which the exchange with outer CO_2 stops and aggressive CO_2 solved in water is depleted to "zero" as the burried depth of the aquifer and flow paths increase. On the other words, boundary II is the boundary line in which the content of Ca^{2+} and CO_3^{2-} reaches saturation balance under the condition of certain temperature and pressure. Thus the calculation is performed by Eq.(K) to determine the saturation index SI_c of Ca^{2+} in water in the carbonate rock with various depth. SI_c value of 223 complete analysis water samples were calculated in the region (various depths from the recharge area to flow area) in accordance with the above principle and formula ($t = 20°C$ and one atmospheric pressure) H-SI_c relationship curve (Fig.2) was drawn in accordance with the elevations of C_2 top surface occupied by each water sample point. When the scattered point figure was made, the abnormal points from pollution and gapsum of at the shallow part had been omitted to obtain the elevation with $SI_c = 1$ in the normal case (curve I) and tectonic condition (curve II). Figure 2 show that in the normal geological condition in the region, the elevation of lower limit for the most possibly dissolved calcium carbonate is -160 m. It is shown that in the regional section above the elevation, water has corrosion capability for $Ca\,CO_3$, but the corrosive capability is generally from large to small; Below the elevation, water has no corrosive capability for $CaCO_3$.

with the type of HCO_3-Ca. Using the previous formula, we obtain $I = 0.0171$;

$$\left[H_2CO_3\right] = 4.295x10^{-4},\ \left[H_2CO_3\right]_s = 2.992x10^{-4},\ \left[H_2CO_3\right]_{ag} = 1.303x10^{-4},$$

aggressive $CO_2 = 5.734$ mg/l; $\alpha_2 = 10^{-3.126}$;

$$\left[Ca\right]_s = \sqrt{10^{-8.28}/10^{-3.126}} = 2.6485x10^{-3}$$

$$\Delta Ca = 79.499 - 106.16 = -26.653 \text{ mg/l}$$

$$SI_c = \frac{79.499}{106.15} = 0.749$$

In the water supply well at the pump house with +32 m elevation in Huangsha mine pit where the elevation of the top surface of O_2 limestone is -45 m, the water analysis data are

PH	W. T.	Na^+	Ca^{2+}	Mg^{2+}	Cl^-	SO_4^{2+}	HCO_3^-	NO_2^-	NO_3^-	unit
7.3	20°	15.64	80.16	22.01	24.82	46.5	284.96	0.65	8.85	mg/l
		0.86	4.00	1.81	0.70	0.97	4.67	0.01	0.14	me/l

According to the previous formula, we obtain: $I = 0.00988$;

$$\left[H_2CO_3\right] = 5.0933x10^{-4},\ \left[H_2CO_3\right]_s = 4.667x10^{-4},$$

$$\left[H_2CO_3\right]_{ag.} = 0.426x10^{-4},$$

aggressive $CO_2 = 0.426x4.4 = 1.876$ mg/l; $\alpha_2 = 10^{-3.126}$,

$$\left[Ca\right]_s = \sqrt{10^{-8.28}/10^{-3.126}} = 2.6485x10^{-3}$$

$\left[Ca\right]_s = 2.6485x40.08 = 106.15$ mg/l, thus $\Delta Ca = 80.16 - 106.15 =$

$= -25.99$ mg/l, $SI_c = \frac{80.16}{106.15} = 0.755$ with HCO_3-Ca Mg type.

When groundwater moves to the place where aggressive CO_2 exhausts, i.e. near the limit of the occurrence of $CaCO_3$ sediment, although the content of Ca^{2+} and CO_3^{2-} reaches saturated state to settle, $CaSO_4\ 3H_2O$ and dolomite can still be dissolved and the salinity in water increases as flow path become long. Therefore, general tendency of change in the content of Ca^{2+} and SO_4^{2-} in the water still increases, so groundwater chemical type is $HCO_3\ SO_4$-Ca^{2+} or $HCO_3\ SO_4$-Ca Mg near the limit.

Below the limit of Ca^{2+} and CO_3^{2-} balance, since no CO_2 is replenished in karstic water and the groundwater has no erosion capacity for carbonatite rock, dedolomitization i.e. the hydrochemical action of karstic water in deep sulfate-carbonatite rock may occur. The conditions of the occurrence of this phenomena are the existence of dolomite rock and gypsum, higher content of Ca^{2+} in water and very slow circulation and exchange of karstic water. If the phenomena occurs, the reaction equation is

$$nCaSO_4\ 2H_2O \rightleftharpoons nCa^{2+} + nSO_4^{2-} + 2nH_2O \qquad K_n \qquad (9)$$

$$mCaMg(CO_3)_2 + mCa^{2+} \rightleftharpoons 2mCaCO_3 + mMg^{2+} \qquad K_m \qquad (10)$$

Since the solubility of gypsum is more than that of dolomite, generally n m Eq.(9) and (10) are combined to obtain

$$nCaSO_4\ 2H_2O + mCaMg(CO_3)_2 \rightleftharpoons (n-m)Ca^{2+} + nSO_4^{2-} + mMg^{2+} + 2nH_2O + 2mCaCO_3 \qquad (11)$$

Thus $K = K_n K_m$

with $K = \left[Ca^{2+}\right]^{n-m} \left[Mg^{2+}\right]^{m} \left[SO_4^{2-}\right]^{n}$ (12)

It can be known from Eq.(12) that the content of Ca^{2+} and Mg^{2+} in water is controlled by SO_4^{2-} concentration in this regional section, therefore, SO_4^{2-} is the key ion for the chemical action of karstic water. Because of the existence of the previous chemical

The dividing line between them is boundary II in the model. Near the tectonic zones, the lower limit of water corrosion capability for $CaCO_3$ is deeper (-350 m in Fig. 2) than that in the normal geological condition. It should be pointed out that there is the dividing line between phreatic water area and confined water area in the regional section between boundary I and II. Above the dividing line, $[Ca]_s$ is calculated using Eq.(H). According to the boundary line of the exposed limestone area and the observed data for a long term, the elevation of the top surface of carbonatite with +140 m may be taken as the dividing line between phreatic water and confined water (the line is not shown in the model). In other words, in the regional section more that +140 m elevation of the top surface of the limestone, the calculation is performed by Eq.(H), and in the area less than +140 m Eq.(K) is used.

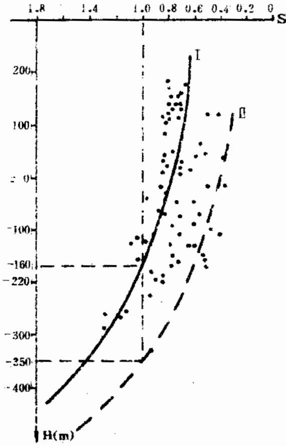

Fig. 2. SI_c-H curve

Boundary III is the boundary line of $CaSO_4$ reaching saturation and balance. The method for determination of the boundary is that the chemical constant under the standard condition is determined in accordance with the thermodynamic law and the values of the enthalpy and entropy of the various materials with standard state, then these values are corrected into the constants under the required temperature according to Van't Hoff's formula. Thus, from $CaSO_4 \rightleftharpoons Ca^{2+} + SO_4^{2-}$, the enthalpy and free energy are obtained from the table and $K_{SO_{25}}$ is yielded:

$$\lg K_{SO_{25}} = \frac{G^o{}_{f*}}{2.303\ RT} = \frac{-6.04}{2.303 \times 0.001987 \times 298.15} = -4.4282$$

Thus K_{SO} at 20°C using Van't Hoff's formula is

$$\lg K_{SO} = \lg K_{SO_{25}} - \frac{H^{0}_{r*}}{2.303\ R}\left(\frac{1}{T} - \frac{1}{T*}\right)$$

$$= -4.4282 - \frac{-4.22}{2.303 \times 0.001987}\left(\frac{1}{293.15} - \frac{1}{298.15}\right)$$

$$= -4.3751$$

$$\left[SO_4^{2-}\right]_s^2 = 10^{-4.3751}$$

$$\left[SO_4^{2-}\right]_s = 10^{-2.18755} = 6.493 \times 10^{-3}\ \mathrm{mol/l}$$

so $$\left[SO_4^{2-}\right]_s = \frac{6.4931 \times 10^{-3}}{2} = 3.247 \times 10^{-3}\ \mathrm{me/l}$$

$$\left[SO_4^{2-}\right]_s = 3.247 \times 48.03 = 155.93\ \mathrm{mg/l}$$

$\left[SO_4^{2-}\right]_s$ obtained is compared with the analysis values of SO_4^{2-} from water samples in the region to obtain the saturation index

$$SI_s = \frac{\left[SO_4^{2-}\right]}{\left[SO_4^{2-}\right]_s}.$$

For example, from the dat from the complete analysis water sample collected from the depth of 200 m in No. 2409 drill hole, the fourth mine of Feng Feng, the content of SO_4^{2-} was obtained to be 61.34 mg/l, therefore,

$$SI_c = \frac{61.34}{155.96} = 0.3933.$$

It shows that the gypsum is in dissolved state.

From the data of the complete analysis water sample collected from No. 7-2 drill hole in Piaozi area, the content of SO_4^{2-} was obtained to be 2038.8639 mg/l, so $SI_s = \frac{2038.8639}{155.93} = 13.08$. It shows that the gypsum is in the settlement state at the place (the elevation of the top surface of O_2 limestone is -416.32 m).

SI_c values of all water sample point throughout the region are obtained with the same method. Then the curve (Fig. 3) of SI_c-H relationship are drawn in accordance with SI_c values and the elevation of the top surface of the limestone. Therefore, the lower limit of $CaSO_4$ settlement is determined to approach to -450 m. In other words, for the section above the elevation, $CaSO_4$ is in the dissolved state and the section below the elevation, $CaSO_4$ is in the settlement state. The line with the elevation is boundary III in the model.

In order to demonstrate the variation in the hydrochemical types and hydrochemical action of karstic water, we have drawn up the plane map of karstic water chemical types (Fig. 4). The change from the shallow to the deep is basically similar to the model in Fig. 1.

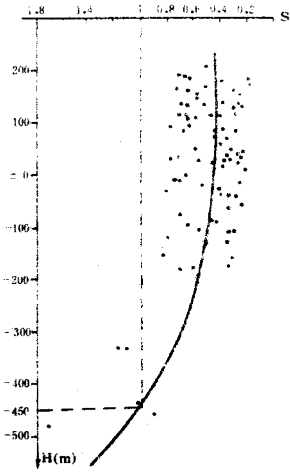

Fig. 3 The relationship curve of SO_4 saturation index SI_c-H in Feng-Feng coalfield

II. THE CORROSION QUANTITY AND THE FEATURE OF KARST DEVELOPMENT IN THE REGION

The Evaluation of the Corrosion Quantity in the Mine Area

In the independet hydrogeological unit, the section from the recharge area to SI_c = 1 line is the region in which the carbonatite rock is mainly dissolved in which flowing water quantity is important part of water quantity in the unit. Therefore, the flow rate and the chemical composition of the springs in the region can generally show general pattern of the carbonate rock dissolution. The calculation may be performed with the simplified formula pre-

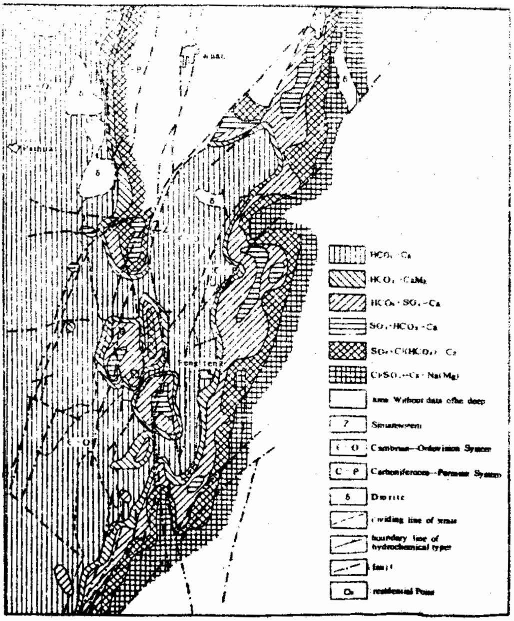

Fig. 4. The plane map of karstic water chemical types in Feng-Feng mine area

sented by Corbel (1975):

$$X_1 = \frac{4ET}{100\ h}\ (\mathrm{mm}/1000y) = \frac{4x1.5933x263.01}{100x0.5559} = 30.15\ \mathrm{mm}/1000y$$

If the calculation is performed using the total salinity of water, we obtain:

$$X_2 = \frac{4ET}{100\ h} = \frac{4x1.5933x310.23}{100x0.5559} = 35.57\ \mathrm{mm}/1000y$$

Thus, the corroded rate of carbonate rock in the region obtained is 30.15-35.57 mm/1000y and the chemical runoff modulus (M_c) is

$$M_c = \frac{1000\ Q_o}{F} C = \frac{13.54x3.1536x10^{10}}{2680x10^8} x\ 310.23 = 1.5674\ g/s\ km^2 =$$

$= 49.43\ T/y\ km^2$

The deep-karst is acted by dedolomitization to increase the porosity of the rock. This is obtained by Eq.(11) and correlation analysis.

In the monoclinal mine area to the eastern part of Gushan, the quantity of the dissolution and sediment of the mineral is that

The dissolved quantity of gypsum is

$$(1.043x + 1.527)\ CaSO_4\cdot 2H_2O = (1.043x9,921 + 1.527)x\ 172 = 2.04\ T/m^3$$

$$n_g = \frac{2.04x10^{-3}}{2.3} = 8.88x10^{-4}$$

The dissolved quantity of dolomite is

$$(0.309x + 0.445)\ CaMg(CO_3)_2 = (0.309x9.921 + 0.445)x184.3 = 0.647\ T/m^3$$

$$n_d = \frac{0.647x10^{-3}}{2.8} = 2.311x10^{-4}$$

The sediment quantity of calcite is

$$(0.618x + 0.89)\ CaCO_3 = (0.618x9.921+0.89)x100 = 0.702\ T/m^3$$

$$n_c = \frac{0.702x10^{-3}}{2.7} = 2.6x10^{-4}$$

Thus, in the monoclinal area in the east of Gushan, the quantity of dissolved and filled material by the chemical action of the deep-karst is

$$M_{de} = M_g + M_d - M_c = 2.04 + 0.647 - 0.702 = 1.985\ T/m^3$$

or

$$n_{de} = n_g + n_d - n_c = (8.88 + 2.311 - 2.6)x10^{-4} = 8.59x10^{-4}$$

In the fault sunken synclinal basin in the west of Gushan, the total quantity of corrosion and sediment filling for carbonate-sulfate rock is that

The dissolved quantity of gypsum is

$$(1.299x + 0.301)\ CaSO_4 \cdot 2H_2O = (1.299x2.471+0.301)x172 =$$
$$= 0.604\ T/m^3$$

$$n_g = \frac{0.664x10^{-3}}{2.3} = 2.625x10^{-4}$$

The dissolved quantity of dolomite is

$$(0.293x + 0.051)\ CaMg(CO_3)_2 = (0.293x2.471+0.051)x184.3 =$$
$$= 0.143\ T/m^3$$

$$n_d = \frac{0.143x10^{-3}}{2.8} = 5.101x10^{-5}$$

The sediment quantity of calcite is

$$(0.586x + 0.102)\ CaCO_3 = (0.586x2.471+0.102)x100 =$$
$$= 0.155\ T/m^3$$

$$n_c = \frac{0.155x10^{-3}}{2.7} = 5.741x10^{-5}$$

Therefore,

$$M_{de} = 0.604 + 0.143 - 0.155 = 0.592\ T/m^3$$

$$n_{de} = (26.25 + 5.101 - 5.741)x10^{-5} = 25.61x10^{-5} =$$
$$= 2.561x10^{-4}$$

It is seen from the results presented above that below $SI_c = 1$ boundary line, the dedolomitazation is calculated by Eq.(11) to form porosity. The dedolomitazation in "Gudong" area, Feng-Feng coalfield is $8.591x10^{-4}$ and in Hu village basin, Guxi area is $2.561x10^{-4}$.

The Feature of Karst Development in Feng-Feng Coalfield Region

According to statistical data of the pumping tests and karst in the drill holes, the feature and zoning of karst development in the region are given in table 1.

It is known from the calculation and SI_c-H curve that the elevation (-160 m) with $SI_c = 1$ boundary line is located in the median runoff zone. According to statistical data of the various prospecting boreholes, above the elevations, karst caves with the diameter more than 0.2 m were found in the boreholes. Below the boundary line, the fissures and karst porosity were mainly developed and the karst caves were not basically found in normal geological condition.

The elevation with $CaSO_4$ saturation index $SI_s = 1$ is close to the lower limit of the weak runoff zone. Above $SI_s = 1$ limit, karst phenomenon, which are associated with the gypsum dissolution and have effect on mining coal, were found by statistical data of the deep boreholes and driving. Below the limit, the deep karst phenomenon were seen in the boreholes. They mainly are small karstic pores and fissures together with obviously chemical filling ratio is more.

It is further verified by recently prospecting and tests that the hydrochemical model of karst water presented above basically shows the feature of karst development and variation in the region. The fifth mine located in the strong and median runoff zones, for example, has 18 boreholes through O_2 limestone in which the development of fractures and caves has been found at the aquifer section and the real karstic cave height seen in the borehole is 0.5-1.0 m. In the boreholes at the bottom of the mine pit, single well discharge is 1-3 m^3/min. In daqing limestone within the coal system strata about 25 m away from the previous place, the drainage tests were made in a group of boreholes at the bottom of the mine pit in June, 1983. When water level drawdown in the central borehole was 30 m, the discharge was 26.21 m^3/min the unit discharge $q = 0.824$ m^3/min m, and water chemical type was HCO_3 SO_4-Ca Mg water. Yangquhe mine located in the median and weak runoff zone has nearly 20 borehole through O_2 limestone. When the drain and pumping tests were made, $q = 0.72 - 0.0072$ m^3/min m but many boreholes is at 0.01-0.035. The boreholes with more discharge is in the median runoff zone. Water chemical types vary from HCO_3SO_4-CaMg to SO_4HCO_3-CaMg.

The prospecting data in Jiulongkou mine area and in the east explore area of Yangqu located in the weak and extreme weak runoff zone, for example are (1) In the completed boreholes, we saw much of inclination intersection fissures with not smooth planes and locally with the membrane of calcite and the fissures with the width of 1-2 mm have been completely filled by calcite. In the

Table Variation of Karst Feature with the Depth in All the Zones of O_2 Limestone in the Runoff Area in Feng-Feng Coalfield

zoning of runoff areas and the elevation of the top surface of O_2 (m) / item		strong runoff zone	median runoff zone	weak runoff zone	extreme weak runoff zone
		+135-±0	±0—200	-200—500	-500
The form of karstic water chemical action for $CaCO_3$ in water		erosion	erosion → sediment	sediment	sediment
Developing feature of karst	specific discharge q(l/s·m) of the pumping test (unitizing s to 10 m)	normal ≥1-7.4 general≥2.9 near structure≥7.4	normal 7.4-0.6 general 0.92-2.9 near structure 2.3-7.4	normal 2.3-0.3 general 0.92-0.41 near structure 2.6-0.92	<0.3-0.4
	average point numbers of karst fissure and cave in single borehole	3.4	2.2	0.75	
	karst cave ratio (%) of aquifer set	3.32	1.03		
	karstic fissure and cave ratio (%) in aquifer set	8.84	6.58	1.55	
	visibility ratio (%) of karst caves in boreholes	18.8	6.2		
Filling feature of karst	full filling ratio of karst fissure (%)	48-26	26-54	54-66	>66
	filling type	dominant mechanic filling	mechanic and chemical filling	dominant chemical filling	chemical filling
	filling material	clay, sand calcite	clay, calcite	dominant calcite	calcite, gypsum
main karst pattern		karst fissure and cave development	much of karst fissure caves near the shallow and structure	a few of karst pores and fissures	karst fissure not much development much filled by calcite

layers of the upper formation of O_2 exposed for nearly 130 m, karst fissures were found at five to six positions and the karstic pores with the diameter of only 5 mm. were seldom found. (2) The pumping test in a group of well was carried out in Jiulongkou mine from November, 17 to December 18, 1983. The result was q = 0.334 m^3/min m. Whinh the least specific discharge of those of all the pumping tests in the mine area. Up to October, 19, 1985, the water level in O_2 limestone aquifer in the pumped area hadn't recovered to the level before pumping (the difference between them was 1.72 m). (3) In the east explore area of Yangqu mine, water richment of the limestone obviously decreases at the section below the elevation of -500 m. q values from seven boreholes were all less than 0.1 l/s m, q_{cp} = 0.0419 l/s m. In 14 boreholes above the elevation of -500 m, q_{cp} = 3.135 l/sec m. The latter is about 75 times of the former. The hydrochemical types in O_2 limestone of the section vary from SO_4Cl-CaNa water.

In summary, the feature of karst water chemics and karstic development is expounded to provide the theory basis for correct planning of the coal layer development and control in the area. This is of the actual significance.